ASSESSMENT OF A FORECASTING MODEL AND A RISK INDEX FOR IMPROVED MANAGEMENT OF TOMATO SPOTTED WILT VIRUS ON PEANUT (*Arachis hypogaea* L.) AND TOBACCO (*Nicotiana tabacum* L.) IN GEORGIA

By

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(Under the Direction of Robert C. Kemerait)

ABSTRACT

Plant viruses cause serious production constraints and financial losses annually. Most effective management techniques require consideration of both vector populations and virus spread. Through an integrated approach, we investigated the contribution of a multi-model method to manage spotted wilt disease in cultivated peanut. Spotted wilt, caused by thrips-vectored *Tomato spotted wilt virus* (TSWV), is an important viral disease affecting peanut production in the southeast United States. Current management is targeted at minimizing spotted wilt severity and includes an assortment of production practices. Through the introduction of a spotted wilt forecasting model which accounts for these factors, disease pressure can be predicted. These results provide a framework in which models can be developed to increase spotted wilt management in the southeast. Producers will be able to account for both spotted wilt risk and disease pressure, which will subsequently allow them to determine the best production practices to limit spotted wilt incidence.

INDEX WORDS: peanut, tobacco, tomato, virus, model, thrips, risk, pressure, disease, forecast, index, management

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Insect-transmitted Phytopathogens

Vector-borne plant pathogens have co-evolved with wild plant species long before agriculture and implementation of modern farming practices. Studies have shown that monoculture and plant domestication continue to expand as does the interface between managed and natural vegetation. This process promotes disease spread and the emergence of invasive and exotic plant diseases (Jones, 2009). A variety of organisms, mostly insects, but also fungi, nematodes and mites, act as pathogen vectors (Almeida, 2008). These vector-pathogen interactions are present in all environmental niches across the globe and can cause severe economic damage.

Of all known pathogens transmitted via insect vectors, viruses are predominant and comprise 47% of all emerging plant pathogens. Over time, plant species have been transported globally to areas where indigenous plant viruses can cause severe damage. (Jones, 2009; Almeida, 2008). Examples of this scenario include *Wheat streak mosaic virus* (WSMV), transmitted by its vector, the eriophyid mite *Aceria tosichella*, and the Israeli form of *Tomato yellow leaf curl virus* (TYLCV-Is), transmitted by its vector, the whitefly *Bemisia tabaci* (Jones, 2009). WSMV was first described in 1937 in the Great Plains Region of North America and the Fertile Crescent region of the Middle East. However, wheat was introduced to Australia by the Europeans around 200 years ago, followed by the eriophyid mite, and WSMV in 2003 (Jones, 2009). TYLCV-Is is native to the eastern Mediterranean and was found only in that region until the late 1980's. Its primary host plant, tomato, is indigenous to the Andean region of South America. TYLCV-Is was introduced to the Caribbean islands by infected tomato seedlings and further spread to Mexico and southeastern USA through fruits, seedlings, and possibly viruliferous whiteflies dispersed in wind currents (Jones, 2009). These two examples portray the damage, spread, and impact of these pathosystems.

A characteristic of insect-transmitted plant viruses is the "disease quadrangle," as opposed to a disease triangle, which includes the three necessary components of disease; the host, pathogen, and environment (Francl, 2001; Agrios, 2005). The fourth factor is the vector, which plays a critical role in pathogen transmission from infected to non-infected hosts (Groves, 2012). Consideration of vectors and pathogens are necessary for the development of management strategies. The epidemiology of insect-transmitted plant viruses is complex and makes management difficult, especially when collaborative efforts between scientists of different disciplines, including virologists, entomologists, and epidemiologists, are key.

Modeling disease dynamics of insect-transmitted plant viruses requires the identification of three specific components: First, virus multiplication; second, virus acquisition and inoculation; and third, spatio-temporal disease development. Holt *et al.* (1997) developed a model for African cassava mosaic disease (ACMD), caused by either of two begomoviruses and transmitted by the whitefly *Bemisia tabaci*. Factors used in this model that had an impact on disease dynamics included intensity of cassava cropping, rate of crop turnover, virulence and transmission efficiency of the vector, and whitefly population dynamics. Another model was developed using biological and epidemiological data to predict disease dynamics in response to the whitefly transmitted Tomato yellow leaf curl disease (TYLCD) in India (Holt, *et al.*, 1999).

This model provided effective and sustainable disease management strategies in tomato production. Specific tactics included decreasing vector arrival rate, reducing inoculation and acquisition rates, and increasing vector death rate. Modeling disease dynamics to assist with disease managment is an example of effective and sustainable integrated pest management (Jeger, et al., 2004).

Management strategies designed for insect-transmitted plant diseases are specific to each pathosystem and are affected by the vector, pathogen, and host(s). For a viral pathogen having a host range exceeding 1000 species, such as *Tomato spotted wilt virus* (TSWV) (Parrella, et al., 2003), host weeds often serve as both inoculum sources and reservoirs for the vector, e.g., thrips species *Frankliniella fusca*. Both factors, inoculum source and reservoir, should be considered when developing management tactics (Srinivasan, et al., 2014). Case studies have shown that geographic information systems (GIS) and landscape ecology can be used to successfully reduce disease incidence in tomato. This has been accomplished by removing hosts acting as viral reservoirs of tomato diseases in the Del Fuerte Valley of Sinaloa, Mexico (Harvey, et al., 2003). In agriculture, aside from host weed sources, host plant attributes altered to reduce viral disease incidence include host resistance to the vector (Harvey, et al., 2003), host resistance to the pathogen (Liu, et al., 2002), and host tolerance to the pathogen (Shrestha, et al., 2013).

Vector species are critical for virus transmission and subsequent disease occurrence. The current estimate of recognized plant viruses is approaching 1000 and most of these are actively transmitted by vector (Gergerich, et al., 2006). Transmission is determined by the vector-virus relationship and includes non-circulative, circulative, and propagative types. Vectors transmitting in a non-circulative manner do not harbor the virus indefinitely. With circular and propagative, risk of infection occurs with each colonizing act after the vector has acquired the virus.

Acquisition time, retention time, and transmission efficiency are all affected by transmission type (Gutiérrez, et al., 2013). Management tactics include limiting vector acquisition of the virus and preventing viruliferous vectors from transmitting to host species (Purcell and Almeida, 2005). Common interventions used to decrease vector populations and transmission include insecticides, sanitation, physical isolation, varying planting dates, resistant varieties, and insect resistance (Purcell and Almeida, 2005).

Tospoviruses

Thrips-transmitted topsoviruses are among the most damaging and widespread of the plant viruses. Tospoviruses cause significant losses in yield and quality in a broad range of agronomic, horticultural, and ornamental crops worldwide (Persley, et al., 2006; Pappu, et al., 2009). A disease caused by this virus was first discovered in Australia in 1915 in tomato and was described as spotted wilt (Brittlebank, 1919). The causal agent of this disease was termed '*Tomato spotted wilt virus*' and was the sole member of the family *Bunyaviridae* for much of the 20^{th} century. The detection of a second tospovirus, *Impatiens necrotic spot virus*, in the late 20^{th} century has since led to the discovery of nineteen species within the genus *Tospovirus* (Pappu, et al., 2009; Law and Moyer, 1990).

The morphology and genomic organization of all tospoviruses share similar features. *Tospovirus* virions are membrane-bound quasi spherical particles, 18-120 nm in diameter, with 5-10 nm surface projections. The genome is split between three ssRNA fragments, an 8.90 kb negative-sense L segment, a 4.82 kb ambisense M segment, and a 2.92 kb ambisense S segment. Each segment contributes a different property to viral function. The L segment encodes an RNA-dependent RNA polymerase (330 kDa), the M segment is involved in cell-to-cell movement and glycoprotein coat, and the S segment encodes proteins involved in RNA silencing and nucleocapsid formation (Hull, 2009; Pappu, et al., 2009).

A unique characteristic of *Tomato spotted wilt virus* is the large host range and the role of such as a reservoir for subsequent virus spread. Some members of the *Bunyviridae* family, including TSWV, have nearly 1000 host plant species, while others, such as *Capsicum chlorosis virus* (CaCV) and *Iris yellow spot virus* (IYSV) have a more limited known host range (Persley, et al., 2006). The majority of tospoviruses cause systemic infections in economically important crops. Infections that occur at early growth stages result in the greatest damage, including loss of yield and even plant death. Symptoms induced by tospoviruses differ between non-systemic hosts, e.g., local lesions containing possible chlorosis and necrosis, and systemic hosts, which can include any combination of ring spots, line patterns, wilting, stunting, silvering, mottling, bronzing, chlorosis, necrosis, and a wide range of leaf and stem lesions (Mumford, et al., 1996).

The dispersal and survival of tospoviruses is dependent upon the coexistence of compatible virus and vector populations. Because TSWV has such a wide host range, the thrips vector has great potential for virus spread by increasing inoculum reservoirs, e.g., weed hosts, across the landscape. To date, aside from transmission by thrips species, there is no evidence of seed or pollen transmission or any other significant type of transmission of tospoviruses (Mumford, et al., 1996). Thrips species are known to transmit tospoviruses in a persistent, circulative, and propagative manner (Ullman, et al., 1997). First and second instars of immature thrips acquire the virus from infected plants. The virus then disseminates through tissue layers from the alimentary canal to the salivary glands. After acquisition, the virus replicates in the midgut of the vector as it matures (Whitfield, et al., 2005). Virus transmission follows. Mature thrips are capable of moving long distances resulting in significant spatial spread of disease.

Infective thrips remain viruliferous over their lifecycle, on average 30-40 days (Best, 1968), and transmission by piercing-sucking can occur on susceptible host plants in as little as 5 minutes (Groves, et al., 2002, Whitfield, et al., 2005).

Most research involving tospoviruses has centered on TSWV. Since other members of the genus *Tospovirus* are similar with respect to TSWV, the epidemiology and disease management strategies of tospoviruses is analogous for each species. Three important factors contribute to tospovirus outbreaks: 1) prevalence of thrips, 2) magnitude and disposition of inoculum, and 3) types of inoculum sources. Weather also plays a critical role in thrips biology and epidemiology of disease development. Weather factors may affect particular virus isolates, thrips population dynamics, alternative and overwintering weed hosts, and location of susceptible crop species in relation to virus inoculum sources (Groves, et al., 2002; Coutts, et al., 2004; Wijkamp, et al., 1995; Stumpf and Kennedy, 2007). Host weeds that have high infection frequencies account for reservoirs of primary inoculum, especially when these sources are in proximity to susceptible hosts. The primary spread of inoculum to an annual crop from outside the crop provides the largest contribution to disease incidence; little secondary spread occurs from within the crop (Gitaitis, et al., 1998; Culbreath, et al., 2003). The epidemiology of tospoviruses is very complex, which makes management decisions difficult for this pathosystem (Pappu, et al., 2009).

Successful management of tospoviruses requires an understanding of both the epidemiology of this pathosystem and integrated pest management. In the southeastern USA, spotted wilt disease caused by TSWV has had an enormous impact on economically important crops including peanut, tobacco, tomato, and pepper. This has driven development of applicable integrated pest management practices. A method of risk assessment towards spotted wilt of peanut was developed in 1996 and combined cultural practices with host resistance and use of an insecticide (Brown, et al., 2005). Components of this model included peanut cultivar, planting date, plant population, insecticide usage, row pattern, tillage system, and use of Classic® herbicide as factors that affected risk to the viral disease. In pepper and tomato, management techniques included the use of resistant cultivars, reflective metalized mulch (UV-mulch), and chemical treatments (Awondo, et al., 2012). Spotted wilt disease in tobacco has been much more difficult to manage due to the lack of commercially available resistance, although resistance to TSWV has been documented in transgenic tobacco (MacKenzie and Ellis, 1992). Alternative management methods include insecticide and plant-growth regulator treatments and planting date adjustments based on weather modelling (McPherson, et al., 2003; Cumbie, et al., 2011). For tobacco, a weather-based forecasting model was developed by North Carolina State University that predicts thrips populations and TSWV risk (Chappell, et al., 2013). All of these management strategies are specific to crop and have been documented to reduce disease incidence.

Tomato Spotted Wilt Virus

Tomato spotted wilt virus (TSWV), long the sole member of the genus *Tospovirus* in family *Bunyaviridae*, is one of the most widespread and economically destructive plant viruses in the world (Peters, et al., 1996). This virus is an important pathogen of many agricultural crops. The origin of this virus dates back to 1915 in Australia where reports of a “spotted wilt” disease of tomato were first described and subsequently characterized in 1919 (Brittlebank, 1919; Sherwood, et al., 2003). TSWV, exclusively transmitted by certain thrips species, later spread across the Pacific to Hawaii in the 1920’s, reaching California by 1935. Its distribution later extended across the United States reaching the Southeast in the 1970's (Kucharek, et al., 1990; Riley, et al., 2011). This devastating plant virus is now projected to occur worldwide.

Symptomatic host plants are associated with decreased productivity, yield losses, and significant economic consequences (Sherwood, et al., 2003; Brunt, et al., 1996). Symptoms of spotted wilt disease persist through the lifetime of the plant and are associated with severe damage in many agronomic and horticultural crops. Damage is especially severe when plants are infected at early growth stages. In Georgia, spotted wilt became a severe production constraint on peanut (*Arachis hypogaea* L.) and tobacco (*Nicotiana tabacum* L.) in the late 1980's through the 1990's, causing yield losses to reach 100% in areas (Kucharek, et al., 1990). Losses to spotted wilt are still present today (Martinez, 2014).

In 2005, the estimated loss worldwide exceeded $1 billion in vegetable and ornamental crops from TSWV. This devastation was especially severe as a result of the wide range of host species affected (Andret-Link and Fuchs, 2005). Spotted wilt is present annually in the southeastern United States and frequently causes damaging levels in many crops. According to Riley et al. (2011), based on 10 years of data from Georgia, spotted wilt disease caused an estimated annual average annual loss of $12.3 million in peanut, $11.3 million in tobacco, and $9 million in vegetable crops, totaling $326 million from 1996 to 2006. The economic consequences of TSWV on peanut and tobacco have been greatly reduced over the past two decades due to more effective management; however, limitations in yield potential are still present

Tomato spotted wilt virus causes a range of symptoms on host plants. Symptoms may vary from plant to plant based on plant species, cultivar, growth stage, climate, and nutritional and environmental conditions of the plant (EPPO/CABI, 1997; Allen, et al., 1991). Symptoms include necrosis (primarily leaves and stems), chlorosis, ring patterns, mosaic, mottling, silvering, stunting, and local lesions. Several strains of TSWV have been identified; however their particle shape and size, genome, and genome organization are consistent so that they remain members of the same species. Different strains of TSWV have been shown to produce variable symptoms when infecting the same hosts under similar conditions (De Ávila, et al., 1992). Also, it has been shown that the same strains of TSWV can cause different symptom expressions within the same plant (Moyer, et al., 2013). Using enzyme-linked immunosorbent assay (ELISA) techniques, asymptomatic plants have been discovered to harbor TSWV, but this occurrence is poorly understood.

Compared to other members of the *Tospovirus* genus, TSWV is considered to be the most widespread and have the largest host-range, extending to at least 1,090 plant species belonging to 15 monocotyledonous and 69 dicotyledonous plant families worldwide (Parrella, et al., 2003). The large host range of TSWV helps to explain the overwintering survival of the virus and its availability for vector acquisition and subsequent spread on a seasonal basis. Weeds play a pivotal role in the lifecycle and spread of TSWV. Host weeds act as overwintering reservoirs for both thrips vector and virus (Duffus, 1971). Recent studies have shown evidence for movement of TSWV from weed hosts to cultivated crops, and vice versa. This emphasizes the importance of assessing non-conventional hosts when managing spotted wilt (Srinivasan, et al., 2014; Chatzivassiliou, et al., 2007).

The spread of TSWV is facilitated by certain species of its arthropod vector, thrips, of family *Thripidae* and order *Thysanoptera* (Riley, et al., 2011). Without thrips, TSWV cannot be transmitted from one host plant to another. The spread of TSWV is largely due to the behavior, dispersal activity, and rate of development of the local thrips vector species (Mound, 2002). The order *Thysanoptera* contains over 7000 species of thrips; however, only nine species of thrips have been found to transmit TSWV, all found in two distinct genera. The species include *Frankliniella occidentalis* (Pergande) (Medeiros, Nagata, Wijkamp, et al.), *Thrips tabaci* (Lindeman) (Wijkamp, et al.), *Frankliniella schultzei* (Trybom) (Wijkamp, et al., Sakimura), *Frankliniella fusca* (Hinds) (Sakimura, Naidu, et al.), *Frankliniella intonsa* (Trybom) (Wijkamp, et al.), *Frankliniella bispinosa* (Morgan) (Avila, et al.), *Thrips setosus* (Moulton) (Tsuda, et al.), *Frankliniella gemina* (Bagnall) (de Bordon, et al.), and *Frankliniella cephalica* (Crawford) (Ohnishi, et al.) (Riley, et al., 2011). In the southeastern United States, the two predominant species of TSWV-transmitting thrips are *F. fusca* and *F. occidentalis*, both of which are found ubiquitously in peanut and tobacco. Previously it was noted that TSWV was first detected in the southeast in the 1970's (Kucharek, et al., 1990; Riley, et al., 2011). *F. occidentalis* was identified in the southeast in the early 1980's (Beshear, 1983). This coincidental occurrence provides evidence that *F. occidentalis* is an important vector in the southeast (Greenough, et al., 1985), though *F. fusca* is a very common vector in this region (Riley, et al., 2011).

Transmission of TSWV from thrips to susceptible crops can be very extensive. Efficiency of virus spread and dispersal makes spotted wilt difficult to manage. Studies have shown that when viruliferous thrips comprise <3% of the total populations, severe spotted wilt damage can occur. Thus, it is important to understand thrips biology and control measures in managing for spotted wilt disease (McPherson, et al., 2005).

As previously mentioned, overwintering hosts play an important role in the epidemiology of spotted wilt, allowing first and second instar stages of thrips to acquire TSWV from weed hosts for subsequent spread during the spring season (Riley, et al., 2013). In this scenario, a model would be useful in predicting spotted wilt epidemics by accounting for thrips activity and population dynamics. This would help reduce interaction of viruliferous thrips with host plant species and allow management tactics such as planting date and insecticide usage to be utilized appropriately.

Both tobacco thrips (*F. fusca*) and western flower thrips (*F. occidentalis*) occur on peanut and tobacco throughout the southeastern USA; however, tobacco thrips are the predominant species. Growing season for peanut in the southeastern USA extends from late April to early November. The most active planting dates range from May 6 through May 31. Volunteer plants may be present in some locations throughout much of the year, allowing both thrips vector and TSWV to reside, multiply, and act as reservoirs (Culbreath and Srinivasan, 2011; NASS, 2010). Growing season for flue-cured tobacco in the southeastern USA extends from late March to early September. The most active transplant dates range from April 4 to April 25 (NASS, 2010). Both peanut and tobacco growing seasons occur simultaneously with regard to active thrips generations in the southeastern USA. According to a study performed by Olatinwo *et al.* (2011), immature thrips were most prevalent between the months of January and May with peak populations occurring between March and May. This same study found adult thrips were most prevalent between the months of March and August with peak populations occurring between April and June. With thrips species producing peak generations during tobacco and peanut planting windows, the need for effective management practices are necessary for controlling spotted wilt epidemics.

Management of spotted wilt disease depends on host species affected. No single management method provides adequate control of this disease. However, over the past two decades there has been focus in developing interdisciplinary and multifaceted management strategies that significantly reduce risk to spotted wilt and increase yields (Brown, et al., 1996; Culbreath, et al., 2003).

Managing spotted wilt disease is a key example of integrated pest management. This results from different scenarios requiring diverse management tactics. Spotted wilt disease became endemic to the southeastern United States in the early 1990's, causing severe crop losses and the need for immediate management options to combat this disease (Chamberlain, et al., 1992). Two management strategies, a TSWV risk index and a predictive model for spotted wilt epidemics based on climate conditions, were developed and show efficacy in reducing spotted wilt in peanut (Olatinwo, et al., 2008). Another management strategy, established for tobacco grown in North Carolina and Virginia, was developed by a team at North Carolina State University and is a weather-based model used to forecast thrips populations and TSWV risk (Kennedy, 2014). Each model targets certain aspects of the disease pathosystem and has unique components that allow them to be effective in spotted wilt management.

In the mid-1990's a TSWV risk assessment tool for peanut was developed in Georgia in response to the extreme losses caused by spotted wilt disease. The risk model was designed to help peanut growers deploy effective management tactics based on calculated levels of risk associated with common production practices (Olatinwo, et al., 2008). Over the next decade, the risk index expanded to include not only TSWV, but leaf spot diseases and southern stem rot. The expanded index was renamed Peanut Rx. Peanut Rx is based upon point systems assigned to production practices shown to impact spotted wilt severity. Using this model, a grower can calculate risk to spotted wilt based on his production practices. The summation of these points allows the grower to determine if their field is at low, medium, or high risk to TSWV. Production practices assessed in this model that impact spotted wilt on peanut include variety selection, planting date, plant population, choice of at-plant insecticide, row pattern, tillage system and use of Classic® herbicide (Culbreath, et al., 2009). Research and extension efforts resulted in an efficient management system that used genetic resistance and production practices to reduce risk to spotted wilt and slow development of spotted wilt epidemics (Culbreath, et al., 2003).

Of the components of Peanut Rx, variety selection has been the single most important factor in management of spotted wilt in peanut. Genetic resistance has had the largest and most consistent effect of reducing spotted wilt incidence (Culbreath, et al., 2003; Brown, et al., 1996). Recent studies continue to show that newly developed peanut breeding lines have resistance to TSWV. A number of peanut cultivars developed since 1996 exhibit moderate to high levels of field resistance to TSWV as compared to more susceptible cultivars such as 'Georgia Green' and 'Southern Runner' (Shrestha, *et al.*, 2013). In a recent study conducted by Culbreath, et al. (2012), final spotted wilt severity ranged from 53.3% in 'Georgia Green' to 14.3% in 'Georgia-02C' and 7.3% in 'Georgia-10T'. These results document improved field resistance to TSWV as new cultivars are developed and released. This same study showed that within genotype, the effect plant population had a significant impact on the reduction of spotted wilt severity. In 'Georgia Green', a plant population of 8.4 plants/m resulted in a final severity of 53.3% while a population of 19.7 plants/m had a final severity of 40.0%. This effect was also seen in more resistant peanut genotypes, including 'Georgia-10T', where the final severity of spotted wilt was 7.3% in the reduced population of 9.8 plants/m, and a final severity of 3.0% in the higher population of 19.7 plants/m (Culbreath, et al., 2012). These results show the effects of peanut genotype and plant population on spotted wilt severity. However, it must be noted that seeding rate differs from the final plant population, and that this difference must be accounted for when calculating a risk index value.

The effect of planting date is another important risk factor included in Peanut Rx and it affects risk to tomato spotted wilt by proximity to peak thrips populations. By selecting a planting date to avoid times predicted for thrips flights, growers reduce the opportunity for viruliferous thrips to infect a susceptible peanut crop. The most common explanation for planting date effects on severity of tomato spotted wilt relates to thrips population dynamics in non-crop plants or volunteer peanut plants early in the season, since these host plants may serve as reservoirs for TSWV and thrips vectors (Culbreath, et al., 2003). According to surveys of TSWV infestations in peanut production fields in Georgia, greater spotted wilt epidemics were seen in early and late planted peanuts as compared with peanuts planted in early to mid-May. These data have been consistent throughout the southeastern United States, but may vary from year to year (Culbreath, et al., 2003).

Other production practices that have an effect on final severity of spotted wilt in peanut include tillage system and row pattern. In a five year study performed by Johnson *et al.*, spotted wilt incidence was 42% lower in peanut across all years under reduced tillage compared to conventional tillage (Johnson, et al., 2001). Studies on row pattern have shown that significant reductions in spotted wilt incidence occur when peanuts are planted in twin row peanuts as compared to single rows. The mechanism for such is poorly understood but may involve visual interference of migrating thrips (Culbreath, et al., 2003; Baldwin, et al., 2001). The combination of all of these production practices provides the peanut grower with an effective method for reducing risk to TSWV.

Insecticide use has been shown to affect spotted wilt severity in peanut and tobacco; however, this effect has been highly variable and ineffective in many cases. In peanut, at-plant insecticides have been very effective in controlling thrips damage in early growth stages, but have been largely ineffective in preventing transmission of TSWV (Chamberlin, et al., 1993). One at-plant insecticide, phorate, has shown significant results in reducing spotted wilt, but this has been inconsistent and the mechanism of such if unknown. It has been hypothesized to be a triggering of plant defense responses (Culbreath, et al., 2008; Jain, et al., 2015).

In tobacco, data have shown that use of plant defense activators and insecticides have resulted in lower incidences of spotted wilt. However, as seen in peanut, results can be inconsistent. In tobacco, effectiveness of pesticide usage for reduction of spotted wilt severity depends on the timing of application relative to vector migration and virus transmission (Chappell, et al., 2013). McPherson *et al.* (2005), performed a multi-year study that showed in years with low TSWV incidence, differences in severity of spotted wilt in tray-drench Actigard (acibenzolar-S-methyl) and tray-drench Admire (imidacloprid) were not significant from untreated checks. However in years with high TSWV pressure, significant reductions were observed and both treatments provided significant control.

Predicting epidemics caused by TSWV has been challenging due to the complexity of a pathosystem with three significant components: virus, vector, and host. The interaction of these components with the environment creates additional challenges (Jones, et al., 2010). A number of weather conditions contribute to the population dynamics of the thrips vector. However, temperature plays the most prominent role in thrips development and must be accounted for in a predictive model (Olatinwo, et al., 2008). Olatinwo *et al.* (2011), presented results based on a predictive weather model, termed the Weather Research and Forecasting (WRF) model, that explained 61% of the variability in spotted wilt severity in peanut as a function of the interactions between Peanut Rx and multiple weather factors. These factors included Peanut Rx, average daily temperature in April, average daily minimum temperature between March and

April, accumulated rainfall in March, accumulated rainfall in April, and number of rain days in April, evapotranspiration in April, and number of days from the first of January to the planting date. Since weather factors influence thrips development, thrips populations will fluctuate from year to year depending on field location and changing weather patterns. The WRF model is able to predict thrips peak populations with some accuracy. With the WRF model, growers should be able to determine their risk to TSWV (low, medium, high) and determine a planting window to avoid peak thrips populations (Olatinwo, et al., 2008).

A model similar to the one developed by Olatinwo *et al.* (1998) with respect to weather variables was developed at North Carolina State University in response to spotted wilt severity in tobacco and known biology of tobacco thrips. The relationship between weather variables and thrips populations was examined by Morsello *et al.* (2010) and included the effects of temperature and precipitation on the dispersal and population of adult tobacco thrips. Weather variables determined to have effects on thrips populations and dispersal included degree days, temperatures favorable for thrips flight, and rainfall index estimates (Morsello, et al., 2010). Mean number of adult tobacco thrips captured in 2007 showed increased populations beginning in early March, peaking towards the end of May, and dramatically dropping to low levels towards the end of June. The results from this study showed thrips populations and flights in the spring would be directly related to winter and spring temperatures. Timing and amount of rainfall events were shown to have suppressive effects on thrips populations (Morsello, et al., 2010). This model represents the spatial and temporal effects of weather factors on the dispersal and population dynamics of tobacco thrips in North Carolina. These data were subsequently used to develop a weather-based model that forecasts thrips populations and TSWV risk for tobacco. The underlying objective to developing the weather-based forecasting and risk model was to better understand factors affecting spotted wilt epidemiology. With cultivated tobacco as an example, the TTRF was developed using spotted wilt incidence data from North Carolina and climate data obtained from the North Carolina State Climate Office (SCO) (Chappell, et al., 2013; Morsello, et al., 2010). This model incorporated the complete TSWV pathosystem to include thrips population dynamics, epidemiology of TSWV, and virus lifecycle. According to Chappell *et al.* (2013), primary spread of TSWV from weed hosts to susceptible crops by tobacco thrips in the spring accounts for essentially all spotted wilt incidence in tobacco. Population dynamics and development of tobacco thrips are largely determined by temperature, precipitation, and host plant fitness (Morsello, et al., 2001). The TTRF contained fixed variables including prior-year thrips populations, average winter temperature, and March precipitation (Chappell, et al., 2013; Morsello, et al., 2010). By accounting for disease pressure and thrips transmission of TSWV, this model provides a platform for growers to better manage tobacco and, if properly adjusted, could one day provide a resource for spotted wilt disease management in other crops.

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CHAPTER 2

MANAGING SPOTTED WILT DISEASE IN TOBACCO IN GEORGIA: ASSESSMENT OF THRIPS AND TSWV FORECASTING[1]

[1] Williams, B., R. Kemerait, P. Bertrand, and T. Chappell. 2015. To be submitted to Plant Health Progress.

Abstract

In this study, the application of a forecasting model for spotted wilt disease management in tobacco grown in Georgia was investigated. Spotted wilt, caused by thrips-transmitted *Tomato spotted wilt virus* (TSWV), is an important viral disease affecting tobacco production in Georgia. Resistance is a very effective method of reducing spotted wilt in other crops, but no sources of resistance are commercially available in tobacco. Current management of spotted wilt disease in tobacco in Georgia is primarily through insecticide and plant activator applications. These methods are strictly preventative and limited data is available in which disease can be predicted on a yearly and local basis. However, North Carolina State University developed a Thrips and TSWV Risk Forecasting (TTRF) model for use in cultivated tobacco. The TTRF model uses weather factors to predict thrips populations and spotted wilt incidence based upon thrips biology and activity, as well as availability of overwintering disease inoculum. Spotted wilt field trials in tobacco were evaluated from 2009-2014 to assess the use of TTRF in Georgia. Weather and spotted wilt incidence data were collected for each trial across all years in tobacco. Final disease incidence ranged from 3.8 to 87.1% and the TTRF predicted spotted wilt disease in Georgia (observed versus predicted) with an R^2 value of 0.54%. Disease incidence values from 2013 were greatly over-predicted, but by excluding these values, the R^2 value increased to 38%. Validating the TTRF model was encouraging and displayed accuracy in predicting disease in Georgia, but only with the exclusion of 20% of the data collected from 2013. Further evaluations will be necessary to improve the efficacy of the TTRF in making predictions towards spotted wilt epidemics in tobacco.

Introduction

Tobacco (*Nicotiana tabacum*) is an important agronomic crop and in 2014 worldwide leaf production reached almost 12.5 billion pounds (ULTC, 2015). In the same year, the United States was the fourth leading producer of cultivated tobacco, producing over 875 million pounds with a total crop value of over $1.8 billion (NASS, 2015). Major tobacco producing countries include China, India, Brazil, USA, and Turkey (WHO, 2011). Production constraints revolve around the wide range of pathogens that cause diseases of tobacco. Some of the major diseases and pests of tobacco grown in the United States include bacterial wilt (*Ralstonia solanacearum*), black shank (*Phytophthora parasitica* var. *nicotiana*), plant-parasitic nematodes (*Meloidogyne* spp., *Pratylenchus* spp., etc.), and tomato spotted wilt (*Tomato spotted wilt virus*) (Peterson, et al., 2015). From the flue-cured and burley tobacco grown in North Carolina to the flue-cured tobacco produced in Georgia, tomato spotted wilt has consistently been a devastating and economically important disease of tobacco in the eastern United States. In 2014, North Carolina produced 434.4 million pounds of flue-cured tobacco compared to 35 million pounds in Georgia, but crop losses from tomato spotted wilt were ever present in both regions (Peterson, et al., 2015).

Tomato spotted wilt virus (TSWV) is the causal agent of the highly damaging and economically important tomato spotted wilt disease of tobacco. TSWV was the only member of the genus *Tospovirus* (family Bunyaviridae) for many years. (Matthews, 1982; Cho, et al., 1987; Tsompana and Moyer, 2008; Mandal, et al., 2015; German, et al., 1992). In the United States, spotted wilt disease was initially reported in Texas in 1971 (Halliwell and Philley, 1974). In Georgia, spotted wilt was first diagnosed in flue-cured tobacco in 1986 (Culbreath, et al., 1991). After first detection of this disease in Georgia, spotted wilt epidemics became prevalent in the southeastern states. Disease incidence increased steadily from season to season and in 2002 resulted in stand reduction and crop losses of more than 40% and 20% (>$19 million), respectively. Disease incidence has slowly declined since 2002, but crop losses still cost growers millions of dollars annually (Langston, Jr. and Bertrand, 2008; UGA, 2013; Bertrand, 2003). Losses to spotted wilt are prevalent in all tobacco producing regions of the United States, further establishing the necessity for improved management options.

Transmission of TSWV to a susceptible host is via certain genera and species of thrips (Thysanoptera: Thripidae) (German, et al., 1992; Amin, et al., 1981; Cho, et al., 1984; Ghanekar, et al., 1979; Kobatke, et al., 1984; Sakimura, 1963; Riley, et al., 2011).The predominant species of thrips transmitting TSWV to tobacco in the eastern United States are tobacco thrips (*Frankliniella fusca*) and western flower thrips (*Frankliniella occidentalis*) (Groves, et al., 2003; Diffie, et al., 2008). Current management for spotted wilt in tobacco includes avoidance and direct protection tactics from these viral vectors.

Host plant resistance is the most effective way to minimize spotted wilt in many crops (Culbreath, et al., 1999; Riley, et al., 2011; Gunter, et al., 2012); but resistance to TSWV in tobacco is limited (Pappu, et al., 2000). Through transgenic methods, resistance to TSWV has been observed in tobacco; however, these plants are not commercially available due to market constraints (Prins, et al., 1994; Spassova, et al., 2001; Davison, 2010). In Georgia and most tobacco growing regions, the primary management tactic for spotted wilt is protection of the plants with chemicals. Acibenzolar-S-methyl, a plant defense activator, has also been shown to suppress spotted wilt incidence, but it has little effect on the thrips vector. Imidacloprid and other insecticides have variable efficacy against thrips and spotted wilt incidence (McPherson, et al., 2003; Chatzivassiliou, 2008; Csinos, et al., 2001; Wells, et al., 2002).

A weather-based predictive model, termed "Thrips and TSWV Risk Forecasting Model" (TTRF), was developed at North Carolina State University in response to spotted wilt in tobacco and with knowledge of the biology of tobacco thrips. The relationship between weather variables and thrips populations had been evaluated and was found to include the effects of temperature and precipitation on the dispersal and population sizes of adult tobacco thrips. Results from these studies showed thrips activity in the spring could be directly related to winter temperature. Timing and number of rainfall events were shown to have suppressive effects on thrips populations. Rainfall caused mortality rates to increase in thrips populations (Groves, et al., 2003; Morsello, et al., 2008; Morsello and Kennedy, 2008; Morsello, et al., 2010). These data were used to develop a weather-based management model that forecasts thrips populations and TSWV risk for tobacco.

The TTRF model contains independent variables that include prior-year thrips (PYT) population estimates (positively correlated with virus abundance), average winter temperature (AWT) (affects abundance and persistence of winter weeds and thrips activity), and March precipitation (MP), (known to have a suppressive effect of adult thrips dispersal activity and juvenile mortality). Each of these factors impact spotted wilt intensity and transmission on a season to season basis (Chappell, et al., 2013; Morsello, et al., 2010). This model is associated with multiple aspects of the TSWV pathosystem and is based on the assumption that spotted wilt incidence is correlated to thrips populations (Morsello, et al., 2010).

The TTRF model provides a tool for growers to better manage spotted wilt disease in tobacco. It may be possible that similar models could provide resources for plant virus management in other crops. Since TTRF model was effective in management of spotted wilt of tobacco in North Carolina, the primary objective of this research was to determine the usefulness of the weather-based model in Georgia. As previously mentioned, current spotted wilt management in Georgia is dominated by chemical control; however adoption of an appropriately modified TTRF model may provide a resource to growers looking to improve their management efforts. In this study, the application of a forecasting model (TTRF) for spotted wilt disease management in tobacco grown in Georgia was investigated. Further evaluations will be necessary to improve the predictive power and increase efficacy for Georgia tobacco growers looking to expand spotted wilt disease management.

Materials and Methods

Plant materials and trial setup

Spotted wilt disease intensity trials were established in multiple commercial fields during the spring of 2013 and 2014. In 2013, trial locations included Appling, Ben Hill, Berrien, Candler, Coffee, Cook, Irwin, Jeff Davis, Lowndes, and Tift Counties in Georgia. Thirty-one trials were conducted in 2013. In 2014, trial locations included: Appling, Ben Hill, Berrien, Candler, Coffee, Jeff Davis, Lowndes, and Tift Counties. Twenty-one trials were conducted in 2014. Protocols varied among trials but each included an untreated control for final assessment of incidence of spotted wilt disease.

Many trials included in this study were established to test the effect of different chemical treatments on spotted wilt incidence; however, only untreated plots were analyzed here. Treatments were arranged in a randomized complete block and plots were two rows wide, ranging from 80 to 250 plants per row. Treatments were replicated three or four times, dependent on the trial.

Spotted wilt disease intensity evaluation and data gathering

Spotted wilt intensity ratings were initiated after transplant and continued biweekly through week 12 to 14. Ratings occurred on weeks 0, 2, 4, 6, 10, 12, 14 or on weeks 1, 3, 5, 7, 9, 11, 13. Visual symptoms including necrotic rings, venial necrosis, and spots were used for incidence ratings. Plants lost to mechanical damage, skips, etc. were discounted from total plant count per plot. If additional diseases disrupted rating efficiency (i.e. blackshank, damping off, etc.), rating values for that time period were not used in the analysis. Since tobacco plants could be individually accounted for in each plot, the final spotted wilt incidence rating was used for statistical analysis. Multiple ratings were collected to examine disease progress over time.

Use of historical TSWV incidence data

Historical data from TSWV incidence trials were collected from multiple researchers at the University of Georgia, Tifton, Georgia (unpublished, 1991-2012). Trials from which data were collected included various treatments (insecticide, plant activator, nematicide, black plastic, reduced tillage, plant population, etc.), but only non-treated checks were used in the present study. These data, along with data collected in 2013 and 2014, were used to assess and validate NCSU's TTRF model. Such was achieved by correlating predicted versus observed spotted wilt incidence values. Additional analyses, using regression techniques, will be necessary to re-estimate coefficients and for possible addition of weather components in building a similar model using Georgia tobacco data.

Global positioning system and weather data gathering

Global positioning system coordinates were collected in decimal format at all locations in Georgia for data analysis with the TTRF model. Historical weather data were compiled using NC-CRONOS (NC Climate Retrieval and Observations Network of the Southeast

Database)/ECONet Database developed by the State Climate Office (SCO) of North Carolina, North Carolina State University, Raleigh, NC 27695. These data include the following variables: prior year thrips estimation (output by regression equation containing; cumulative degree days from November 1 through one day prior to the start of the trapping interval; number of days with temperatures favorable for thrips flight during the trapping interval; and rainfall index estimates) (Morsello, et al., 2010); cumulative March precipitation in centimeters; and average winter temperature in degrees Celsius (Chappell, et al., 2013). Prior-year thrips estimation was estimated using methods detailed in a previous study by Morsello, et al., 2010.

Normalizing predictions to eliminate grower/location bias

The TTRF model was designed to output predictions based upon historical incidence and weather data. One dependent factor in this model was a random effect coefficient used to eliminate bias resulting from locations, differences among growers, etc. that resulted in more or less disease pressure for unknown factors. For each grower, average historical incidence (per grower) was used for model input and resulted in altering prediction output so as to be tailored to each grower's history of TSWV. This provided normalized predictions of spotted wilt that were based upon weather factors, but which were centered on known historical incidence for each grower and location.

Data analysis for model validation

Predicted incidence values from the TTRF model were calculated by compiling historical weather data for each trial location. Factors used included prior-year thrips (Morsello, et al., 2008), average winter temperature, and March precipitation. These data were inputted into the TTRF regression equation to obtain predicted spotted wilt incidence. This equation was then converted into TSWV incidence through an inverse logit link function to obtain actual prediction values (33). Historical and recently collected TSWV incidence data were analyzed using PROC REG (regression general-purpose) procedure in SAS version 9.3 (SAS Institute, Cary, NC). Predicted TSWV incidence values were correlated with observed (actual) values for each trial across all years to validate the model's use in Georgia. Again, only non-treated plots were used in this study to prevent any interactions from additional treatments.

Additional analyses were run to determine the significance of each fixed weather effect when using spotted wilt data from Georgia in re-estimating the coefficients. A re-estimation of these effects was analyzed using PROC GLIMMIX (generalized linear mixed model) procedure in SAS version 9.3 (SAS Institute, Cary, NC). Prior-year thrips populations, average winter temperature and March precipitation effects were included in a "best-fit" model using data from tobacco grown in Georgia. Further analyses will be necessary to determine additional weather factors that contribute to spotted wilt incidence; therefore, allowing for increased disease prediction accuracy.

2013 predictions and exclusion in data analyses

Data from 2013 were excluded in part of this experiment. Prior-year thrips estimations for 2013 were extremely high and caused the model to greatly over-predict disease incidence. This, in turn, caused predictions for other years to be less accurate based upon the random effect coefficient. The linear predictors contained the historical data from years 2009-2012, and 2014. Reasons for problems in 2013 have not yet been determined, but are currently being evaluated in order to improve the accuracy of this model for use in Georgia tobacco.

Results

Validation of Thrips and TSWV Risk Forecasting Model

Spotted wilt data on tobacco in Georgia were analyzed using the TTRF model for years 2009 through 2014. The TTRF model contained the following fixed variables gathered from the Georgia Automated Weather Systems (gathered by NC State Climate Office) for each grower and location: prior-year thrips (PYT) populations, average winter temperature (AWT), and March precipitation (MP). In validating the TTRF model, the same framework for the NC-based model was used for analysis. A linear predictor (η) was calculated from the following equation:

$$\eta = 0.0219(PYT) + 0.0916(MP) + 0.156(AWT) - \ 0.00282(PYTxMP) - Z(Co) - 5.369$$

Z (Co) represents the random effect coefficient corresponding to the given grower in each county.

The linear predictor was then converted to TSWV incidence through the inverse logit link function:

$$e^{\eta}(1 + \ e^{\eta})^{-1}$$

Fit plots were developed individually for each year and as a combined dataset (Figures 2.1-2.8). Variation was present across all years, but aside from 2013, predicted values showed good fir to observed incidence. R^2 values were used to determine how effective the model predicted disease incidence. The greatest variability explained was in year 2011 (R^2 = 0.7251), resulting in average deviations of 4.81% of observed spotted wilt incidence from TTRF predicted values (Table 2.1). In year 2013, R^2 was much lower than other years, but had a comparable root mean square error of 8.79%, suggesting that the data fit the trend, but were not within the actual incidence ranges (Table 2.1). Visual results confirmed the over-predictions were caused by prior-year thrips estimates.

Observed incidence data closely follow predictions for the combined dataset containing years 2009 through 2014, with the exception of 2013 resulting in over-prediction. Excluding 2013 in the analyses resulted in an increase in an R^2 values (0.0054 to 0.3876) (Table 2.1).

Re-estimation of coefficients of TTRF using Georgia data

In an attempt to determine what fixed effects had greater importance in spotted wilt incidence in Georgia compared to North Carolina, regression techniques were used to re-estimate model coefficients. Prior-year thrips, average winter temperature, and March precipitation were used in conjunction with Georgia tobacco data to improve the existing NC-based model without altering the framework. The best-fit model determined by Georgia data from years 2009 to 2014 showed the linear predictor (η) being calculated from the following equation:

$$\eta = 0.002152(PYT) + 0.2739(MP) + 0.008511(AWT) - 0.00057(PYTxMP) - Z(Co) - 2.6211$$

The linear predictor was then converted to TSWV incidence through the inverse logit link function:

$$e^{\eta}(1 + e^{\eta})^{-1}$$

Z (Co) represents the random effect coefficient corresponding to the given grower in each county. March precipitation was the most significant factor regarding spotted wilt incidence in Georgia (p = 0.0031), which was similar to North Carolina analyses (Morsello, et al., 2008; Morsello, et al., 2010).

Predictions for 2013 were higher than the other years. Therefore, another best-fit model was evaluated using years 2009-2014, excluding 2013. The linear predictor (η):

$$\eta = 0.0161(PYT) + 0.4959(MP) - 0.09135(AWT) - 0.00267(PYTxMP) - Z(Co) - 3.0294$$

The linear predictor was then converted to TSWV incidence through the inverse logit link function:

$$e^{\eta}(1 + e^{\eta})^{-1}$$

Z (Co) represents the random effect coefficient corresponding to the given grower in each county. Prior-year thrips (p = 0.0054), March precipitation (p = 0.0014) and their interaction (MP*PYT) (p = 0.0163) all showed a significant interaction towards spotted wilt incidence (Table 2.3).

Discussion

Spotted wilt management in Georgia tobacco involves primarily chemical applications shown to reduce disease incidence (Csinos, et al., 2001; Chatzivassiliou, 2008; McPherson, et al., 2005; Groves, et al., 2000; Mandal, et al., 2008). Additional management methods include adjusting the planting data, roguing of infected plants, and re-planting, but these have had limited effect in reducing spotted wilt disease (Pappu, et al., 2000). Predictive models have shown efficacy in spotted wilt disease management in North Carolina and could increase current management systems in Georgia (Morsello, et al., 2010; Chappell, et al., 2013). In this study, an evaluation of a weather-based predictive model developed by North Carolina State University was conducted in flue-cured tobacco in Georgia over the period 2009 to 2014.

The relationship between weather factors to spotted wilt incidence was studied in this experiment. Two components of the pathosystem mediated by weather were used in the model developed by North Carolina State University and included: weed host availability for overwintering TSWV inoculum and tobacco thrips transmission intensity, relating to survival and activity of thrips vector populations (Chappell, et al., 2013). Chappell, et al., 2013, determined a relationship between these variables and allowed for successful predictions of disease incidence. From an epidemiology standpoint, these data have become the basis for model validation for spotted wilt disease in Georgia tobacco.

Spotted wilt disease in tobacco for the state of Georgia each year (2009-14) reached 31, 13, 18, 22, 17, and 23%, respectively (unpublished data). Based upon the developed fit plots for each year, the TTRF model was consistent in predicting disease with all years excluding 2013. The greatest variability explained was observed in years 2010 and 2011 (R^2 = 54.36% and 72.51%, respectively) when disease pressure of these six years was also the lowest (Table 2.1). In the highest disease pressure year, 2009, R^2 = 46.15%, resulting in lower variability explained and 10% average variation in observed disease when compared to TTRF predicted incidence (Table 2.1). These R^2 values are lower than those calculated for North Carolina, but alterations to the current model have yet to be evaluated and could greatly improve model efficacy.

In 2013, extremely high prior-year thrips estimates caused spotted wilt predictions to over-estimate near 95 to 100% incidence levels (Figure 2.7). Sources behind this occurrence are being currently researched; however, for the purpose of this study, 2013 linear predictor values were not used in normalizing predictions for grower prediction estimates. By using these values, predictions would be skewed towards over-estimating. As Figure 2.7 describes, year 2013 is an anomaly, and lowered the variability explained compared to the omission of 2013 predictions. Without 2013 data, combined results indicated a R^2 of 0.3876 (compared to 0.0054). These data exhibit decent fit for running the model exactly as used in North Carolina, but additional tests must be analyzed to improve the prediction power of this model for use in Georgia.

An attempt was made to retain the same framework as the NC-based TTRF model, keeping prior-year thrips, average winter temperature, and March precipitation, but re-estimate coefficients to improve the models usefulness. When using combined data from all years, March precipitation was the only significant contributor to spotted wilt incidence when fitting the model to Georgia data (p = 0.0031). However, when omitting the over-estimated predictions from 2013, all factors had a certain level of significance; prior-year thrips ($p = 0.0054$), March precipitation ($p = 0.0014$), prior-year thrips*March precipitation ($p = 0.0163$), and average winter temperature ($p = 0.1049$).

In this study, we have evaluated a disease prediction model for use in the same system but different geographic location than its original purpose. The ability to predict disease incidence based upon weather factors that contribute to pathosystem activity will give growers more options to manage for disease. Current management centers upon preventative measures, but if disease pressure can be predicted, costs for these measures could possibly be minimized. We have shown that the NC-based model has some degree of effectiveness for use in Georgia, but there are areas in which the model predictions can be improved. Climate in the southeast United States is variable, and should be seriously considered when developing management methods that are based upon stable weather patterns. This study gives the possibility of not only using existing prediction models in different geographic locations, but also provides a basis for developing models based upon similar pathosystems.

Summary and Conclusions

Current management of spotted wilt disease in tobacco in Georgia is through insecticide and plant activator applications. These methods are strictly preventative and limited data is available in which disease pressure can be predicted on a yearly and location basis. North Carolina State University developed a Thrips and TSWV Risk Forecasting (TTRF) model for use in cultivated tobacco. The TTRF model uses weather factors to predict thrips populations and spotted wilt incidence based upon thrips biology and activity, as well as availability of overwintering disease inoculum. It was the goal of this study to evaluate this model for use in

Georgia flue-cured tobacco. Validating the TTRF model displayed success for 80% of the dataset (excluding data from year 2013) and showed accuracy in predicting disease in Georgia. Further evaluations will be necessary to improve the predictive power and increase efficacy for Georgia tobacco growers looking to predict spotted wilt in tobacco.

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Tables and Figures

Table 2.1: Listing of mean square error, root mean square error, and coefficient of determination for each individual year and combination of years 2009 through 2014.

Year(s)	Mean Square Error (MSE)[a]	Root MSE	R^2
2009	0.01008	0.10042	0.4615
2010	0.00231	0.0481	0.5436
2011	0.00349	0.0591	0.7251
2012	0.00935	0.09667	0.2837
2013	0.00773	0.08794	0.0604
2014	0.01031	0.10152	0.3179
2009-2014	0.01314	0.11462	0.0054
2009-2012,2014[b]	0.00903	0.09501	0.3876

[a]Denotes the average percent deviation from prediction value for each observation
[b]Excluding 2013, in which predictions were greatly over-predicted and skewed results for remaining years analyzed

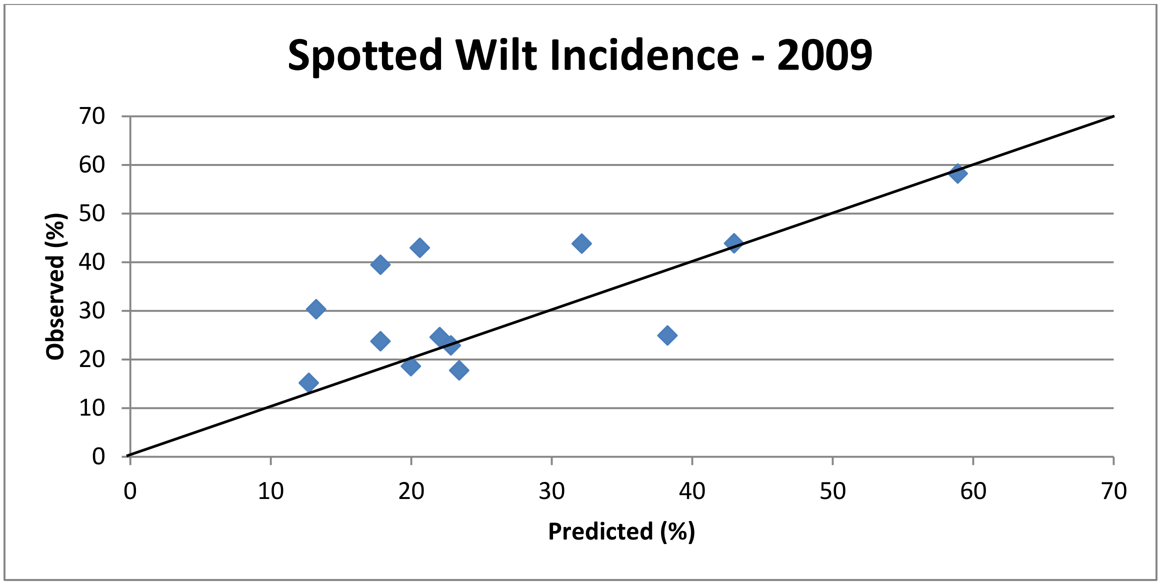

Figure 2.1: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 13, MSE = 0.01008, R^2 = 0.4615.

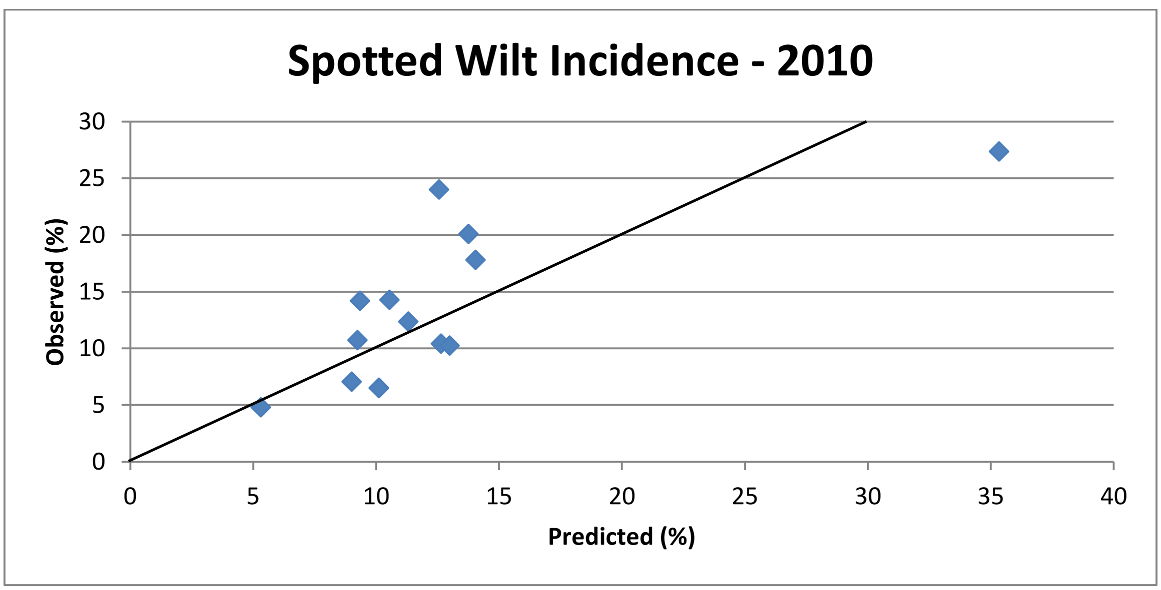

Figure 2.2: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 14, MSE = 0.00231, R^2 = 0.5436.

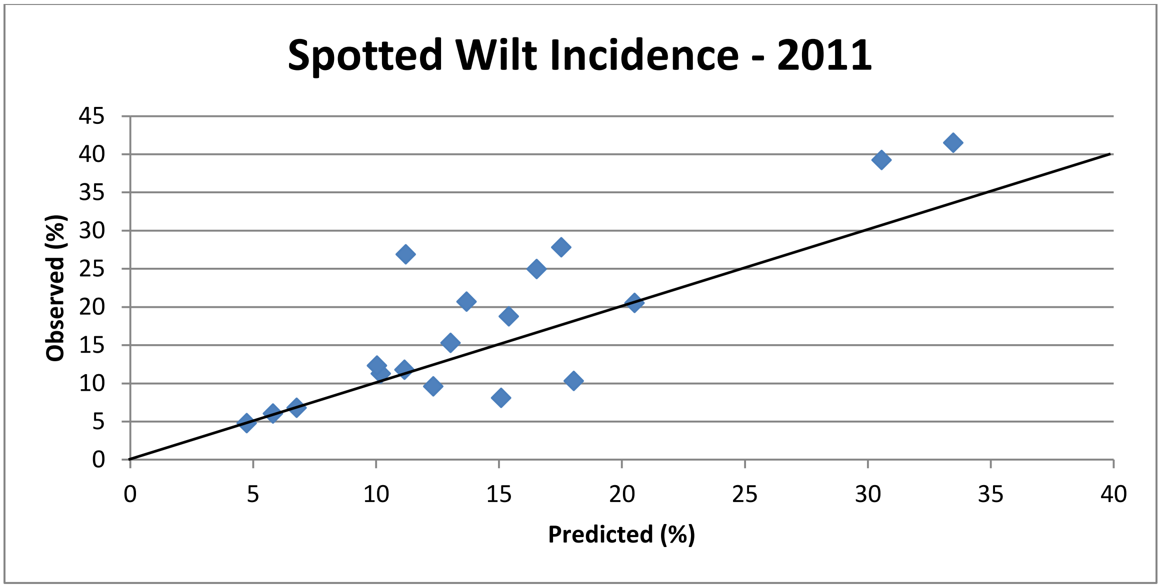

Figure 2.3: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 18, MSE = 0.00349, R^2 = 0.7251.

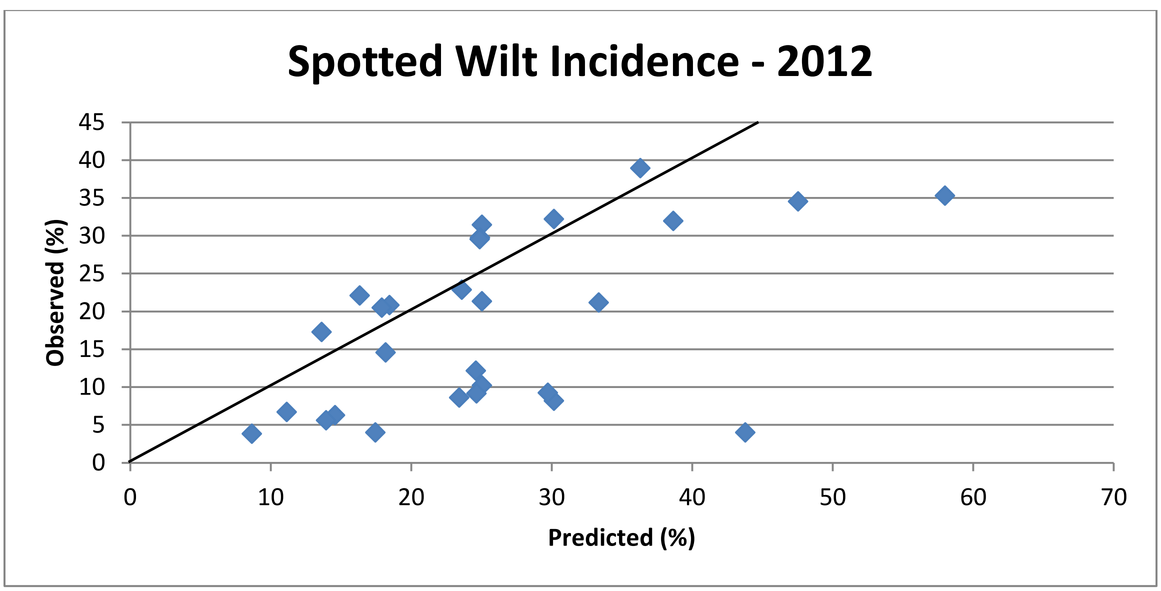

Figure 2.4: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 28, MSE = 0.00935, R^2 = 0.2837.

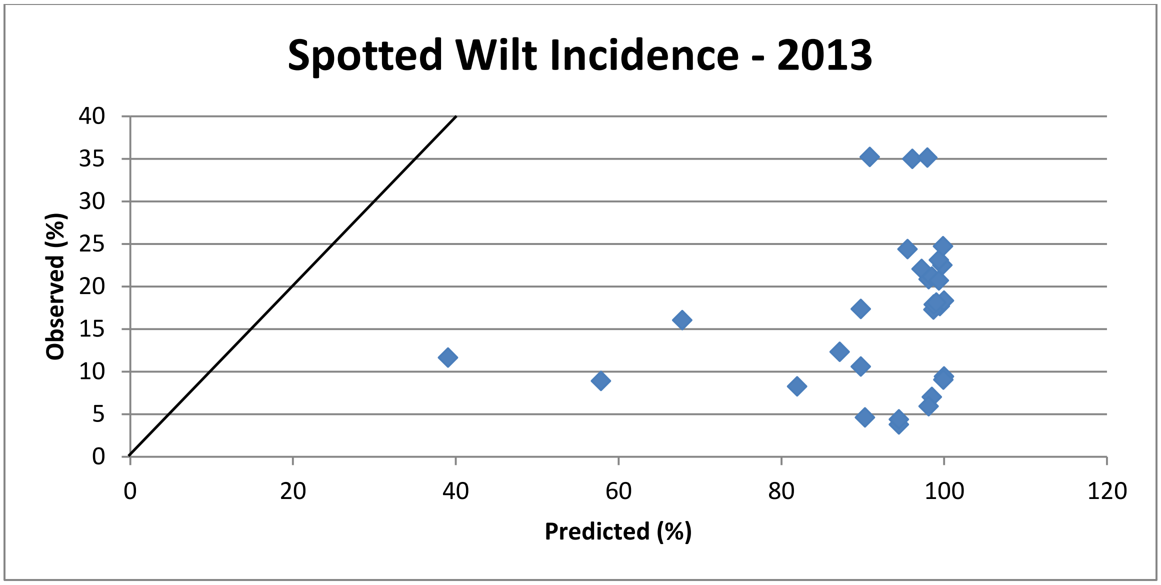

Figure 2.5: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 30, MSE = 0.00773, R^2 = 0.0604.

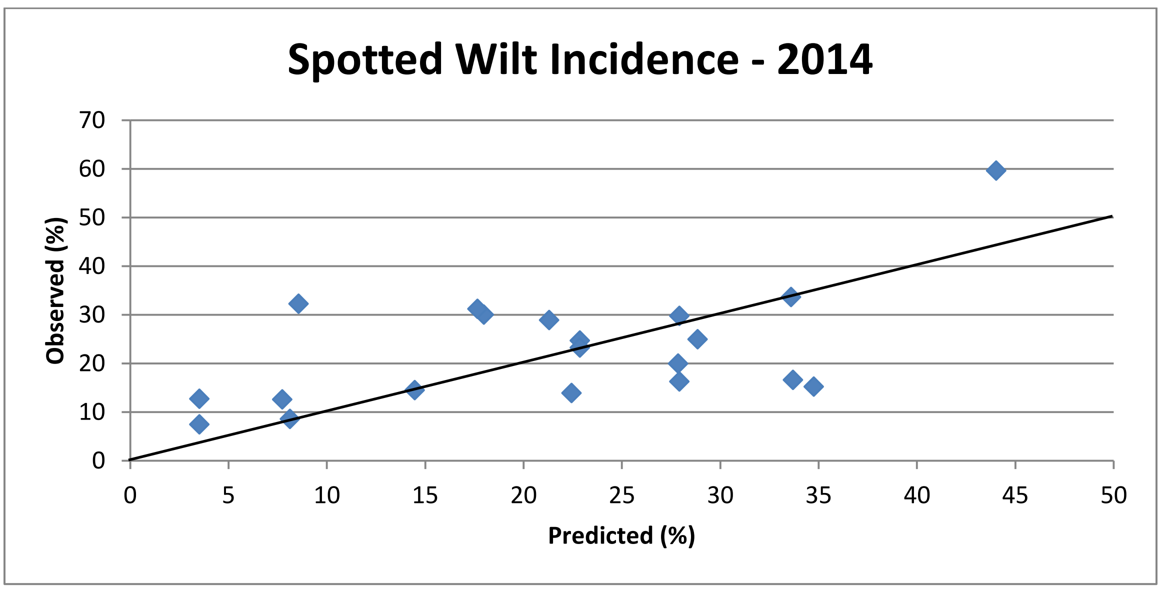

Figure 2.6: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 20, MSE = 0.01031, R^2 = 0.3179.

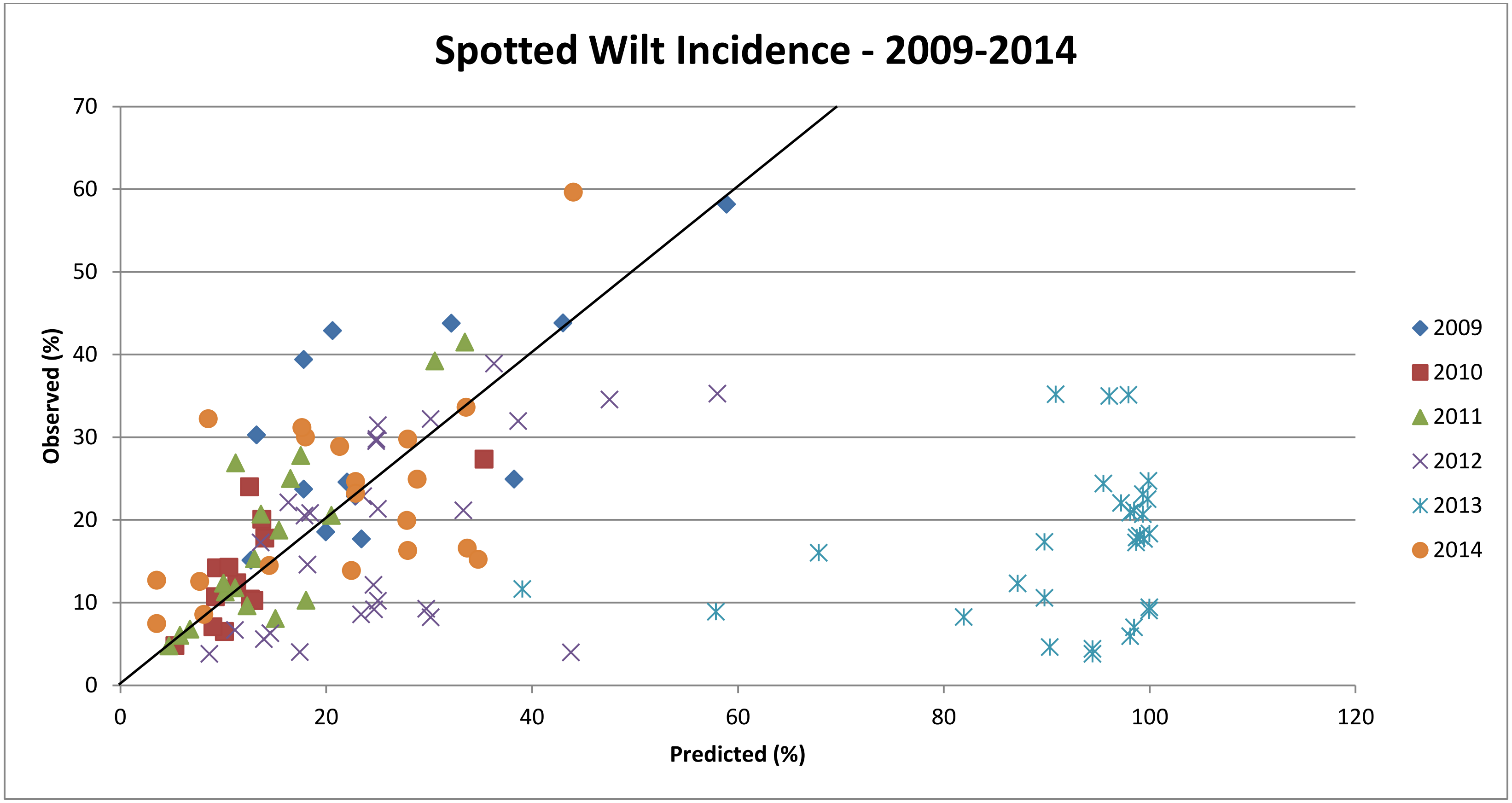

Figure 2.7: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 123, MSE = 0.01314, R^2 = 0.0054.

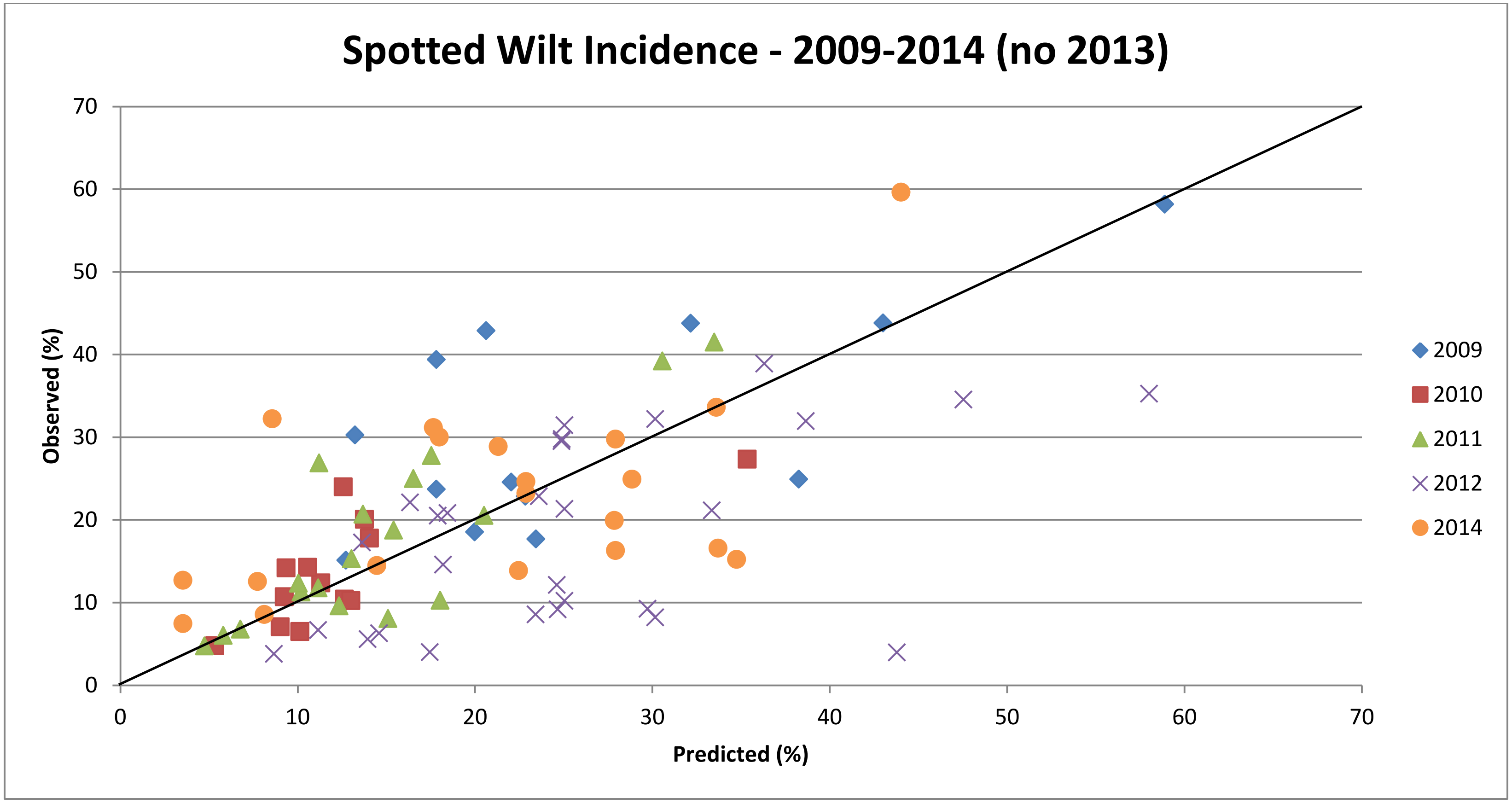

Figure 2.8: Fit plot for TTRF model, observed spotted wilt data from Georgia on NC-based model predictions, n = 93, MSE = 0.00903, R^2 = 0.3876.

Table 2.2: Listing of solutions for fixed effects for re-estimation of coefficients using Georgia data for framework of NC-based model (2009-2014).

Effect	Estimate[a]	Standard Error	DF	t-Value	Pr > |t|
Intercept	-2.6211	0.4276	28	-6.13	<.0001
PYT	0.002152	0.001656	90	1.30	0.1969
MP	0.2739	0.09023	90	3.04	0.0031
PYT*MP	-0.00057	0.000435	90	-1.30	0.1964
AWT	0.008511	0.04046	90	0.21	0.8339

All values are reported for generalized linear mixed models. The County variable is treated as a random effect based upon grower. Abbreviations for fixed effects are as follows: PYT – prior-year thrips estimate (units of dispersing adult thrips caught on sticky traps); MP – March precipitation in centimeters; AWT – average winter temperature in degrees Celsius.
[a]Re-estimated coefficients based upon Georgia spotted wilt data

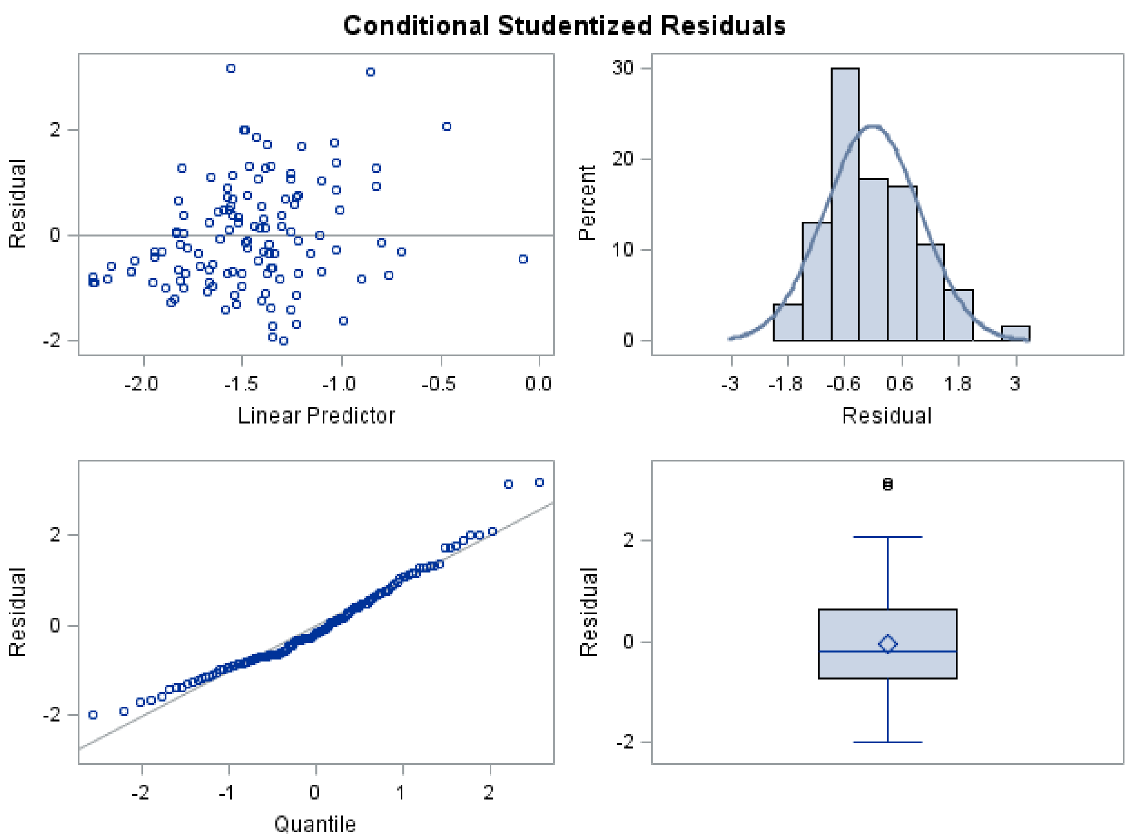

Figure 2.9: Panel of diagnostic plots for model validation based on Georgia data framework, showing conditional Studentized residuals (2009-2014).

Table 2.3: Listing of solutions for fixed effects for re-estimation of coefficients using Georgia data for framework of NC-based model (2009-2012,2014).

Effect	Estimate[a]	Standard Error	DF	t-Value	Pr > |t|
Intercept	-3.0294	0.5757	28	-5.26	<.0001
PYT	0.0161	0.005571	60	2.89	0.0054
MP	0.4959	0.1476	60	3.36	0.0014
PYT*MP	-0.00267	0.00108	60	-2.47	0.0163
AWT	-0.09135	0.05548	60	-1.65	0.1049

All values are reported for generalized linear mixed models. The County variable is treated as a random effect based upon grower. Abbreviations for fixed effects are as follows: PYT – prior-year thrips estimate (units of dispersing adult thrips caught on sticky traps); MP – March precipitation in centimeters; AWT – average winter temperature in degrees Celsius.
[a]Re-estimated coefficients based upon Georgia spotted wilt data

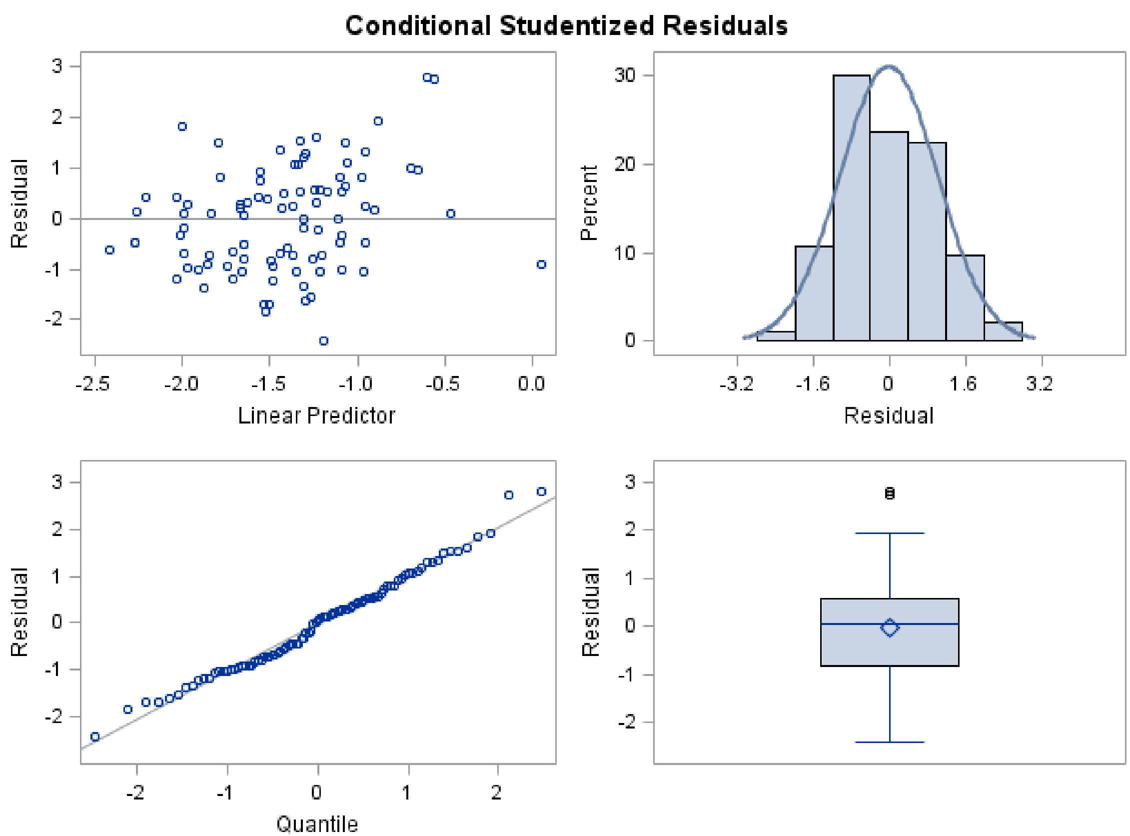

Figure 2.10: Panel of diagnostic plots for model validation based on Georgia data framework, showing conditional Studentized residuals (2009-2012, 2014).

CHAPTER 3

PEANUT RX 2.0 – COMBINING RISK MODEL AND TSWV PREDICTIVE MODEL TO IMPROVE MANAGEMENT OF SPOTTED WILT IN PEANUT IN THE SOUTHEAST UNITED STATES[1]

[1] Williams, B., R. Kemerait, J. Sherwood, G. Kennedy, T. Chappell, and P. Bertrand. 2015. To be submitted to Phytopathology.

Abstract

Plant viruses cause serious production constraints and financial losses annually. Most effective management techniques require consideration of both vector populations and virus spread. Through an integrated approach, we investigated the contribution of a multi-model method to manage spotted wilt disease in cultivated peanut. Spotted wilt, caused by thrips-vectored *Tomato spotted wilt virus* (TSWV), is an important viral disease affecting peanut production in the southeast United States. Current management is targeted at minimizing spotted wilt severity and includes an assortment of production practices comprising varietal resistance, chemical, and cultural controls. These factors are included in a risk index (Peanut Rx) and describe risk to spotted wilt based on level of risk. However, this method fails to reflect vector population dynamics and disease pressure. Through the introduction of a spotted wilt forecasting model (TTRF) which accounts for these factors, disease pressure can be predicted. The aforementioned predictive model was previously developed by North Carolina State University and is based upon multiple weather components known to impact thrips vector biology and population dynamics. In this study, weather and spotted wilt incidence data were collected for each trial across all years in peanut. Spotted wilt field trials in peanut across south Georgia and north Florida were evaluated from 2010-2014. Final disease incidence data ranged from 0 to 68.7 percent. Independent variables from Peanut Rx and TTRF were integrated in an attempt to improve current management of spotted wilt in peanut. The new model, Peanut Rx 2.0, was constructed by regression analysis in an attempt to predict disease in southeastern peanut. With Peanut Rx 2.0, 26.24% of the variability was explained with a mean square error from the cross-validation of just over 10%. These results provide a framework in which improved models can be developed to increase spotted wilt management in the southeast United States. Growers will

be able to account for both spotted wilt risk and disease pressure, which will subsequently allow them to determine the best production practices to limit spotted wilt incidence.

Introduction

Tomato spotted wilt virus (TSWV) (family *Bunyaviridae*, genus *Tospovirus*), the causal agent of spotted wilt disease, is one of the most widespread plant viruses worldwide. Economic losses from spotted wilt result from an extended host range, exceeding 1000 plant species and 80 families that include many agronomic, horticultural, and vegetable crops (German, et al., 1992; Parrella, et al., 2003; Mertelik, et al., 1998; Cho, et al., 1986; Cho, et al., 1987). Symptomatic host plants are associated with decreased productivity, yield losses, and significant economic consequences (Sherwood, et al., 2003; Brunt, et al., 1996). Early season spotted wilt epidemics contribute greatly to marketable yield losses compared to disease development later in the season (Olatinwo, et al., 2008). In Georgia, spotted wilt became a severe production constraint in peanut (*Arachis hypogaea* L.) and tobacco (*Nicotiana tabacum* L.) in the late 1980's through the 1990's, causing yield losses to reach 100% in some regions (Csinos, et al., 2001; Kucharek, et al., 1990). Spotted wilt disease, though reduced in crop damages over the past decade, is still of major concern today.

Tomato spotted wilt was first observed in the southeastern United States in 1986 and quickly become a major production constraint in the early to mid-1990's (Hagan, et al., 1998; Chamberlain, et al., 1992). In the southeast, TSWV is primarily transmitted by two thrips species, tobacco thrips (*Frankliniella fusca* (Hinds)) and western flower thrips (*Frankliniella occidentalis* (Pergande)) (Riley, et al., 2011). In 1997, yield losses in peanut to spotted wilt in Georgia exceeded 12% of total acreage, resulting in almost $45 million in losses. Yield losses subsequently dwindled to almost 1% by 2002 and have since fluctuated between 0.5 and 8% (Cooperative Extension Service, UGA, 2015). However, reports from the previous two years showed increases in disease prevalence (unpublished data). In tobacco, spotted wilt steadily increased from 1995 to the mid-2000's, peaking in 2002, with a 41% stand loss and 20% crop loss. Losses in tobacco have decreased to present date, but have ranged between 3 and 18% annually (CAES, UGA, 2015). In 2014, crop losses in peanut associated with spotted wilt disease reached 3%, an increase of 1% from 2013 (2014 plant disease loss estimates; Martinez-Espinoza, et al., 2014). Continued losses to spotted wilt in the southeastern United States and the recent flux of disease in peanut signify the necessity of increased spotted wilt management for future crop production.

Management of spotted wilt disease is dictated by crop species affected. Unlike many plant disease complexes, no single management method provides adequate control of this disease. Multiple models and risk indices have been developed specifically for certain crop and vector species. In 1996, a risk index was released by the University of Georgia and comprised a method in which growers could assess their relative risk to spotted wilt based upon factors shown to suppress spotted wilt incidence in peanut (Brown, et al., 2005). Factors included in what is now known as the 'Peanut Rx' risk index include: variety selection, planting date, plant population, at-plant insecticide, row pattern, tillage system, and the use of Classic® herbicide. The grower identifies their risk to spotted wilt as being low, medium, or high based upon selections within each factor.

Another method of spotted wilt management uses a forecasting model to predict thrips activity and TSWV risk based upon weather factors. This model, termed the 'Thrips and TSWV Risk Forecasting Tool' (TTRF) was developed by North Carolina State University for use in cultivated tobacco. TTRF uses management interventions based upon an epidemiological model centered on the interaction of insect-mediated effects of spotted wilt epidemics (Chappell, et al., 2013). Temperature and precipitation have been shown to contribute to thrips activity and population dynamics (Morsello, et al., 2010; Morsello, et al., 2008). Subsequently, similar weather factors and thrips activity were shown to have a correlation with spotted wilt disease in tobacco. These factors included: prior-year thrips (Morsello, et al., 2010), March precipitation, and average winter temperature (Chappell, et al., 2013). This study examined the relationship of weather to spotted wilt incidence in tobacco, providing a best-fit regression model that explained 89.9% of the variability (Chappell, et al., 2013). This model, distinctly different from the aforementioned risk index, provides another success in the management of spotted wilt.

The goal of this study is to merge both risk index and forecasting model for improved management. Both risk index (Peanut Rx) and forecasting model (TTRF) target the spotted wilt pathosystem in an attempt to mitigate disease incidence, but do so from different aspects. Peanut Rx explains levels of disease risk while the TTRF model accounts for disease pressure. For instance, with a given risk value from Peanut Rx, a grower can determine his predicted disease level given a certain level of disease pressure. A field can be at high risk to spotted wilt and not have major losses, if disease pressure is not high. Conversely, the TTRF model predicts disease pressure, but does not account for disease risk. This study involves the integration of such a model which accounts for both disease risk and disease pressure. This model, Peanut Rx 2.0, could provide growers with a more accurate management tool. The objective of this study was to incorporate both Peanut Rx risk index and the TTRF predictive model for improved management of spotted wilt in peanut in the southeastern United States, as well as test the validity of such a model in peanut.

Materials and Methods

Plant materials and trial set up

Spotted wilt disease intensity trials were conducted in multiple locations during the summers of 2013 and 2014. In 2013, trial locations included: Gibbs Farm (Tift County, Georgia), Lang-Rigdon Farm (Tift County, Georgia), Fishpond (Tift County, Georgia), and Attapulgus Research and Education Center (Decatur County, Georgia). In 2014, trial locations included: Lang-Rigdon Farm (Tift County, Georgia), Blackshank Farm (Tift County, Georgia), Ponder Farm (Tift County, Georgia), Attapulgus Research and Education Center (Decatur County, Georgia), and North Florida Research and Education Center (Gadsden County, Florida). Protocols varied among trials and all were implemented by multiple research professionals, but each included the effects of one or more production practices listed by Peanut Rx risk index (Table 3.1).

Table 3.1: Information for spotted wilt incidence trials in 2013-2014.

Year	Trial PI	Trial Name	Location	Planting DOY	Cultivar(s)	Pesticide(s)	Row Pattern(s)	Tillage System(s)	Plots	Reps
2013	Beasley	TF1314	Gibbs Farm, Tifton, Ga	30-Apr	Bailey	CruiserMaxx, Thimet, UTC	Single	Conventional	16	4
2013	Beasley	TF1315	Gibbs Farm, Tifton, Ga	30-Apr	06G, 12Y, Greener	CruiserMaxx, Thimet, UTC	Single	Conventional	48	4
2013	Beasley	TF1316	Gibbs Farm, Tifton, Ga	30-Apr	06G, 07W, 09B, Florun 107, Greener, Tifguard	None	Single	Conventional	28	4
2013	Beasley	TF1317	Gibbs Farm, Tifton, Ga	30-Apr	06G, 09B	CruiserMaxx, Thimet, UTC	Single	Conventional	32	4
2013	Beasley	TF1329	Gibbs Farm, Tifton, Ga	30-Apr	06G	CruiserMaxx, Thimet, UTC	Single	Conventional	32	4
2013	Culbreath	Index	Lang Farm, Tifton, Ga	8-May	Bailey, 06G, 12Y, Greener	Thimet, UTC	Single	Conventional	64	4
2013	Culbreath	InoxThi	Lang Farm, Tifton, Ga	28-May	06G, 07W, 09B, 12Y, Greener	Thimet, UTC	Single	Conventional	40	4
2013	Culbreath	PMAP	Lang Farm, Tifton, Ga	25-Apr	06G	Admire Pro, Assail, HGW86, Karate, Movento, Orthene, Radiant, Thimet, Tracer, UTC	Single	Conventional	48	4
2013	Tubbs	11511	Lang Farm, Tifton, Ga	13-May	06G	None	Single, Twin	Conventional, Strip	48	4
2013	Tubbs	Block14	Attapulgus, Ga	20-May	06G, 07W, 09B, 10T, 12Y, Florun 107, Greener	None	Twin	Conventional	96	4
2013	Tubbs	Strip	Fishpond, Tifton, Ga	27-May	06G, 12Y	Thimet, UTC	Single	Strip	16	4
2014	Culbreath	Regional	Lang Farm, Tifton, Ga	13-May	Bailey, 06G, 09B, 12Y	CruiserMaxx, Orthene, Thimet, UTC	Single	Conventional	96	4
2014	Culbreath	Index	Lang Farm,	9-May	06G,09B, 12Y,	Thimet, UTC	Single	Conventional	80	4

			Tifton, Ga		Florun 107, Greener, Tifguard					
2014	Culbreath	AMVAC	Lang Farm, Tifton, Ga	8-May	06G, 09B	CruiserMaxx, Orthene, Thimet, UTC	Single	Conventional	56	4
2014	Culbreath	Bayer	Lang Farm, Tifton, Ga	5-May	06G	Temik, Velum Total, Propulse, Admire Pro, Orthene, HGW86, Thimet, UTC	Single	Conventional	48	4
2014	Paulk	TF14-1	Ponder Farm, Tifton, Ga	28-Apr, 12-May	06G, 09B, 12Y, Florun 107	Thimet	Single	Conventional	128	4
2014	Srinivasan	Objective 2	Qunicy, Fl	21-Apr	06G, 12Y	Thimet, CruiserMaxx	Single	Conventional	32	4
2014	Srinivasan	Objective 3	Qunicy, Fl	22-Apr	06G, 12Y	Thimet, CruiserMaxx, Admire Pro, UTC	Single, Twin	Conventional	64	4
2014	Srinivasan	Objective 1	Attapulgus, Ga	29-Apr, 15-May	06G, 12Y	Thimet, CruiserMaxx, Admire Pro, UTC	Single, Twin	Conventional	64	4
2014	Srinivasan	Objective 2	Attapulgus, Ga	29-Apr	06G, 12Y	Thimet, CruiserMaxx	Single	Conventional	32	4
2014	Tubbs	10410	Lang Farm, Tifton, Ga	10-May	06G, 12Y, 13M, TUFRunner 511	None	Single, Twin	Conventional	96	4
2014	Tubbs	11430	Lang Farm, Tifton, Ga	8-May	06G	None	Single	Conventional	52	4
2014	Tubbs	11445	Lang Farm, Tifton, Ga	14-May	06G	None	Single, Twin	Conventional, Strip	48	4
2014	Tubbs	10410	Lang Farm, Tifton, Ga	28-May	06G, 12Y, TUFRunner 511	None	Single	Conventional	36	4
2014	Tubbs	11431	Lang Farm, Tifton, Ga	8-May	06G	None	Single	Strip	52	4

Peanut genotypes listed by Peanut Rx, namely: Florida-07 (Gorbet and Tillman, 2008), Florun-107, Georgia-06G (Branch, 2007), Georgia-07W (Branch and Brenneman, 2007), Georgia-09B (Branch, 2009), Georgia-10T (Branch and Culbreath, 2010), Georgia-12Y (Branch, 2012), Georgia Green (Branch, 1996), Georgia Greener (Branch, 2007), and Tifguard (Holbrook, et al., 2008) were used in this experiment, among others not listed by Peanut Rx. Additional Peanut Rx factors used in this experiment included planting date, plant population, at-plant insecticide, row pattern, and tillage system (Kemerait, et al., 2011). The use of Classic® herbicide was not evaluated in this study. The following table represents all treatments conducted:

Table 3.2: Peanut Rx factors (aside from variety selection) evaluated in this experiment.

Planting date	Prior to May 1, May 1 to May 10, May 11 to May 31
Plant population	Less than 3 plants/ft, 3 to 4 plants/ft, More than 4 plants/ft
At-plant insecticide	None, Other than Thimet® 20G or Phorate 20G, Thimet® 20G, Phorate 20G
Row pattern	Single rows, Twin rows
Tillage system	Conventional, Reduced

Pesticide spray programs (fungicide, herbicide, and insecticide) were applied to each trial to provide adequate control of pests for maximum rating efficiency. Randomized complete block, split-plot, and factorial experimental designs were represented. Plot sizes ranged from 15 to 45 feet and contained two rows per plot. Replication sizes ranged from four to seven replications.

TSWV disease intensity ratings and data gathering

Initial spotted wilt disease intensity ratings were conducted roughly 30-40 days after planting (DAP) before spotted wilt epidemics arose and continued until harvest (130-160 DAP). Ratings were measured biweekly during this timeframe using the hit-stick method which represents a combination of both incidence and severity (Culbreath, et al., 1996). Pivot tracks, skips, and mechanical damage within plots were discounted from total plot length. If additional diseases disrupted rating efficiency (near-harvest ratings), rating values for that time period were not used in this experiment.

Mining of historical TSWV incidence data

Historical data from 2010 to 2012 were collected from multiple research professionals at the University of Georgia in Tifton, Georgia (unpublished, 2010-2012). Data collected included all factors listed by Peanut Rx (Table 3.3). Many older varieties were collected, i.e. ‘Georgia Green’, ‘AP4’ (Tillman and Gorbet, 2009) and ‘C99R’, for a more complete analysis of Peanut Rx and disease over time. These data were compiled with previously collected data from 2013 and 2014 for analysis. AUDPC was not used in these analyses due to many historical data containing only final disease intensity ratings. All rating was evaluated using the hit-stick method.

Table 3.3: Information on spotted wilt incidence trials for 2010-2012.

Year	Trial PI	Trial Name	Location	Planting DOY	Cultivar(s)	Pesticide(s)	Row Pattern(s)	Tillage System(s)	Plots	Reps
2010	Tubbs	T303610	Lang Farm, Tifton, Ga	11-May	C99R, GG	None	Single, Twin	Conventional, Strip	24	4
2010	Tubbs	TNC10	Lang Farm, Tifton, Ga	13-May	06G, 07W, 09B, Greener	None	Single, Twin	Conventional	96	4
2010	Tubbs	TSF10	Lang Farm, Tifton, Ga	21-Apr	06G	Thimet, UTC	Single	Conventional, Strip	32	4
2010	Tubbs	TSR10	Lang Farm, Tifton, Ga	12-May	AP4, 06G, GG	None	Single	Conventional	36	4
2010	Tubbs	TTSR10	Attapulgus, Ga	16-Jun	06G, Florida 07, GG, Tifguard	None	Twin	Conventional	100	4
2010	Tubbs	TWPRL10	Lang Farm, Tifton, Ga	10-May, 1-Jun	06G, GG, Tifguard	None	Single	Conventional, Strip	96	4
2010	Tubbs	TWPRP10	Plains, Ga	9-May, 1-Jun	06G, GG, Tifguard	None	Single	Conventional, Strip	96	4
2011	Tubbs	TCWL11	Lang Farm, Tifton, Ga	3-May, 23-May	06G	None	Single	Strip	48	4
2011	Tubbs	TCWP11	Plains, Ga	5-May, 30-May	06G	None	Single	Strip	48	4
2011	Tubbs	TNCP11	Lang Farm, Tifton, Ga	11-May	06G	None	Single	Conventional, Strip	56	4
2011	Tubbs	TNCRPA11	Attapulgus, Ga	24-May	06G, 07W, 09B, Florun 107, Greener	None	Single, Twin	Conventional	120	4
2011	Tubbs	TSF11	Lang Farm, Tifton, Ga	24-Apr	06G	Thimet, UTC	Single	Conventional, Strip	32	4
2011	Tubbs	TWPP11	Plains, Ga	8-May, 30-May	06G, GG, Tifguard	None	Single	Conventional, Strip	96	4
2011	Tubbs	TWPRL11	Lang Farm, Tifton, Ga	4-May, 23-May	06G, GG, Tifguard	None	Single	Strip	96	4
2012	Tubbs	TAP12	Attapulgus, Ga	28-May	06G, 07W, 09B, Florun 107, Greener	Thimet	Twin	Conventional	80	4
2012	Tubbs	TCWL12	Lang Farm, Tifton, Ga	19-Apr	06G	None	Single	Strip	28	4

2012	Tubbs	TCWP12	Plains, Ga	24-Apr, 16-May	06G	None	Single	Strip	48	4
2012	Tubbs	TPO12	Ponder Farm, Tifton, Ga	24-May	06G, 07W, 09B, Florun 107, Greener	Thimet	Twin	Conventional	80	4
2012	Tubbs	TRP12	Lang Farm, Tifton, Ga	8-May	06G	None	Single, Twin	Conventional, Strip	36	4
2012	Tubbs	TSF12	Lang Farm, Tifton, Ga	25-Apr	06G	Thimet	Single	Conventional, Strip	32	4

Compiling and organization of Peanut Rx data

All data collected, both field data and historical, were compiled into a comma separated values file (.cvs) and each trial was listed by year, location, latitude, and longitude. For each trial, all Peanut Rx factors (variety, planting date, plant population, at-plant insecticide, row pattern, tillage system, and Classic use) were listed by detail and point value for each observation. Final disease incidence was also listed for each observation as the dependent variable. Total risk points were calculated for each observation.

Global positioning system and climate data gathering

Global positioning system coordinates were collected in decimal format at all locations for data analysis and model building involving the TTRF model. Historical and current climate data were compiled for each observation using NC-CRONOS (NC Climate Retrieval and Observations Network of the Southeast Database)/ECONet Database developed by the State Climate Office of North Carolina, North Carolina State University, Raleigh, NC 27695. These data include the following variables used in the model building process: current year thrips, prior-year thrips, average winter temperature, and March precipitation (Chappell, et al., 2013; Morsello, et al., 2010).

Model development, selection, and validation

Using compiled data of TSWV incidence in peanut from 2010-2014, a linear mixed model was used to determine the significance each factor contributed to TSWV incidence. Two models were evaluated; one containing only TTRF variables, and a combined model with both TTRF and Peanut Rx variables. TSWV incidence models were constructed using both Peanut Rx variables and weather data provided by NCSU's TTRF model. Weather factors used in this study were chosen based upon their impact on thrips biology affecting TSWV incidence. Each of the factors used has been shown to affect transmission intensity of TSWV. These include numbers of dispersing thrips, which were estimated using weather variables known to affect thrips activity (Morsello, et al., 2010; Morsello, et al., 2008), among average monthly temperature and spring precipitation (Chappell, et al., 2013).

The format used for the combined model is similar to the TTRF model, but with the inclusion of Peanut Rx variables. The GLM procedure of the SAS system was used to determine the significance of total factors, as well as individual factors alone (both TTRF and Peanut Rx). The regression model was chosen using GLMSELECT of the SAS System. The LASSO (Least Absolute Shrinkage and Selection Operator) method using corrected Akiake's information criterion (AICC) was used to determine the best-fit (minimum mean squared error) model. The best-fit model was compared to alternative models including variations of independent variables to evaluate significant differences between the models. This process determined the stability of the best-fit model. Cross-validation of the best-fit model was performed using PROC REG and a random sample of the complete dataset for predicted versus observed values.

Results

Initially, a model was constructed using only TTRF variables to determine the impact of weather alone on spotted wilt in peanut (Table 3.4). Using this method, 27.81% of the variability was explained, but Peanut Rx factors were not considered. Therefore, a model was tested using both TTRF and Peanut Rx framework. Spotted wilt data on peanut in Georgia were analyzed from years 2010 to 2014 using the Peanut Rx and Thrips and TSWV Risk Forecasting models as a single model. This model will be referred to as Peanut Rx 2.0. A total of 2487 observations covering 45 trials were evaluated. Several factors from both models showed significance towards final TSWV incidence. Multiple combinations were tested using various independent variables in order to determine the best-fit model chosen by corrected Akaike's information criterion (AICC). AICC measures the quality of each model relative to other models.

The best-fit model for Peanut Rx 2.0 chosen by AICC is described by the following regression equation:

$$\log(TSWV) = 0.0147(CP) - 0.00876(PDOY) + 0.0220(IP) + 0.0924(RP) + 0.0374(TP) + 0.0682(MP) + 0.000928(PYT) - 0.0000959(PDOY*AWT) - 3.055$$

where log(TSWV) is spotted wilt final disease incidence in logarithmic form, CP is cultivar points, PDOY is planting date of year, IP is at-plant insecticide points, RP is row pattern points, TP is tillage system points, MP is March precipitation, PYT is prior-year thrips, and AWT is average winter temperature (Table 3.4). Points used to develop this equation are obtained from Peanut Rx. Many factors were significant from both Peanut Rx and TTRF, and the best-fit model explained 26.24% of the variability (Table 3.4). A significant interaction between planting date of year and average winter temperature was found ($p = 0.0110$).

A five-fold cross-validation was used to test the accuracy of the best-fit model (Figure 3.5). Eighty percent of the data were used to train the model using the same independent variables in the best-fit model. The remaining 20% (validation data) were tested for predictions of spotted wilt incidence. Subsequently, the relationship between observed and predicted disease was evaluated. The validation detected the stability of prediction error ($R^2 = 0.1003$, RMSE = 0.1105). The model constructed using the training data was significant in describing the validation data ($p = <.0001$). Table 3.4 displays coefficient averages and standard deviations, including the best-fit estimates, for each independent variable of the best-fit model.

Discussion

In this study, factors from both a risk index and predictive model were integrated in an attempt to improve management of spotted wilt of peanut. Factors from Peanut Rx, a risk index, were used to account for risk to disease, whereas additional factors from the TTRF predictive model accounted for disease pressure. Risk to disease in this scenario is defined as a range of spotted wilt incidence per risk point value. The greater the risk value, the higher the range of spotted wilt. Disease pressure is defined as the amount of disease present at a given location and time (expressed by percent disease). By addressing the relationship between disease risk and pressure, management of spotted wilt should, in theory, become more accurate. The best-fit model for spotted wilt in peanut contained a mixture of both disease mitigating factors from Peanut Rx (Brown, et al., 2005) and knowledge of thrips biology/transmission intensity from TTRF (Chappell, et al., 2013).

It is important to note that when Peanut Rx is used without the inclusion of the TTRF, risk point values versus observed spotted wilt show little correlation, with all observations (R^2 = .0445, Figure 3.1) and with higher incidence observations (R^2 = 0.0298, Figure 3.2). However, with Peanut Rx 2.0, containing both Peanut Rx and TTRF variables, the variability explained increases six-fold, R^2 = 0.2624 (Table 3.5). This shows the importance of accounting for both disease risk and pressure. Though evaluating the model using only TTRF variables, variability explained increased to 27.81%, but it is important to account for Peanut Rx variables, as they impact spotted wilt significantly (Table 3.6).

Due to the range of field resistance that each cultivar exhibited, cultivar points were significant in predicting spotted wilt. Higher point values contribute to a higher incidence of spotted wilt based on less field resistance. Field resistance in peanut is host-plant resistance observed in field settings, occurring from breeding efforts, and not based on known mechanisms of action (Culbreath, et al., 2005). Naturally, the greater the value, the greater the risk to spotted wilt. Therefore, more resistant varieties displayed less disease. Varietal resistance from cultivar selections over the past two decades has been the most effective management factor in mitigating disease (Culbreath, et al., 2003). This model provides a method of testing point structure of Peanut Rx based and can contribute to future cultivar placement into newer editions of Peanut Rx. Additional Peanut Rx factors that displayed significant results were planting date of year, insecticide points, row pattern points and tillage system points.

Planting date of year, having a larger impact, was used in Peanut Rx 2.0 instead of planting date points. Based upon incidence data used in the study from 2010-2014, on average, as the planting dates extends to later in the year, spotted wilt also is reduced. This inverse relationship has been shown in many individual datasets (unpublished data), but is not accurately depicted by Peanut Rx. According to Peanut Rx, peanuts planted in late May/early June are at higher risk to spotted wilt than early/mid May (UGA, UF, AU, 2015). The results from this study, however, contradict the point structure of Peanut Rx. One aspect that is built into Peanut Rx is the subjective changes made by research and extension personnel annually to the risk index with the introduction of newer varieties. One hypothesis is that point structure of many of these factors may not be accurately represented in varieties with greater inherited resistance. Production practices such as at-plant insecticide and planting date may not significantly reduce disease in a highly resistant variety that may incur low percentages of spotted wilt on average per season.

At-plant insecticide points were also found to show significance in Peanut Rx 2.0. Current structure of Peanut Rx places the use of Thimet® at 5 risk points, while untreated or alternative at-plant insecticides result in 15 risk points (UGA, UF, AU, 2015). Insecticide type alone was also examined and did show significance ($p = <.0001$), but of the twenty treatments used, only Admire Pro®, CruiserMaxx®, Orthene®, Thimet®, and untreated control showed significance at reducing overall disease. It was interesting to see the difference between the coefficients of Thimet® compared to the other significant at-plant insecticides was almost 33% greater at reducing disease. Each of the additional insecticides was similar to the untreated control, concluding the accuracy of Peanut Rx within at-plant insecticide point structure. Both row pattern points and tillage system points were significant. According to Peanut Rx, row pattern (5 to 10 points) has less of an effect on mitigating spotted wilt compared to tillage system (5 to 15 points), but these results suggest differently (Table 3.5). The coefficient for row pattern is double the amount for tillage system, signifying more importance on row pattern in reducing spotted wilt incidence.

Population was found to not be significant towards spotted wilt incidence based on Peanut Rx point values ($p = 0.7672$). This was interesting due to the range of values for plant populations (25 points for <3/foot, 10(15) for 3-4/foot, and 5 for >4/foot). It has been noted in previous studies that plant population effects tend to show effects only in varieties that are susceptible to the disease, i.e. have low varietal field resistance and incur much disease (Culbreath and Srinivasan, 2011). Most varieties used in this study were moderately resistant to highly resistant varieties, therefore population effects may have been reduced due to lower disease incidence. Effects of Classic® herbicide on spotted wilt incidence was not examined in this study. The use of Classic® has historically shown minimal and variable effects at reducing spotted wilt (Culbreath and Srinivasan, 2011).

In an attempt to increase the accuracy of Peanut Rx for spotted wilt management, weather factors from the TTRF model were included in this study. Previous studies have shown the effect of certain weather factors on spotted wilt of tobacco (Chappell, et al., 2013; Morsello, et al., 2010; Morsello, et al. 2008). In Peanut Rx 2.0, March precipitation had a positive correlation with spotted wilt disease (Table 3.5). However, in the TTRF model, increases in March precipitation resulted in decreased disease, possibly due to the interaction of rainfall on thrips populations and activity (Chappell, et al., 2013). Based on Peanut Rx 2.0, the effect of March precipitation could possibly play a role in weed vigor and survival, which could promote a steady population of weeds and thrips populations necessary for successful spread of disease from overwintering inoculum to peanut in the spring. It must be noted that most tobacco transplanting occurs in late March/early April, whereas the range of peanut planting in Georgia is late April through May (USDA, 1997). This gap could provide the time for thrips populations to recover from heavy March precipitation and provide time for thrips reservoirs to flourish.

Prior-year thrips, reported as number of adult *Frankliniella fusca* per sticky trap (Morsello, et al., 2010), showed positive effects on spotted wilt incidence, as did the interaction of planting date of year and average winter temperature. Based on thrips biology and previous studies with prior-year thrips (Chappell, et al., 2013), the positive correlation between prior-year thrips populations and disease incidence is not surprising. Prior-year thrips not only provide the inoculum sources for disease spread for the following year, but also provide offspring that facilitate this spread. Previously in this study, it was reported that planting date of year was negatively correlated with disease incidence, i.e. the later the planting date, the lesser incidence of disease. However, it is known that thrips require a minimum temperature for development (McDonald, et al., 1999), and when this temperature is reached at certain times of the year, thrips development increases. Therefore as higher temperatures are seen within planting date, disease pressure increases due to increases in thrips biological activity.

The remaining two weather factors included in this model were negatively correlated to spotted wilt incidence. These include both average winter temperature and the interaction between March precipitation and prior-year thrips. Based on average winter temperature values, as winter temperature increased, incidence of spotted wilt decreased. This result was unexpected as higher winter temperatures should increase winter annual weed vigor and promote earlier thrips biological activity, both of which should intensify disease pressure in the spring. The interaction between March precipitation and prior-year thrips was expected. Both were individually shown to be positively correlated to spotted wilt incidence, however, when these factors interact, thrips populations decrease, as does transmission intensity in the spring. This interaction shows the complexity of weather and thrips biology on spotted wilt transmission into spring crops, and is consistent with previous findings (Chappell, et al., 2013).

It is important to note that by including factors directly affecting risk to spotted wilt (Peanut Rx) with those affecting disease pressure (TTRF), the resulting model increases six fold the amount of variability explained. Though the strength of Peanut Rx 2.0 is quite small (R^2 = 0.2624), an outline for a more complete model system has been evaluated and tested. It was necessary to include weather variables in this study to improve model efficacy. These results provide a framework for how each individual factor in Peanut Rx 2.0 contributes to disease. Peanut Rx was scrutinized, and these results from including TTRF provide answers that increase the power of the risk index. Peanut Rx 2.0 explains both disease risk and pressure into a management system, and will improve spotted wilt disease predictions for growers looking to reduce disease in peanut. Overall, the difference and importance of both disease and vector biology was examined in an attempt to improve spotted wilt management in peanut.

Future work will be addressed in helping to improve Peanut Rx 2.0 and make it applicable for end users. For one, the only weather components used to develop Peanut Rx were derived from the TTRF model. Additional weather variables and by altering current weather factors may improve the predictive power of Peanut Rx 2.0. This is especially promising because the TTRF model was built based on North Carolina thrips population dynamics. In Georgia, different weather factors may impact thrips biology and activity. Altering Peanut Rx point structure for the model may also provide model improvement. This model circuitously ranks Peanut Rx factors based on importance towards predicting spotted wilt incidence. If point structure of Peanut Rx can be adjusted based on Peanut Rx 2.0 results, model accuracy will be improved. Future work will look to address both inclusion of weather factors to Peanut Rx 2.0 and ways the current status of Peanut Rx can be improved to help increase accuracy of Peanut Rx 2.0. Subsequently, these efforts will help growers improve management of spotted wilt disease in peanut.

An important objective of this study is to envision the final product of this work. In other words, how will a grower/producer be able to use Peanut Rx 2.0? Peanut Rx has been a hardcopy risk model since its initial development in the mid-1990’s. Recently, Peanut Rx has been converted into an accessible cellular device application for iPhone and Android operating systems. The TTRF is a web-based input model that allows growers to access all information from an online portal. Peanut Rx 2.0 is the integration of each of these models. It will take certain computer processing for a user to reach an expected prediction. That being said, a web-based or cellular application would be best suited for growers/producers looking to improve spotted wilt management in peanut.

Summary and Conclusions

In this study, independent variables from two existing spotted wilt management models were integrated in an attempt to improve current management of spotted wilt in peanut. Peanut Rx provided risk index factors that are used to assess risk levels to spotted wilt. The TTRF model uses weather factors known to impact thrips vector biology and populations to predict disease pressure. By combining models that explain both disease risk (Peanut Rx) and pressure (TTRF), disease management can be improved. Peanut Rx 2.0 was constructed to include both Peanut Rx and TTRF factors in an attempt to predict disease for certain locations in southeastern peanut. With Peanut Rx 2.0, 26.24% of the variability was explained compared to 4.44% using Peanut Rx alone, with a mean square error from the cross-validation of just over 7%. These results provide an excellent framework in which improved models can be developed to increase spotted wilt management in the southeast United States. Growers will be able to improve management by identifying a predicted amount of disease, which will subsequently allow them to determine the best production practices to limit spotted wilt incidence.

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Tables and Figures

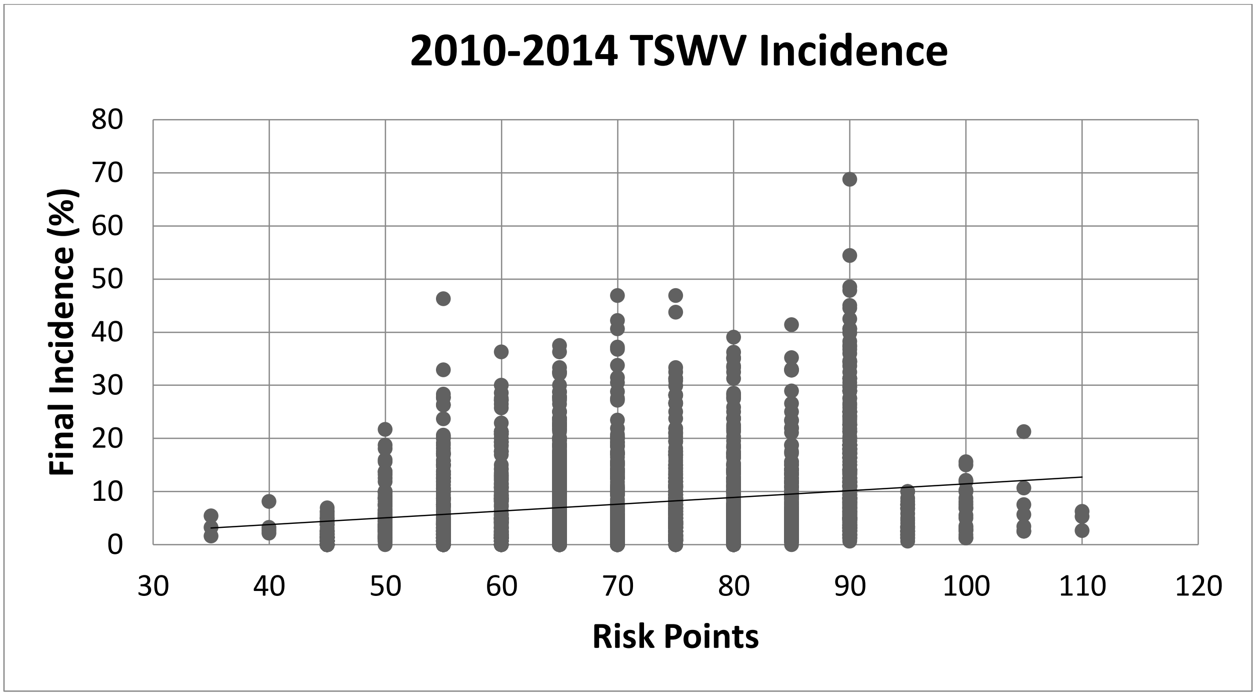

Figure 3.1. Plot describing relationship of Peanut Rx risk point values to observed spotted wilt incidence (all observations), R^2 = 0.0445.

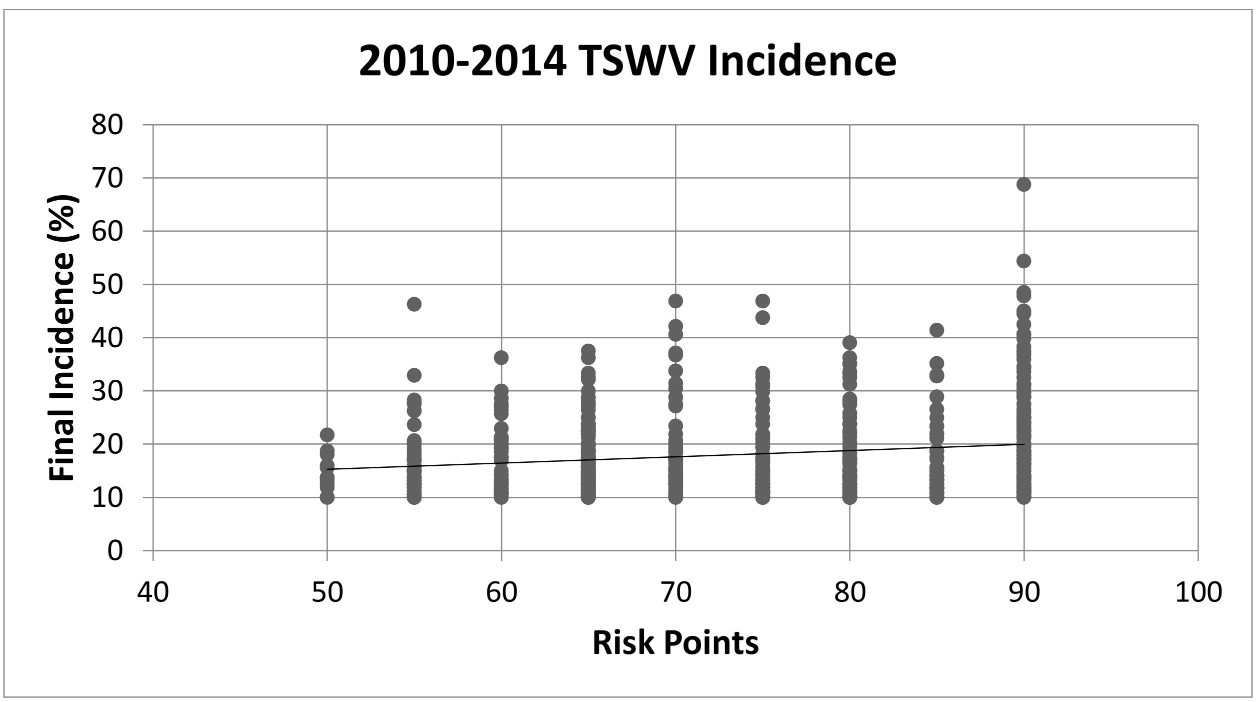

Figure 3.2. Plot describing relationship of Peanut Rx risk point values to observed spotted wilt incidence (observations with incidence ≥10% and ≤90 risk points), R^2 = 0.0298.

Table 3.4: Listing of coefficient estimates, standard error, t-value, and p-value for the best fit model, followed by the best-fit estimate from cross validation technique using only TTRF variables.

Fixed effect	Estimate	SE	t Value	Pr > |t|	Best-fit
Intercept	-3.466841	0.22374	-15.49	<.0001	-3.329351
PYT	0.000884	0.00022	4.02	<.0001	0.000882
PYT*MP	0.014168	0.00051	27.86	<.0001	0.013011
AWT	0.000042	0.00455	0.01	0.9925	-0.001491
PYT*MP*AWT	-0.000251	0.00001	-28.28	<.0001	-0.000230

Abbreviations for fixed effects are as follows: PYT = prior-year thrips estimate (as determined by TTRF); MP = March precipitation (as determined by TTRF); AWT = average winter temperature. Best fit model is listed on the far left column (R^2 = 0.2624).

Table 3.5: Listing of selected significant fixed effects and corrected Akiake's Information Criterion values for the best-fit model using combined TTRF and Peanut Rx variables.

Fixed effect	AICC	SBC	ASE	Validation ASE
Intercept	1053.87	-908.55	0.628	0.545
Planting_DOY	982.09	-974.75	0.604	0.523
PYT	946.73	-1004.54	0.593	0.514
RowPat_points	884.63	-1061.06	0.574	0.499
Till_points	762.93	-1177.19	0.539	0.472
MP	724.89	-1209.66	0.528	0.464
Insect_points	684.95	-1244.04	0.517	0.456
Cultivar_points	610.40	-1313.03	0.497	0.442
Planting_DOY*AWT	519.53*	-1398.33*	0.474	0.431*

All corrected AIC values are reported for general linear mixed models in which only the fixed effects appear. Abbreviations for fixed effects are as follows: Planting_DOY = planting date of year (Julian date); PYT = prior-year thrips estimate (as determined by TTRF); RowPat_points = risk points for row pattern (as determined by Peanut Rx); Till_points = risk points for tillage system (as determined by Peanut Rx); MP = March precipitation (as determined by TTRF); Insect_points = risk points for at-plant insecticide (as determined by Peanut Rx); Cultivar_points = risk points for cultivar selection (as determined by Peanut Rx); Planting_DOY*AWT = interaction of planting date of year and average winter temperature. Asterisks indicated the optimal value of criterion for the best-fit model.

Table 3.6: Listing of coefficient estimates, standard error, t-value, and p-value for the best fit model, followed by the best-fit estimate from cross validation technique using combined TTRF and Peanut Rx variables..

Fixed effect	Estimate	SE	t Value	Pr > |t|	Best-fit
Intercept	3.528097	2.08152	1.69	0.0902	-3.054890
Cultivar_points	0.016129	0.00225	7.16	<.0001	0.014672
Planting_DOY	-0.05469	0.01623	-3.37	0.0008	-0.008762
Insect_points	0.024599	0.00388	6.34	<.0001	0.022040
Rowpat_points	0.073852	0.00830	8.9	<.0001	0.092434
Till_points	0.036178	0.0034	10.49	<.0001	0.037386
MP	0.160252	0.01371	11.69	<.0001	0.068175
PYT	0.003981	0.00035	11.24	<.0001	0.000928
MP*PYT	-0.0007	0.00007	-8.96	<.0001	n/a
AWT	-0.13972	0.04252	-3.29	0.001	n/a
Planting_DOY*AWT	0.000833	0.00033	2.54	0.011	-0.000095896

Abbreviations for fixed effects are as follows: Planting_DOY = planting date of year (Julian date); PYT = prior-year thrips estimate (as determined by TTRF); RowPat_points = risk points for row pattern (as determined by Peanut Rx); Till_points = risk points for tillage system (as determined by Peanut Rx); MP = March precipitation (as determined by TTRF); Insect_points = risk points for at-plant insecticide (as determined by Peanut Rx); Cultivar_points = risk points for cultivar selection (as determined by Peanut Rx); Planting_DOY*AWT = interaction of planting date of year and average winter temperature. Best fit model is listed on the far left column (R^2 = 0.2624).

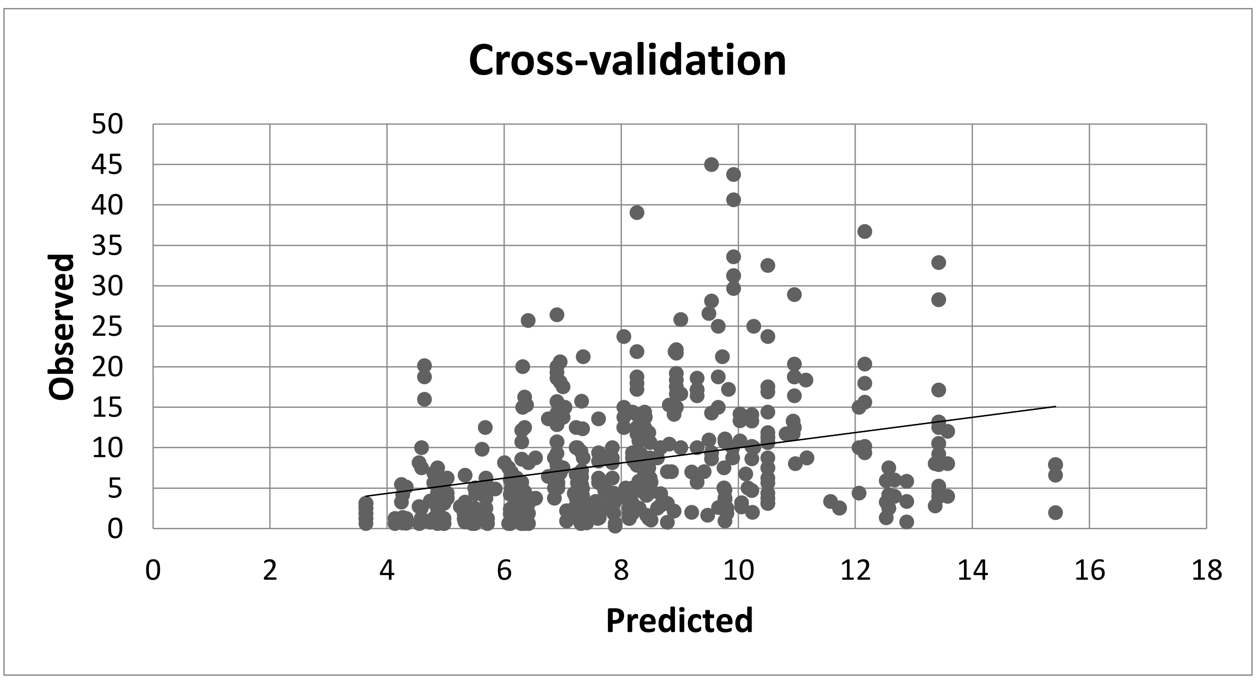

Figure 3.2. Prediction plot for model cross-validation, a regression of observed on fitted TSWV incidence, R^2 = 0.1056.

CHAPTER 4

THE EVOLUTION OF PEANUT RX: EFFECTS OF INCREASED FIELD RESISTANCE TO SPOTTED WILT DISEASE ON THE IMPACT OF OTHER PRODUCTION PRACTICES IN PEANUT[1]

[1] Williams, B., R. Kemerait, J. Sherwood, A. Culbreath, S. Tubbs, M. Abney, R. Srinivasan, T. Brenneman. 2015. To be submitted to Peanut Science.

Abstract

Tomato spotted wilt virus (TSWV), the causal agent of spotted wilt disease of peanut, is an important virus affecting peanut production in the southeast United States. Current management is targeted at minimizing TSWV severity and includes an assortment of production practices including use of varieties with moderate to high TSWV resistance and implementation of chemical and cultural controls. Each factor (variety selection, planting date, plant population, at-plant insecticide, row pattern, tillage system, and use of Classic® herbicide) contributes a component of a disease risk assessment index. At the introduction of the risk index in 1996, the effects of these production practices in reducing TSWV were significant; however, as greater levels of host resistance became available, diminishing effects have been observed. The objective of this study was to evaluate the effects of production practices with varieties containing varying levels of TSWV resistance. This experiment determined the contribution Peanut Rx is making in current spotted wilt management, compared to years in which more resistant varieties were not available. Using historical data, TSWV intensity based on chemical and cultural practices was evaluated in susceptible variety ‘Georgia Green’ and moderately resistant variety ‘Georgia-06G’. Subsequently, collected data from 2013 and 2014 was used to evaluate the impact of these factors on currently used moderately and highly resistant peanut cultivars. With each production practice, significant reductions were consistently observed in susceptible variety ‘Georgia Green’. Even with less disease, significant results were observed with moderately resistant varieties, including ‘Georgia-06G’. However, with highly resistant varieties, much of the reductions were only nominal. Results conclude that the effects of cultural and chemical production practices are diminishing with the introduction of greater TSWV-resistant varieties.

Introduction

Cultivated peanut (*Arachis hypogaea*) is an important crop in the southeastern United States but its production is severely affected by spotted wilt disease (Sundaraj, et al., 2014). On a global scale, peanut is cultivated on 42 million acres worldwide resulting in an average annual production of 29 million metric tons. India, China, and the United States have been the leading producers of peanut over the past 25 years and account for 70% of production (Putnam, et al., 1991; National Peanut Board, 2014). In 2013, southeastern states (Alabama, Florida, and Georgia) accounted for almost 70% of peanut production in the United States (American Peanut Council, 2014). Peanuts are grown primarily for human consumption due to their dietary benefits, but additional uses are numerous and include livestock feed, mulch, soaps, medicines, cosmetics, and lubricants (Putnam, et al., 1991; American Peanut Council, 2014).

The causal agent of spotted wilt disease is *Tomato spotted wilt virus* (TSWV). TSWV is a member of genus *Tospovirus* in family *Bunyaviridae*, and is one of the most widespread and economically destructive plant viruses in the world (Francki, et al., 1991; German, et al., 1992). In the United States, TSWV was first reported in peanut in Texas in 1971. The virus subsequently spread to the southeastern United States resulting in spotted wilt incidences of over 50% in some fields in the late 1980's (Kucharek, et al., 1990; Hagan and Weeks, 1998). Spotted wilt disease occurs throughout the southeastern peanut belt and frequently causes damaging levels in peanut. According to Riley et al. (2011), spotted wilt caused an estimated average annual loss of $12.3 million in peanut grown in Georgia over a ten year period from 1996 to 2006. Yield losses to spotted wilt disease in peanut reached 12% in 1997 resulting in a decrease of over $40 million in crop value. After 1997, crop losses declined due to the discovery of host-plant resistance and alternative production practices. The lowest recorded yield losses since its introduction occurred in 2010, with a 0.25% reduction in crop value (University of Georgia, 2008; Williams-Woodward, et al., 2013; Yang, et al., 2004).

Virus spread is facilitated by its arthropod vector, thrips (Thysanoptera: Thripidae) (Riley, et al., 2011). The predominant thrips vectors in the southeastern United States are tobacco thrips, *Frankliniella fusca*, and Western flower thrips, *Frankliniella occidentalis* (Todd, et al., 1995). Thrips transmit the virus in a propagative and persistent manner (Whitfield, et al., 2005). Insecticides have been successfully applied to control thrips populations and reduce feeding damage peanut, but have been largely ineffective in preventing transmission of TSWV. Additional production practices are required to significantly impact spotted wilt disease (Yang, et al., 2004; Chamberlin, et al., 1993).

The development of a risk assessment model began in 1996 through a collaborative effort between University of Georgia, University of Florida and Auburn University. After spotted wilt disease reached the southeastern peanut belt, reduced disease severity was observed in a number of Runner-type varieties when compared to current susceptible variety, 'Florunner'. Moderate resistance was seen in 'Southern Runner', 'Georgia Browne', and 'Georgia Green' (Brown, et al., 1996; Branch, 1994; Branch, 1996; Gorbet, et al., 1987). In addition to varietal resistance, other production practices have been shown to reduce spotted wilt severity in peanut. These practices include planting date, plant population, at-plant insecticide, row pattern, tillage systems, and the use of chlorimuron herbicide (Yang, et al., 2004; Brown, et al., 2005). Each factor is a component of a current risk index, termed Peanut Rx. Risk points are attributed to each component of Peanut Rx. Summation of spotted wilt points result in situations of low, medium, or high risk to spotted wilt. Growers can subsequently alter management techniques to reach a desired risk level.

Varietal resistance from these selections has been the most effective management factor in mitigating disease (Culbreath, et al., 2003). Since low levels of field resistance was first observed in varieties such as 'Southern Runner' and 'Georgia Green', breeding efforts have been introduced to reduce spotted wilt and increase yield (Culbreath, et al., 2005; Culbreath, et al., 1996; Yang, et al., 2004). The mechanisms conferring resistance to TSWV in peanut have not been identified (Sundaraj, et al., 2014; Shrestha, et al., 2013). However, it is believed to be host-plant resistance to the virus, and not of the thrips vector. Resistance to thrips has been documented in solanaceous crops (Maris, et al., 2003), but has not been documented in peanut genotypes grown in the United States (Culbreath, et al., 1992; Culbreath, et al., 1994; Culbreath, et al., 1996; Culbreath, et al., 1997; Culbreath, et al., 2003). Successive breeding produced moderately resistant peanut genotypes with higher levels of field resistance to TSWV. These varieties include 'Georgia Greener', 'Georgia-06G', 'Georganic', and 'Tifguard', among others. Highly resistant peanut genotypes, expressing even greater field resistance, have been developed and evaluated in research settings, but have not been widely grown commercially (Sundaraj, et al., 2014; Branch, 2007; Branch, 2007; Holbrook and Culbreath, 2008; Holbrook, et al., 2008). By grower standards, significant steps forward were made with the introduction of moderately resistant 'Georgia-06G'. These standards are likely to continue with even more resistant varieties, such as 'Georgia-12Y'. Overall, the replacement of varieties with newer generations not only increases TSWV resistance, but yield potential as well. For the purposes of this paper, peanut varieties will be grouped into tiers, based on Peanut Rx risk point values. These tiers include: >20 point varieties (tier 1), 10-20 point varieties (tier 2), and <10 point varieties (tier 3). The following table includes the tiered classification system used in this study:

Table 4.1: Classification of peanut varieties used in the study. Tiered based on Peanut Rx risk point value.

Tier 1	Tier 2	Tier 3
Georgia Green	Bailey	Georgia-10T[a]
CHAMPS[a]	Florida-07	Georgia-12Y
	FloRun '107'	
	Georgia-06G	
	Georgia-07W	
	Georgia-09B	
	Georgia-11J[a]	
	Georgia-13M[a]	
	Georgia Greener	
	Sugg[a]	
	Tifguard	
	TUFRunner '727'	
	TUFRunner '511'	

[a]Point value not established. Placement based on similar effects of disease incidence compared to other varieties.

The impact of planting date on spotted wilt disease in the United States was first observed in Texas (Black, 1990; Mitchell, et al., 1991). Location of peanut fields can also be a significant factor, but this factor is not included on Peanut Rx (Culbreath, et al., 2003). Previous studies in the southeastern United States indicated that planting peanuts in early May consistently result in lower incidences of spotted wilt compared to April plantings (Mckeown, et al., 2001; Todd, et al., 1998). Reasons for the impact of planting date are based on indirect observations centered on thrips population dynamics (Todd, et al., 1995). By avoiding peak thrips populations, spotted wilt disease is reduced. Recent data have indicated that planting date effects are less on more resistant, compared to susceptible cultivars (Hagan, et al., 2012).

According to Culbreath, et al., 2003, infection of a single peanut plant with TSWV is greater when populations are more sparsely planted. Plant populations, not seeding rate, has shown impact in many studies in the southeast United States (Gorbet and Shokes, 1994; Culbreath, et al., 2012; Culbreath, et al., 2013). Achieving higher plant populations does not reduce number of infected plants, but does reduce percentage infected in more densely planted stands. Though plant population has continued to reduce disease in more resistant varieties, results are nominal in most cases (unpublished data). Planting cultivars with higher levels of field resistance may allow flexibility when considering plant population as a management method.

Insecticide and chemical usage have shown minimizing effects on spotted wilt severity in peanut and tobacco; however, this effect has been highly variable and ineffective in many cases. In peanut, at-plant insecticides have been very effective in controlling thrips damage in early growth stages, but have been largely ineffective in preventing transmission of TSWV (Chamberlin, et al., 1993). One at-plant insecticide, phorate, has shown significant results in reducing spotted wilt, but this has been inconsistent and causes of this occurrence are unknown. It has been hypothesized to be a triggering of plant defense responses (Culbreath, et al., 2008).

Other production practices having reducing effects on spotted wilt in peanut include tillage system and row pattern. In a five year study performed by Johnson *et al.*, spotted wilt incidence was 42% lower in peanut across all years under reduced tillage compared to conventional tillage (Johnson, et al., 2001). Studies on row pattern have shown that significant reductions in spotted wilt incidence occur when planting twin row peanuts compared to single row. This process is poorly understood but may involve visual interference of migrating thrips (Culbreath, et al., 2003; Baldwin, et al., 2001). The combination of these production practices provides the peanut grower with the most effective methods at reducing TSWV risk.

On an annual basis, the Peanut Rx risk index is updated to include the most recent cultivar introductions for which sufficient field evaluations are available (Prostko, et al., 2014). In this study, final disease incidence was used to compare tier 1 variety ‘Georgia Green’ with tier

2 ‘Georgia-06G’. Each production practice included as a component of Peanut Rx was evaluated. Next, final disease incidence, standardized AUPDC and disease onset were used to evaluate the impact of production practices on severity of spotted wilt in cultivars classified in tiers 2 and 3. Tier 2 and 3 variety standards used in this portion of the study were ‘Georgia-06G’ and ‘Georgia-12Y’, respectively. As field resistance to TSWV increases, there is likelihood that the impact of production practices to significantly or further reduce disease severity will diminish (Culbreath and Srinivasan, 2011). The objective of this study was to assess the use of Peanut Rx in a production system and to determine its continued value to growers for management of tomato spotted wilt as increasingly resistant varieties become available.

Materials and Methods

Plant materials and trial setup

Spotted wilt disease intensity trials were established in multiple locations during the summers of 2013 and 2014. In 2013, trial locations included: Gibbs Farm (Tift County, Georgia), Lang-Rigdon Farm (Tift County, Georgia), Fishpond (Tift County, Georgia), Attapulgus Research and Education Center (Decatur County, Georgia), and Southwest Georgia Research and Education Center (Sumter County, Georgia). In 2014, trial locations included: Lang-Rigdon Farm (Tift County, Georgia), Ponder Farm (Tift County, Georgia), Attapulgus Research and Education Center (Decatur County, Georgia), and North Florida Research and Education Center (Gadsden County, Florida). As these trials were established by different researchers, specific protocols varied, but each trial included treatments that assessed the effects of one or more production practices included as a component of the Peanut Rx risk index (Table 4.2).

Table 4.2: Trial information from years 2013-2014.

Trial #	Year	Trial PI	Trial Name	Location	Planting DOY	Cultivar(s)	Pesticide(s)	Row Pattern(s)	Tillage System(s)	Plots	Reps
1	2013	Beasley	TF1316[a]	Gibbs Farm, Tifton, Ga	30-Apr	06G, 07W, 09B, Florida-07, FloRun 107, Greener, Tifguard, TUFRunner '727'	None	Single	Conventional	28	4
2	2013	Beasley	TF1329[a]	Gibbs Farm, Tifton, Ga	30-Apr	06G	CruiserMaxx, Thimet, UTC	Single	Conventional	32	4
3	2013	Beasley	TF1315[c]	Gibbs Farm, Tifton, Ga	30-Apr	06G, 12Y, Greener	CruiserMaxx, Thimet, UTC	Single	Conventional	48	4
4	2013	Culbreath	InoxThi[b]	Lang Farm, Tifton, Ga	28-May	06G, 07W, 09B, 10T, 11J, 12Y, Greener, Tifguard	Thimet, UTC	Single	Conventional	40	4
5	2013	Culbreath	Index[b]	Lang Farm, Tifton, Ga	8-May	Bailey, CHAMPS, Sugg, 06G, 12Y, Greener	Thimet, UTC	Single	Conventional	64	4
6	2013	Tubbs	Block14[c]	Attapulgus, Ga	20-May	06G, 07W, 09B, 10T, 12Y, Florun 107, Greener	None	Twin	Conventional	96	4
7	2013	Tubbs	Strip[c]	Fishpond, Tifton, Ga	27-May	06G, 12Y	Thimet, UTC	Single	Strip	16	4
8	2013	Tubbs	Plains[c]	Plains, Ga	29-May	06G, 07W, 09B, 12Y, Greener	Thimet, UTC	Single	Conventional	40	4
9	2013	Tubbs	11511[c]	Lang Farm, Tifton, Ga	134	06G	None	Single, Twin	Conventional, Strip	48	4
10	2014	Culbreath	Regional[c]	Lang Farm, Tifton, Ga	13-May	Bailey, 06G, 09B, 12Y	CruiserMaxx, Orthene, Thimet, UTC	Single	Conventional	96	4
11	2014	Culbreath	Index[b]	Lang Farm, Tifton, Ga	9-May	06G,09B, 12Y, Florun 107, Greener, Tifguard	Thimet, UTC	Single	Conventional	80	4
12	2014	Culbreath	AMVAC[b]	Lang Farm, Tifton, Ga	8-May	06G, 09B	CruiserMaxx, Orthene, Thimet, UTC	Single	Conventional	56	4
13	2014	Paulk	TF14-1[c]	Ponder Farm,	28-Apr, 12-May	06G, 09B, 12Y, Florun 107	Thimet	Single	Conventional	128	4

				Tifton, Ga							
14	2014	Srinivasan	Obj. 2[b]	Qunicy, Fl	21-Apr	06G, 12Y	Thimet, CruiserMaxx	Single	Conventional	32	4
15	2014	Srinivasan	Obj. 3[b]	Qunicy, Fl	22-Apr	06G, 12Y	Thimet, CruiserMaxx, Admire Pro, UTC	Single, Twin	Conventional	64	4
16	2014	Srinivasan	Obj. 1[b]	Attapulgus, Ga	29-Apr, 15-May	06G, 12Y	Thimet, CruiserMaxx, Admire Pro, UTC	Single, Twin	Conventional	64	4
17	2014	Srinivasan	Obj. 2[b]	Attapulgus, Ga	29-Apr	06G, 12Y	Thimet, CruiserMaxx	Single	Conventional	32	4
18	2014	Tubbs	10410[b]	Lang Farm, Tifton, Ga	28-May	06G, 12Y, TUFRunner 511	None	Single	Conventional	36	4
19	2014	Tubbs	10410[c]	Lang Farm, Tifton, Ga	10-May	06G, 12Y, 13M, TUFRunner 511	None	Single, Twin	Conventional	96	4
20	2014	Tubbs	11430[c]	Lang Farm, Tifton, Ga	8-May	06G	None	Single	Conventional	16	4
21	2014	Tubbs	11445[c]	Lang Farm, Tifton, Ga	42138	06G	None	Single, Twin	Conventional, Strip	48	4

[a]Denotes randomized complete block experimental design.

[b]Denotes split-plot experimental design.

[c]Denotes factorial experimental design.

Peanut cultivars rated based on Peanut Rx and similar resistances, to include: Bailey, (Isleib, et al., 2011), CHAMPS (Mozingo, et al., 2006), Florida-07 (Gorbet and Tillman, 2008), Florun-107 (Tillman and Gorbet, 2015), Georgia-06G (Branch, 2007), Georgia-07W (Branch and Brenneman, 2007), Georgia-09B (Branch, 2009), Georgia-10T (Branch and Culbreath, 2010), Georgia-11J (Branch, 2012), Georgia-12Y (Branch, 2012), Georgia-13M (Branch, 2014), Georgia Greener (Branch, 2007), Sugg (Isleib, et al., 2014), Tifguard (Holbrook, et al., 2008), TUFRunner '511' (), and TUFRunner '727' () were assessed in this study. Additional components of Peanut Rx assessed in this study included planting date, plant population, at-plant insecticide, row pattern, and tillage system (Kemerait, et al., 2011). The use of Classic® herbicide was not evaluated in this study. The following table represents all treatments conducted:

Table 4.3: Peanut Rx factors (aside from variety selection) evaluated in this experiment.

Planting date	Prior to May 1, May 1 to May 10, May 11 to May 31
Plant population	Less than 3 plants/ft, 3 to 4 plants/ft, More than 4 plants/ft
At-plant insecticide	None, Other than Thimet® 20G or Phorate 20G, Thimet® 20G, Phorate 20G
Row pattern	Single rows, Twin rows
Tillage system	Conventional, Reduced

Pesticide spray programs (fungicide, herbicide, and insecticide) were applied to each trial to provide adequate control of pests for maximum rating efficiency and yield. Randomized complete block, split-plot, and factorial experimental designs were included among these trials. Plot sizes ranged from 9.1 to 13.7 meters and contained two rows per plot. In these trials, treatments were replicated at least four times and as much as seven times.

TSWV disease intensity ratings and data gathering

Initial spotted wilt disease intensity ratings were collected approximately 30-40 days after planting (DAP) at the time of initial symptom expression. Ratings continued until harvest (130-160 DAP). Ratings were taken biweekly during this timeframe using the hit-stick method which represents a combination of both incidence and severity (Culbreath, et al., 1997). This method, developed by researchers at the University of Georgia, uses one foot measuring stick to measure length of symptomatic tissue per plot length. Pivot tracks, skips, and mechanical damage within plots were discounted from total plot length. If other diseases disrupted rating efficiency (near-harvest ratings), rating values for that time period were not included in the analysis.

Mining of historical TSWV incidence data for analysis of tier 1 standard 'Georgia Green' and tier 2 standard 'Georgia-06G'

Historical data from tier 1 'Georgia Green' and tier 2 'Georgia-06G' were collected from multiple researchers at the University of Georgia in Tifton, Georgia (unpublished, 2007-2011). Data collected included assessment of all components from Peanut Rx, except for the use of Classic® herbicide (Table 4.4). These data were used to compare spotted wilt disease intensity between 'Georgia Green' and 'Georgia-06G' represented in historical data and previously described evaluations.

Table 4.4: Trial information from years 2007-2011 ('Georgia Green' and 'Georgia-06G').

Year	Trial PI	Trial Name	Location	Planting DOY	Cultivar(s)	Seeding Rate(s)	Pesticide(s)	Row Pattern(s)	Tillage System(s)	Plots	Reps
Variety Trials											
2007	Culbreath	CRP07	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	6	3
2007	Culbreath	CINS07	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	6	3
2008	Tubbs	TTCR08	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	24	4
2008	Culbreath	CINS08	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	8	4
2009	Tubbs	TTCRP09	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	24	4
2009	Tubbs	TWRBF09	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	48	4
2009	Culbreath	CINS09	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	8	4
2010	Tubbs	TWPRL10	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	48	4
2010	Culbreath	CINS10	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional	8	4
2008	Tubbs	TRSC08	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional	24	4
2009	Tubbs	TWPR09	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional	48	4
2009	Tubbs	TRSC09	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional	24	4
2010	Tubbs	TWPRP10	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional	48	4
2011	Tubbs	TWPP11	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional	32	4
Planting Date Trials											
2009	Tubbs	TWPR09	Plains, Ga	May 11-31, After June 10	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2009	Tubbs	TWRBF09	Tifton, Ga	May 1-10, June 1-10	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2010	Tubbs	TWPRL10	Tifton, Ga	May 11-31, June 1-10	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2010	Tubbs	TWPRP10	Plains, Ga	May 1-10, June 1-10	06G, GG	N/A	None	Single	Conventional, Strip	64	4

2011	Tubbs	TWPP11	Plains, Ga	May 1-10, May 11-31	06G, GG	N/A	None	Single	Conventional, Strip	52	4
2011	Tubbs	TWPRL11	Plains, Ga	May 1-10, May 11-31	06G, GG	N/A	None	Single	Conventional, Strip	64	4
Plant Population Trials											
2008	Tubbs	TRSC08	Plains, Ga	N/A	06G, GG	<3 spf, 3-4 spf, 4 spf	None	Single	Conventional	24	4
2009	Tubbs	TLSR09	Plains, Ga	N/A	06G, GG	<3 spf, 3-4 spf	None	Single	Conventional	48	6
2009	Tubbs	TRSC09	Plains, Ga	N/A	06G, GG	<3 spf, 3-4 spf, 4 spf	None	Single	Conventional	24	4
2009	Tubbs	TTCRP09	Tifton, Ga	N/A	06G, GG	<3 spf, 3-4 spf, 4 spf	None	Single	Conventional	8	4
2009	Tubbs	TWPR09	Plains, Ga	N/A	06G, GG	<3 spf, 3-4 spf, 4 spf	None	Single	Conventional	32	4
2009	Tubbs	TWRBF09	Tifton, Ga	N/A	06G, GG	<3 spf, 3-4 spf	None	Single	Conventional	30	4
2010	Tubbs	TWPRP10	Plains, Ga	N/A	06G, GG	<3 spf, 3-4 spf, 4 spf	None	Single	Conventional	32	4
2011	Tubbs	TWPP11	Plains, Ga	N/A	06G, GG	<3 spf, 3-4 spf	None	Single	Conventional	30	4
At-plant Insecticide Trials											
2007	Culbreath	CINS07	Tifton, Ga	N/A	06G, GG	N/A	Thimet, UTC	Single	Conventional	12	4
2008	Culbreath	CINS108	Tifton, Ga	N/A	06G, GG	N/A	Thimet, UTC	Single	Conventional	16	4
2009	Culbreath	CINS09	Tifton, Ga	N/A	06G, GG	N/A	Thimet, UTC	Single	Conventional	16	4
2010	Culbreath	CINS10	Tifton, Ga	N/A	06G, GG	N/A	Thimet, UTC	Single	Conventional	20	4

Row Pattern Trials											
2008	Tubbs	TRSC08	Plains, Ga	N/A	06G, GG	N/A	None	Single, Twin	Conventional	48	4
2008	Tubbs	TTCR08	Tifton, Ga	N/A	06G, GG	N/A	None	Single, Twin	Conventional, Strip	32	4
2009	Tubbs	TRSC09	Plains, Ga	N/A	06G, GG	N/A	None	Single, Twin	Conventional	48	4
2009	Tubbs	TTCR09	Tifton, Ga	N/A	06G, GG	N/A	None	Single, Twin	Conventional, Strip	32	4
Tillage System Trials											
2008	Tubbs	TTCR08	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	16	4
2009	Tubbs	TTCR09	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	16	4
2009	Tubbs	TWPR09	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2009	Tubbs	TWRBF09	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2010	Tubbs	TWPRL10	Tifton, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2010	Tubbs	TWPRP10	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	64	4
2011	Tubbs	TWPP11	Plains, Ga	N/A	06G, GG	N/A	None	Single	Conventional, Strip	64	4

Data analysis for TSWV incidence ratings (Analysis of tier 1 and 2 standard varieties)

Collected historical data were analyzed using the PROC GLIMMIX (generalized linear mixed model) procedure in SAS version 9.3 (SAS Institute, Cary, NC) to test TSWV disease intensity ratings for all treatments in plots planted to 'Georgia Green' and 'Georgia-06G'. No single trial contained all factors included in Peanut Rx. Therefore, data were compiled for each factor and interactions were tested. For each fixed variable, any data with significant interactions from different factors were removed from the analysis. Interactions were tested for year and location to account for variation in disease pressure. These data were analyzed to show differences between the two varieties. Each component of Peanut Rx, with the exception of use of Classic herbicide, was evaluated in this analysis (variety selection, planting date, plant population, at-plant insecticide, row pattern, and tillage system). Each trial contained both 'Georgia Green' and 'Georgia-06G'.

Data analysis for TSWV standardized AUDPC and onset (All tier analysis)

Data collected from 2013 and 2014 were analyzed using the PROC GLIMMIX (generalized linear mixed model) procedure in SAS version 9.3 (SAS Institute, Cary, NC) to test spotted wilt disease progress (AUDPC) and onset of disease. This analysis was conducted only on data from varieties currently grown in the southeast in order to evaluate the continued importance of production practices (Peanut Rx) on minimizing spotted wilt. Comparisons were made between tier 1, 2, and 3 varieties based on the previous analysis between tier 1 standard 'Georgia Green' and tier 2 standard 'Georgia-06G' (Materials and Methods 4.3.4). All trials contained different experimental design and setup, but each contained one or more components of Peanut Rx. These data were used to provide more in-depth analysis of the effect of production practices mitigating spotted wilt disease on current tier 2 and 3 peanut cultivars.

Results – Analysis of tier 1 and tier 2 standard varieties

Variety selection trials: There were significant differences in mean spotted wilt intensity ratings (y_{max}) between tier 1 'Georgia Green' and tier 2 'Georgia-06G' (Table 4.5). There was a significant interaction between Tifton and Plains (p = <.0001). In both locations, a significant interaction was observed by year (p = <.0001). In all years and locations, tier 2 'Georgia-06G' displayed significantly less disease than tier 1 'Georgia Green'.

Planting date trials: Spotted wilt intensity decreased from early May planting dates to late May/early June planting dates in both 'Georgia Green' and 'Georgia-06G' (Table 4.6). No interaction was observed between Tifton and Plains (p = 0.7283); therefore data were pooled for these two locations. However, there was an interaction between years 2009 and 2010-11 (p = <.0001). Another fixed effect present was tillage system, but no significant interaction was observed (p = 0.2427). In 2009, reductions in spotted wilt occurred in 'Georgia Green' in the latter two planting date windows. A similar trend was observed in 'Georgia-06G', but only nominal reductions were seen between the May 11-31 and after June 10 planting dates. In 2010-11, spotted wilt reductions were detected in both 'Georgia Green' and 'Georgia-06G' in May 11-31 or June 1-10 planting dates. No observations for planting dates after June 10 were observed in 2010-11.

Plant population trials: Significant differences were indicated in spotted wilt intensity when plant population increased in seed per foot (spf) (Table 4.7). No interaction was found between Tifton and Plains (p = 0.3901), but an interaction was observed between 2009 and years 2008, 2010-11 (p = <.0001). In 2009, plant population did impact disease in 'Georgia Green', but a nominal decrease was observed when adjusting from <3 spf and 3-4 spf, to >4 spf. No reductions were observed between <3 spf and 3-4 spf in 'Georgia-06G' in 2009. No observations were recorded for 'Georgia-06G' in 2009 for >4 spf. Increased spotted wilt disease was observed at 3-4 spf compared to <3 spf in 'Georgia Green' for years 2008, 2010-11. However, for these years, significantly less disease was seen in 'Georgia-06G' when increasing plant population.

At-plant insecticide trials: Incorporating phorate (Thimet®) as an at-plant insecticide significantly reduced disease in both tier 1 'Georgia Green' and tier 2 'Georgia-06G' (Table 4.8). All trials used for this factor were located in Tifton. An interaction was found between years 2007, 2008-09, and 2010 (p = <.0001). Increased spotted wilt was observed in earlier years, but a significant decrease in disease was observed when applying Thimet® in 'Georgia Green' for all years. This observation was similar for 'Georgia-06G' with the exception of one year, 2010, in which only a nominal reduction in disease was observed.

Row pattern trials: Spotted wilt intensity was significantly reduced when tier 1 'Georgia Green' and tier 2 'Georgia-06G' were planted in twin-row versus single row patterns (Table 4.9). No interaction was found between Tifton and Plains locations (p = 0.3654), but an interaction was observed between years 2008 and 2009 in Plains (p = <.0001). This interaction was not detected at the Tifton location (p = 0.5240). Another fixed effect present was tillage system, but no significant interaction was observed (p = 0.8638). Consequently, after pooling 2008 and 2009 data in Tifton for 'Georgia Green', a significant decrease in disease was detected in twin row patterns. For 'Georgia-06G', a nominal reductions was detected. In Plains, less spotted wilt incidence was observed in 2008, but nominal decreases in disease for twin row patterns was seen in both 'Georgia Green' and 'Georgia-06G'. Increased disease levels were observed in 2009, and twin row pattern reduced disease for 'Georgia Green'. In, 'Georgia-06G', nominal reductions were seen in 2009.

Tillage system trials: Use of reduced tillage systems led to decreases in spotted wilt in both tier 1 'Georgia Green' and tier 2 'Georgia-06G' (Table 4.10). An interaction was found between year and location (p = <.0001). No additional fixed effects were examined. For years 2008-09 in Tifton, a nominal reductions was detected in 'Georgia Green' when planting in reduced tillage, but no differences were seen in 'Georgia-06G'. Nominal disease reductions in 'Georgia Green' were observed in 2009 in Plains and 2010-11 in both Plains and Tifton. A significant increase in spotted wilt was observed in 'Georgia-06G' when planting in a reduced tillage system in Plains in 2009. In 2010-11, nominal reductions in disease with reduced tillage was detected in 'Georgia-06G'.

Results – Analysis of tier 2 and tier 3 standard varieties

Variety selection trials: Significant differences in y_{max} and AUDPC were observed between tier 2 and tier 3 peanut cultivars (Tables 4.11-4.15). In 2013 and 2014, significantly less disease was detected in y_{max} and AUDPC in tier 3 standard 'Georgia-12Y' when compared to 2^{nd}-generation standard, 'Georgia-06G'. Data were not pooled over 2013 and 2014 due to an interaction between years (p = 0.0023) for both y_{max} and AUDPC (Table 4.15). This observation between 'Georgia-06G' and 'Georgia-12Y' was also shown in Tables 4.11-4.13. These were individual trials in 2014. In Table 4.11, tier 2 'TUFRunner '511'' (20 risk points) had significantly higher y_{max} and AUDPC disease values than tier 2 'Georgia-06G' and tier 3 'Georgia-12Y'. This observation was also seen in Table 4.12. Tier 2 cultivars displayed greater y_{max} and AUDPC values compared to tier 3 'Georgia-12Y' and 'Georgia-10T' (Table 4.13). Differences in tier 2 cultivars were consistent with Peanut Rx. Greater disease levels were detected in tier 2 'TUFRunner '727'' (20 risk points), compared to other tier 2 varieties (Table 4.14).

Onset of disease occurred later in season in tier 3 'Georgia-12Y' when compared to tier 2 cultivars (Tables 4.11, 4.13, and 4.15). It was noted that tier 2 'TUFRunner '511'' displayed an earlier onset compared to tier 2 'Georgia-06G' (Table 4.12).

Planting date trials: In both tier 2 and 3 peanut cultivars, planting date impacted spotted wilt intensity (Tables 4.23-24). Spotted wilt AUDPC was significantly greater when planting in April (30 risk points) compared to May (5-15 risk points). Only nominal differences were observed in y_{max} (Table 4.24). Nominal reductions in AUDPC and y_{max} for May planting date were detected in tier 2 varieties 'FloRun 107' and 'Georgia-09B' (Table 4.23). Planting date did not impact spotted wilt in tier 3 'Georgia-12Y' (Tables 4.23-24).

Disease onset occurred later for April planting dates for both tier 2 and tier 3 varieties (Tables 4.23-24). In both 'Georgia-06G' and 'Georgia-12Y', disease onset was significantly delayed for April planting, compared to May planting.

Plant population trials: By increasing the seeding rate from 1 (25 risk points) to 4 (5 risk points) seed per foot (spf) in one seed increments, spotted wilt was reduced in tier 2 'Georgia-06G' (Table 4.25). However, an increase in disease was observed in another trial when increasing seed per foot from 3 (10 risk points) to 6 (5 risk points) (Tables 4.26). Data from Table 4.26 was pooled for y_{max} (location interaction, p = 0.9803) and sAUDPC (location interaction, p = 0.6525), but an insecticide interaction was observed for y_{max} (0.0112) and sAUDPC (p = 0.0136). With the use of Thimet®, reduced disease in lower plant populations was not as great, compared to CruiserMaxx® treated cultivars (Table 4.26). Similar observations were seen in tier 3 'Georgia-12Y'.

Plant population did not impact disease onset in both tier 2 and 3 varieties. Even without significance, results were variable (Tables 4.25-26).

At-plant insecticide trials: Impact of at-plant insecticide on spotted wilt disease was detected in both tier 2 and 3 peanut cultivars (Tables 4.16-22). In tier 2 'Georgia-06G', spotted wilt was reduced with use of Thimet® (5 risk points), compared to an untreated control (15 risk points) (Tables 4.16-18,20-22). A significant reduction in both y_{max} and AUDPC was observed in Tables 4.16,18, and 20. In these trials, use of Thimet® reduced spotted wilt compared to an untreated treatment in tier 3 'Georgia-12Y'. Significant disease reductions were observed with AUDPC, but not y_{max}, with use of Thimet® in 'Georgia-12Y' (Table 4.22). Differences in treatments within the same tier were similar. However, a significant reduction in both y_{max} and AUDPC with the use of Thimet® was observed in tier 2 'Georgia-09B' (20 risk points), but not in tier 2 and 3 varieties with 10 or less risk points (Table 4.17,20). Use of CruiserMaxx® (15 risk points) did not impact spotted wilt disease (Tables 4.16,18).

Use of Thimet® in tier 3 'Georgia-12Y' delayed onset of disease (Tables 4.19,21). Nominal reductions were observed for 'Georgia-12Y' in other trials (Table 4.17). Onset delays were observed in many tier 2 varieties with the use of Thimet® and CruiserMaxx®, but these were only nominal differences (Tables 4.16,17,19,21).

Row pattern trials: Reductions in spotted wilt were observed in both tier 2 'Georgia-06G' and tier 3 'Georgia-12Y' when planting in a twin row pattern (5 risk points), compared to single row pattern (10 risk points) (Tables 4.27-29). Significant reductions were only observed in one trial containing 'Georgia-06G' and additional tier 2 varieties (Table 4.27). Nominal disease reductions were observed with 'Georgia-12Y' when planting a twin row pattern.

Disease onset was not affected by row pattern for both tier 2 and 3 peanut varieties (Tables 4.27-29).

Tillage system trials: Impact of tillage system on spotted wilt disease was only studied using tier 2 'Georgia-06G'. In a similar trial repeated in 2013 and 2014, significant reductions in spotted wilt AUDPC and y_{max} were observed when planting into reduced tillage (5 risk points) compared to conventional tillage (15 risk points) (Table 4.30). A year interaction ($p = <.0001$) was detected, therefore data were not pooled across years.

Onset of disease occurred later when planting into reduced tillage for tier 2 'Georgia-06G' in both 2013 and 2014 (Table 4.30).

Discussion

Increase in genetic field resistance to TSWV has had the greatest impact and is the largest single factor attributed to a reduction in spotted wilt disease from Peanut Rx. Advanced peanut genotypes commonly show significantly less spotted wilt and have increased levels of field resistance to TSWV (Culbreath and Srinivasan, 2011; Culbreath, et al., 2013; Culbreath, et al., 2008; Brown, et al., 2005). Over the past decade, crop losses due to spotted wilt have decreased (Martinez, et al., 2008; Williams-Woodward, et al., 2011; Martinez, 2014), but have not been eliminated, with the introduction of increased varietal resistance. Consequently, it is useful to determine the impact of spotted wilt management in peanut with newly released cultivars displaying field-resistance to TSWV. Disease levels fluctuate from year to year and from location to location (Culbreath, et al. 1999; Culbreath, et al., 2005; Culbreath, et al., 2008; Culbreath, et al., 2010; Olatinwo, et al., 2010; Culbreath and Srinivasan, 2011), and much of these results are the product of a diverse collection of experiments. By evaluating the impact of production practices over many years and locations with cultivars with different levels of varietal resistance, we can determine the continued impact of Peanut Rx in the southeast United States.

In an analysis comparing tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’, significant differences in spotted wilt were observed using final disease intensity as an evaluation component, . Tier 1 ‘Georgia Green’ was used as the susceptible “control” of this study and displayed significantly higher spotted wilt than tier 2 ‘Georgia-06G’. These results were consistent with previously published data (Culbreath, et al., 2013; Culbreath, et al., 2005; Culbreath and Srinivasan, 2011; Culbreath, et al., 1999; Culbreath, et al., 2010). This study confirms increased TSWV resistance in ‘Georgia-06G’ compared to ‘Georgia Green’, similarly shown in multiple studies (Culbreath, et al., 2010; Culbreath, et al., 2008; Culbreath, et al., 2009). Increased resistance provides more flexibility for growers managing for spotted wilt with newer varieties. More specifically, y_{max} and standardized AUDPC were used to show differences in disease between tier 2 and 3 varieties in 2013 and 2014. Differences in disease were noted between tier 3 ‘Georgia-12Y’ and tier 2 ‘Georgia-06G’, along with many additional tier 2 varieties, based upon risk points assigned by Peanut Rx. It is important to note that some varieties attributed different risk point values, were placed into the same tier, i.e. ‘Georgia-06G’ (10 risk points) and ‘Georgia-09B’ (20 risk points) are both tier 2 varieties. Disease onset was also delayed significantly in ‘Georgia-12Y’, sometimes extending onset by more than two weeks compared to tier 2 varieties.

Previous studies show that planting date impacts spotted wilt incidence in peanut (Mckeown, et al., 2001; Culbreath, et al., 2003), but results with tier 2 cultivars have been variable (Hagan, et al., 2012). Spotted wilt was reduced when planting in later planting date window in both tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’. In 2009, a reduction of disease in 'Georgia Green' occurred as planting date was extended later in the season, but did not follow Peanut Rx risk point classification as did 'Georgia-06G' (May 1-10 = 15 risk points, May 11-31 = 5 risk points, June 1-10 = 10 risk points, and after June 10 = 15 risk points). A significant decrease was not detected in 'Georgia Green' at the May 11-31 planting. A nominal disease reduction at this planting date window was seen in 'Georgia-06G', along with a disease increase after June 10. In 2010, similar significant reductions were seen in both varieties moving from a May 1-10 to May 11-31 and June 1-10 planting date. However, with less disease in tier 2 varieties, effects of planting date may not always be present (Culbreath and Srinivasan, 2011). Previous data has shown the lessened effect of planting date on spotted wilt disease with tier 2 varieties, compared to tier 1 varieties (Culbreath, et al., 2010). In 2013 and 2014 data from this study, disease reductions in both y_{max} and AUDPC were observed when planting in April, compared to a May planting window. Peanut Rx risk values are much higher in April (30 risk points) than in May (5-15 risk points). Tier 2 'Georgia-06G' showed significant reductions, but tier 3 'Georgia-12Y' showed nominal reductions, if any. It is important to note that while we are not seeing significant reductions in spotted wilt in tier 3 varieties, nominal reductions are still present. Reduced impact of planting date on TSWV in tier 3 varieties could allow a larger planting window for growers looking to adjust their management program (Culbreath and Srinivasan, 2011). Significant delays in disease onset occurred for early planting date windows in both tier 2 and 3 peanut cultivars, but may be due in part to having an established crop before major thrips peak populations and spotted wilt epidemic.

Few significant reductions in spotted wilt were observed by increasing plant population from <3 plants/ft (25 risk points) to 3-4 or >4 plants/ft (5-10 risk points) in tier 1 standard 'Georgia Green' and tier 2 standard 'Georgia-06G'. Previous studies show that by increasing plant population to ensure greater coverage and opportunity to eclipse diseased plants, spotted wilt disease is reduced (Culbreath, et al., 2011; Culbreath, et al., 2013). While numerical reductions in spotted wilt were observed in ‘Georgia Green’ in 2009 adjusting from <3 spf to >4 spf, an increase was also observed at the 3-4 spf population. Greater spotted wilt incidence with increasing population were seen in years 2008, 2010-11 as well. Similar nominal outcomes, though with lower disease incidence, were observed in ‘Georgia-06G’. Culbreath et al., 2009, provided results suggesting that greater effects from plant population on spotted wilt were seen in ‘Georgia Green’ than in many varieties with greater levels of field resistance (Culbreath, et al., 2009). In results presented in this study, effect of plant population was not consistent and had no impact. Nevertheless, growers may have the opportunity to be flexible with plant population with more resistant varieties. Reduced disease pressure may affect the capability for significant reductions in spotted wilt when increasing plant population. In previous years with more susceptible cultivars, growers were encouraged to increase seeding rates (Brown, et al., 2005); however, this data help illustrate that additional seed costs may not be necessary if the primary objective is to reduce spotted wilt disease. Data on y_{max} and AUDPC show variable results in tier 2 and 3 cultivars. Tier 2 ‘Georgia-06G’, the most widely grown peanut in Georgia, still indicates nominal effects of reducing spotted wilt by increasing plant population, but this occurrence was not consistently detected.

Use of Thimet® to reduced spotted wilt disease of peanut has been variable across many years and locations, but has generally reduced disease (Culbreath, et al., 2003; Culbreath, et al., 2008). By incorporating Thimet® (5 risk points) as an at-plant insecticide compared to untreated controls (15 risk points), significant reductions were seen in tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’. Similar results were shown by Culbreath et al. (2008), using tier 1

‘Georgia Green’ and tier 2 ‘Tifguard’. In 2013 and 2014, differences in spotted wilt y_{max} and AUDPC were observed between Thimet® and untreated controls in both tier 2 and 3 varieties. Mostly nominal results were observed in tier 3 ‘Georgia-12Y’. A new seed treatment, CruiserMaxx® (15 risk points), showed disease reductions and increases, but overall did not significantly impact spotted wilt disease. Disease onset occurred later in season in ‘Georgia-12Y’ with the use of Thimet®, but this observation may be due to the effect of such high field resistance to spotted wilt. Disease reductions were observed in all tiers, but with lesser disease intensity in tier 3 cultivars, the effects are minimal (Culbreath, et al., 2008). Applying Thimet® as an at-plant insecticide may not be necessary from a spotted wilt scenario in tier 3 cultivars; however, it does have significant effects on reducing mechanical damage on peanut by the thrips vector (Lynch, et al., 1984).

Planting into twin row pattern (5 risk points) compared to single row pattern (10 risk points) to reduced spotted wilt disease in both tier 1 ‘Georgia Green’ and tier 2 ‘Georgia-06G’. Scenarios where disease reductions were nominal in ‘Georgia-06G’, but was not significant, may be due to the reduced disease pressure. Although planting into twin row pattern in peanut has historically resulted in spotted wilt reductions (Culbreath, et al., 2003; Culbreath, et al., 2008; Brown, et al., 2005), these results demonstrate that this production practice is variable across years and the reductions may decrease with cultivars of higher TSWV resistance. Moderately to highly resistant varieties show less effects of row pattern than susceptible varieties, but continue to show yield responses aside from disease management (Culbreath, et al., 2008; Tillman, et al., 2006). Data from 2013 and 2104 showed reductions in spotted wilt in both tier 2 and tier 2 varieties, but significance in both y_{max} and AUDPC was only observed once with ‘Georgia-06G’, other results being nominal. Row pattern did not impact disease onset. Effects of twin row pattern on spotted wilt could be influenced by an increased plant coverage (Culbreath, et al., 2003); however, both show little statistical difference on disease with tier 2 and tier 3 cultivars.

Effects of planting into reduced tillage on minimizing spotted wilt disease were observed in both ‘Georgia Green’ and ‘Georgia-06G’. Heavy disease pressure was seen in 2008-09 in Tifton, but only nominal reductions were detected by planting into reduced tillage. Similar results were seen in years 2009 in Plains and 2010-11 in Plains and Tifton. Previous evaluations of tillage system on spotted wilt has shown that implementing a reduced tillage system (5 risk points), as opposed to conventional tillage (15 risk points), decreases spotted wilt intensity (Culbreath, et al., 2003). In 2013 and 2014, tier 3 cultivars were not evaluated, however significant reductions were observed in tier 2 ‘Georgia-06G’ when incorporating a reduced tillage system. These results were from a study repeated across both years. Reduced tillage delayed onset of spotted wilt until later in the season, possibly due to interference of residual vegetation on thrips activity (Culbreath and Srinivasan, 2011; Brown, et al., 1996).

These results suggest that with less disease pressure through increased resistance, impact of production practices historically known to reduce spotted wilt in peanut is diminishing. However, even though significant reductions were not detected in many of these trials, nominal reductions in spotted wilt disease were observed in most tier 2 and 3 varieties. It is relevant to remember that not one single management technique is capable of providing adequate management of spotted wilt disease in peanut alone. It is also important to note that the study with tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’ showed that even with less disease incidence, a significant impact of production practices on disease was still consistently observed in tier 2 ‘Georgia-06G’. The results from 2013 and 2014 with tier 2 and 3 varieties expressing increased resistance enabled us to examine the current status of Peanut Rx in the southeast United States. It was helpful to address both y_{max} and AUDPC values relating to disease presence. Based upon the findings, few differences in significance were noted between y_{max} and AUDPC. Therefore, using either method of disease quantification is appropriate for spotted wilt analysis. Peanut Rx risk points and management methods continue to provide reductions in spotted wilt even under scenarios with widely grown tier 2 and the upcoming tier 3 varieties. Growers can continue to use Peanut Rx with confidence in helping to manage spotted wilt disease and increase yield.

Summary and Conclusions

The impact of other production practices on minimizing spotted wilt has decreased with the introduction of peanut genotypes with increased field resistance. For the analysis comparing tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’, significant reductions in spotted wilt incidence from production practices were observed. When compared to ‘Georgia Green’, ‘Georgia-06G’ displayed variable results across multiple years and locations. These results should be interpreted with knowledge that many of the earlier experiments were conducted under much heavier disease pressure than what occurred in the past few years. According to the results from data collected in 2013 and 2014, significant differences in AUDPC were observed in both tier 2 and tier 3 varieties, but was variable in many instances across tier and production practice. Reductions in disease continued to occur when using production practices listed by Peanut Rx that are known to mitigate spotted wilt disease, albeit many reductions were only nominal. It was interesting to note that tier 3 ‘Georgia-12Y’ had significant delays in disease onset compared to more susceptible varieties, which possibly contributed to lower disease progress and final disease intensity. Results also showed few incidences where

y_{max} and AUDPC differed on levels of significance. Therefore, using either method of disease quantification is appropriate for spotted wilt analysis. These results conclude that as breeding programs select the most field resistant varieties, management practices targeted at minimizing spotted wilt disease in peanut may have lesser effects due to less disease pressure. This could aid growers by providing opportunities to use more cost-effective management practices with less concern for increased crop losses from heavy spotted wilt pressure.

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Tables and Figures

Table 4.5. Mean TSWV incidence values of tier 1 standard 'Georgia Green' and tier 2 standard 'Georgia-06G' under similar experimental design.

Location	Year	Cultivar	y_{final}[b]
Tifton, GA	2007	Georgia Green[c]	77.41 a
		Georgia-06G[d]	29.58 b
	2008-09	Georgia Green	29.24 a
		Georgia-06G	10.68 b
	2010	Georgia Green	7.64 a
		Georgia-06G	2.14 b
Plains, GA	2008	Georgia Green	11.38 a
		Georgia-06G	6.02 b
	2009	Georgia Green	25.80 a
		Georgia-06G	11.94 b
	2010-11	Georgia Green	5.75 a
		Georgia-06G	4.30 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. Location (p = <.0001) and year (<.0001) interaction.
[b]Means are compared within column by location and year. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[c]Tier 1 cultivar.
[d]Tier 2 cultivar.

Table 4.6. Mean TSWV incidence values of tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’ under similar experimental design.

Year	Cultivar	Planting Date	y_{final}[b]
2009	Georgia Green[c]	May 1-10	27.74 a
		May 11-31	24.66 a
		June 1-10	15.57 b
		After June 10	15.95 b
	Georgia-06G[d]	May 1-10	16.47 b
		May 11-31	12.76 bc
		June 1-10	7.15 d
		After June 10	10.56 cd
2010-11	Georgia Green	May 1-10	6.08 a
		May 11-31	4.55 b
		June 1-10	4.30 b
	Georgia-06G	May 1-10	3.69 b
		May 11-31	2.19 c
		June 1-10	1.02 c

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. Year (p = <.0001) interaction.
[b]Means are compared within column by year. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[c]Tier 1 cultivar.
[d]Tier 2 cultivar.

Table 4.7. Mean TSWV incidence values of tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’ under similar experimental design.

Year	Cultivar	Plant Population	y_{final}[b]
2009	Georgia Green[c]	<3 spf	21.74 a
		3-4 spf	26.89 a
		>4 spf	14.36 ab
	Georgia-06G[d]	<3 spf	11.34 b
		3-4 spf	12.96 b
		>4 spf	N/A
2008,10-11	Georgia Green	<3 spf	4.24 bc
		3-4 spf	8.13 a
		>4 spf	7.50 ab
	Georgia-06G	<3 spf	4.07 bc
		3-4 spf	5.46 b
		>4 spf	1.25 c

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. Year (p = <.0001) interaction.
[b]Means are compared within column by year. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[c]Tier 1 cultivar.
[d]Tier 2 cultivar.

Table 4.8. Mean TSWV incidence values of tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’ under similar experimental design.

Year	Cultivar	At-plant Insecticide	y_{final}[b]
2007	Georgia Green[c]	Thimet	69.40 a
		Untreated	37.33 b
	Georgia-06G[d]	Thimet	34.10 b
		Untreated	14.40 c
2008-9	Georgia Green	Thimet	37.51 a
		Untreated	21.80 b
	Georgia-06G	Thimet	14.68 b
		Untreated	5.49 c
2010	Georgia Green	Thimet	12.90 a
		Untreated	7.88 b
	Georgia-06G	Thimet	2.40 c
		Untreated	2.28 c

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. Year (p = <.0001) interaction.
[b]Means are compared within column by year. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[c]Tier 1 cultivar.
[d]Tier 2 cultivar.

Table 4.9. Mean TSWV incidence values of tier 1 standard 'Georgia Green' and tier 2 standard 'Georgia-06G' under similar experimental design.

Location	Year	Cultivar	Row Pattern	y_{final}[b]
Tifton	2008-09	Georgia Green[c]	Single	24.12 a
			Twin	18.47 b
		Georgia-06G[d]	Single	9.14 c
			Twin	6.20 c
Plains	2008	Georgia Green	Single	11.53 a
			Twin	9.45 ab
		Georgia-06G	Single	6.02 bc
			Twin	2.72 c
	2009	Georgia Green	Single	32.25 a
			Twin	23.13 b
		Georgia-06G	Single	15.67 c
			Twin	11.56 c

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. Location ($p = <.0001$) and year ($p = <.0001$) interaction.
[b]Means are compared within column by location and year. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[c]Tier 1 cultivar.
[d]Tier 2 cultivar.

Table 4.10. Mean TSWV incidence values of tier 1 standard 'Georgia Green' and tier 2 standard 'Georgia-06G' under similar experimental design.

Year	Location	Cultivar	Tillage System	y_{final}[b]
2008-09	Tifton	Georgia Green[c]	Reduced	24.07 a
			Conventional	26.00 a
		Georgia-06G[d]	Reduced	10.93 b
			Conventional	10.98 b
2009	Plains	Georgia Green	Reduced	17.47 a
			Conventional	20.96 a
		Georgia-06G	Reduced	12.78 b
			Conventional	10.00 a
2010-11	Plains/Tifton	Georgia Green	Reduced	4.54 ab
			Conventional	5.77 a
		Georgia-06G	Reduced	2.71 c
			Conventional	3.28 bc

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. Location (p = <.0001) and year (p = <.0001) interaction.
[b]Means are compared within column by year (2008-09) and year and location (2010-11). Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[c]Tier 1 cultivar.
[d]Tier 2 cultivar.

Table 4.11. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3 peanut cultivars (Trial 18).

Cultivar	y_{max}[a]	sAUDPC[a]	Disease Onset[b]
Georgia-06G[d]	16.56 b	10.265 b	50.67 ab
Georgia-12Y[e]	7.39 c	4.515 b	57.33 a
TUFRunner '511'[d]	40.31 a	25.573 a	41.67 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar.
[c]Onset of disease measured as days after planting (DAP).
[d]Means are compared within columns. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.12. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3peanut cultivars (Trial 19).

Cultivar	y_{max}[a]	sAUDPC[a]	Disease Onset[b]
Georgia-06G[d]	13.05 b	7.706 b	55.54 a
Georgia-12Y[e]	6.43 c	3.606 c	57.46 a
Georgia-13M[d]	11.04 b	6.201 b	61.00 a
TUFRunner ‘511’[d]	24.05 a	14.562 a	48.04 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar.
[c]Onset of disease measured as days after planting (DAP).
[d]Means are compared within columns. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.13. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3 peanut cultivars (Trial 4).

Cultivar	y_{max}[a]	sAUDPC[b]	Disease Onset[c]
Georgia Greener[d]	16.31 ab	8.563 ab	42.63 b
Georgia-06G[d]	12.14 b	7.378 ab	42.63 b
Georgia-07W[d]	19.63 a	10.287 a	42.63 b
Georgia-09B[d]	14.84 ab	8.760 ab	41.00 b
Georgia-10T[e]	10.74 bc	5.523 bc	41.00 b
Georgia-11J[d]	18.36 a	8.943 ab	43.63 b
Georgia-12Y[e]	6.74 c	4.117 c	49.13 a
Tifguard[d]	15.23 ab	8.274 ab	41.00 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms.
[c]Onset of disease measured as days after planting (DAP).
[d]Means are compared within columns. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.14. Mean y_{max}, standardized AUDPC and onset values of tier 2 peanut cultivars (Trial 1).

Cultivar[e]	y_{max}[a]	sAUDPC[b]	Disease Onset[d]
Florida-07	5.78 ab	2.397 ab	55.94 a
FloRun 107	4.06 bc	1.709 b	59.31 a
Georgia Greener	4.06 bc	1.817 ab	56.06 a
Georgia-06G	4.02 bc	1.925 ab	59.69 a
Georgia-07W	4.34 bc	1.781 b	62.11 a
Georgia-09B	3.28 c	1.635 b	61.75 a
Tifguard	4.14 bc	1.474 b	59.63 a
TUFRunner '727'	7.03 a	2.756 a	58.63 a

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar.
[c]Onset of disease measured as days after planting (DAP).
[d]Means are compared within columns. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.

Table 4.15. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3 peanut cultivars (Trials 1, 4-8, 10, 11, 14-19).

Year	Cultivar	y_{max}[a]	sAUDPC[b]	Disease Onset[c]
2013	Georgia-06G[d]	11.71 a	5.72 a	51.13 a
	Georgia-12Y[e]	5.96 b	3.05 b	45.71 a
2014	Georgia-06G	15.84 a	9.48 a	62.50 a
	Georgia-12Y	6.41 b	3.59 b	54.40 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Location (0.2520) and year (0.1416) interaction.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. Location (0.3665) and year (0.0023) interaction.
[c]Onset of disease measured as days after planting (DAP). Location (0.1276) and year (<.0001) interaction.
[d]Means are compared within columns. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.16. Mean y_{max}, standardized AUDPC and onset values of a tier 2 peanut cultivar with different at-plant insecticides (Trial 2).

Cultivar	At-Plant Insecticide	y_{max}[a]	sAUDPC[b]	Disease Onset[c]
Georgia-06G[d]	Dynasty	15.00 a	8.114 a	49.75 a
	Cruiser	9.69 ab	4.629 b	54.50 a
	Dynasty+Orthene	7.97 b	4.290 b	54.50 a
	Cruiser+Orthene	9.06 b	3.944 b	57.25 a
	Dynasty+Thimet	6.64 b	3.005 b	49.75 a
	Cruiser+Thimet	5.86 b	2.983 b	51.13 a

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. No interactions were present.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. No interactions were present.
[c]Onset of disease measured as days after planting (DAP). No interactions were present.
[d]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.

Table 4.17. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3 cultivars with different at-plant insecticides (Trial 11).

Cultivar	At-Plant Insecticide	y_{max}[a]	sAUDPC[b]	Disease Onset[c]
Georgia Greener[e]	Thimet	6.25 a-e	3.30 abc	64.50 abc
	Untreated	9.77 ab	4.82 a	69.50 abc
Georgia-06G[e]	Thimet	5.66 b-e	3.13 abc	51.00 c
	Untreated	8.01 abc	4.64 a	54.50 bc
Georgia-09B[e]	Thimet	4.88 cde	2.06 c	76.50 a
	Untreated	10.16 a	4.63 a	64.50 abc
Georgia-12Y[f]	Thimet	3.52 de	1.61 c	68.50 abc
	Untreated	3.32 de	1.49 c	73.00 ab
Georgia-13M[e]	Thimet	7.42 a-d	3.10 abc	76.50 a
	Untreated	7.42 a-d	4.17 ab	61.00 bc
Tifguard[e]	Thimet	4.49 cde	2.30 bc	70.00 abc
	Untreated	2.54 e	1.36 c	73.00 ab

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. No interactions were present.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. No interactions were present.
[c]Onset of disease measured as days after planting (DAP). No interactions were present.
[d]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.18. Mean y_{max} and standardized AUDPC values of tier 2 and 3 cultivars with different at-plant insecticides (Trials 15-16).

Cultivar	At-Plant Insecticide	y_{max}[a]	sAUDPC[b]
Georgia-06G[d]	Admire Pro	12.10 ab	8.02 ab
	Cruiser	11.66 ab	7.56 b
	Thimet	9.16 b	5.82 b
	Untreated	13.07 a	8.16 a
Georgia-12Y[e]	Admire Pro	3.84 c	2.32 c
	Cruiser	4.09 c	2.59 c
	Thimet	1.86 c	0.98 c
	Untreated	3.74 c	2.11 c

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Location interaction (p = 0.2235), row pattern interaction (p = 0.7445).
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. Location interaction (p = 0.1089), row pattern interaction (p = 0.7156).
[c]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[d]Tier 2 cultivar.
[e]Tier 3 cultivar.

Table 4.19. Mean onset values of tier 2 and 3 cultivars with different at-plant insecticides (Trials 15-16).

Location	Row Pattern	Cultivar	At-plant Insecticide[a]			
			Admire Pro	CruiserMaxx	Thimet	Untreated
Attapulgus/ Quincy	Single/Twin	Georgia-06G[c]	54.42 d	68.58 bc	60.08 cd	61.08 bcd
		Georgia-12Y[e]	71.92 b	64.50 bcd	98.92 a	66.67 bc
Attapulgus	Twin	Georgia-06G	47.50 b	54.50 ab	47.50 b	57.75 ab
		Georgia-12Y	63.00 ab	50.75 ab	64.50 a	61.25 ab

[a]Onset of disease measured as days after planting (DAP). Location interaction (0.0226), row pattern interaction (p = 0.0465).
[b]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[c]Tier 2 cultivar.
[d]Tier 3 cultivar.

Table 4.20. Mean y_{max}, standardized AUDPC and onset values of tier 2 cultivars with different at-plant insecticides (Trial 12).

Cultivar	At-Plant Insecticide	Y_{max}[a]	sAUDPC[b]	Disease Onset[c]
Georgia-06G[e]	Cruiser	20.22 a	11.11 a	51.88 a
	Cruiser+Thimet	12.89 ab	6.57 ab	46.25 a
	Thimet	11.33 b	5.62 b	57.75 a
	Untreated	12.99 ab	7.14 ab	54.38 a
Georgia-09B[e]	Cruiser	18.46 ab	9.61 ab	47.88 a
	Cruiser+Thimet	16.02 ab	7.99 ab	60.75 a
	Thimet	11.91 b	6.41 b	52.50 a
	Untreated	20.90 a	10.62 a	46.25 a

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. No interactions were present.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. No interactions were present.
[c]Onset of disease measured as days after planting (DAP). No interactions were present.
[d]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.

Table 4.21. Mean onset values of tier 2 and 3 cultivars with different at-plant insecticides (Trials 3-5, 7-8, 10-11, 15-16).

Year	Location	Cultivar	At-plant Insecticide[a]	
			Thimet	Untreated
2013	Tifton	Georgia-06G	48.17 b	45.71 b
		Georgia-12Y	58.00 a	51.13 ab
2014	Attapulgus/Tifton	Georgia-06G	50.88 c	52.56 bc
		Georgia-12Y	79.19 a	62.69 b
	Quincy	Georgia-06G	61.13 b	66.13 b
		Georgia-12Y	100.38 a	67.75 b

[a]Onset of disease measured as days after planting (DAP). Location interaction (0.0015), year interaction (0.0015), row pattern interaction ($p = 0.1875$).
[c]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[d]Tier 2 cultivar.
[e]Tier 3 cultivar.

Table 4.22. Mean y_{max} and standardized AUDPC values of tier 2 and 3 cultivars with different at-plant insecticides (Trials 3-5, 7-8, 10-11, 15-16).

Cultivar	At-plant Insecticide	y_{max}[a]	sAUDPC[b]
Georgia-06G[d]	Thimet	9.71 b	5.21 b
	Untreated	12.91 a	6.73 a
Georgia-12Y[e]	Thimet	3.19 c	1.41 d
	Untreated	5.06 c	2.68 c

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Location interaction (p = 0.0754), year interaction (p = 0.6060), row pattern interaction (p = 0.8093).
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. Location interaction (p = 0.0684), year interaction (p = 0.6573), row pattern interaction (p = 0.9716).
[c]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[d]Tier 2 cultivar.
[e]Tier 3 cultivar.

Table 4.23. Mean y_{max}, standardized AUDPC values and onset of tier 2 and 3 cultivars with different planting dates (Trial 13).

Cultivar	Planting Date	y_{max}	sAUDPC[a]	Disease Onset[b]
FloRun 107[d]	28-Apr	23.36 a	13.528 a	55.38 c
	12-May	19.69 ab	11.441 ab	51.81 c
Georgia-06G[d]	28-Apr	17.27 bc	10.824 abc	56.19 bc
	12-May	14.84 bc	8.721 bc	53.75 c
Georgia-09B[d]	28-Apr	16.25 bc	9.293 bc	56.25 bc
	12-May	13.98 c	7.674 c	49.19 c
Georgia-12Y[e]	28-Apr	6.79 d	3.733 d	64.87 ab
	12-May	6.02 d	3.276 d	67.25 a

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. No interactions were present.
[a]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. No interactions were present.
[b]Onset of disease measured as days after planting (DAP). No interactions were present.
[c]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[d]Tier 2 cultivar.
[e]Tier 3 cultivar.

Table 4.24. Mean y_{max}, standardized AUDPC and onset values of tier 2 ‘Georgia-06G’ and tier 3 ‘Georgia-12Y’ with different planting dates (Trial 16).

Cultivar	Planting Date	y_{max}[a]	sAUDPC[b]	Onset[c]
Georgia-06G[e]	22-Apr	12.90 a	8.087 a	65.50 b
	15-May	7.50 a	4.865 b	43.13 c
Georgia-12Y[f]	22-Apr	3.28 bc	2.018 c	80.25 a
	15-May	3.96 c	2.677 c	52.63 bc

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. No significant interaction was found for insecticide ($p = 0.2149$) or row pattern ($p = 0.9728$).
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. No significant interaction was found for insecticide ($p = 0.2647$) or row pattern ($p = 0.9374$).
[c]Onset of disease measured as days after planting (DAP). No significant interaction was found for insecticide ($p = 0.4572$) or row pattern ($p = 0.1868$).
[d]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.25. Mean y_{max}, standardized AUDPC and onset values of tier 2 ‘Georgia-06G’ with different plant populations (Trial 20).

Cultivar	Plant Population	y_{max}	sAUDPC[a]	Onset[b]
Georgia-06G[d]	1	37.78 a	23.108 a	41.75 a
	2	35.56 a	21.467 a	43.50 a
	3	28.21 a	17.236 a	47.00 a
	4	18.21 a	11.342 a	47.00 a

[a]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar.
[b]Onset of disease measured as days after planting (DAP).
[c]Means are compared within column. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[d]Tier 2 cultivar.

Table 4.26. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3 cultivars under different seeding rates (Trial 14).

Insecticide	Cultivar	Seeding Rate (SPF)	y_{max}[a]	sAUDPC[b]	Onset[c]
CruiserMaxx	Georgia-06G[e]	3	4.99 b	2.94 b	67.87 b
		6	10.56 a	5.72 a	62.00 b
	Georgia-12Y[f]	3	4.12 b	2.18 b	88.25 a
		6	7.04 ab	3.94 ab	72.75 ab
Thimet	Georgia-06G	3	4.94 a	2.77 a	70.38 a
		6	5.30 a	3.04 a	75.38 a
	Georgia-12Y	3	3.35 a	1.60 a	80.25 a
		6	2.34 a	1.29 a	77.00 a

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. A significant insecticide interaction was found ($p = 0.0112$). Location was not significant ($p = 0.9803$).
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. A significant insecticide interaction was found ($p = 0.0136$). Location was not significant ($p = 0.6525$).
[c]Onset of disease measured as days after planting (DAP). No significant interaction was found: insecticide ($p = 0.5383$), location ($p = 0.9949$).
[d]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher's Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.27. Mean y_{max}, standardized AUDPC and onset values of tier 2 and 3 cultivars under different row patterns (Trial 19).

Cultivar	Row Pattern	y_{max} [a]	sAUDPC [b]	Onset [c]
Georgia-06G [e]	Single	16.13 b	9.396 a	55.75 a
	Twin	9.98 cd	6.017 b	55.33 a
Georgia-12Y [f]	Single	7.20 d	3.991 a	55.75 a
	Twin	5.66 d	3.221 a	59.17 a
Georgia-13M [e]	Single	13.33 bc	7.506 ab	63.33 a
	Twin	8.75 cd	4.897 b	58.67 a
TUFRunner ‘511’ [e]	Single	25.00 a	15.326 a	48.25 a
	Twin	23.10 a	13.798 a	47.83 a

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. No interactions were present.
[b]Standardized AUDPC is the area of disease progress of visible tissue exhibiting TSWV symptoms. Mean values were calculated from four replicates for each cultivar. No interactions were present.
[b]Onset of disease measured as days after planting (DAP). No interactions were present.
[d]Means are compared within column for each specific cultivar. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[e]Tier 2 cultivar.
[f]Tier 3 cultivar.

Table 4.28. Mean y_{max} and standardized AUDPC values of tier 2 ‘Georgia-06G’ and tier 3 ‘Georgia-12Y’ under different row patterns (Trials 15-16, 19).

Cultivar	Row Pattern	y_{max} [a]	sAUDPC [b]
Georgia-06G [c]	Single	12.86 a	8.06 a
	Twin	10.99 a	6.89 a
Georgia-12Y [d]	Single	4.55 b	2.62 b
	Twin	3.78 b	2.26 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar. No significant location (p = 0.1206) and insecticide (p = 0.0899) interaction.
[b]Means are compared within column by year. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$). No significant location (p = 0.1074) and insecticide (p = 0.1064) interaction.
[c]Tier 2 cultivar.
[d]Tier 3 cultivar.

Table 4.29. Mean onset values of tier 2 ‘Georgia-06G’ and tier 3 ‘Georgia-12Y’ under different row patterns (Trials 15-16, 19).

Location	Cultivar	Row Pattern[b]	
		Single	Twin
Attapulgus	Georgia-06G[c]	51.00 a	57.75 a
	Georgia-12Y[d]	64.50 a	61.25 a
Quincy	Georgia-06G	67.75 a	64.50 a
	Georgia-12Y	67.75 a	67.75 a
Tifton	Georgia-06G	55.75 a	55.33 a
	Georgia-12Y	55.75 a	59.17 a

[a]Onset is the number of days after planting (DAP) in which disease incidence is first detected. A significant location interaction was observed (p = 0.0080).
[b]Means are compared by row. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[c]Tier 2 cultivar.
[d]Tier 3 cultivar.

Table 4.30. Mean y_{max}, standardized AUDPC and onset values of tier 2 ‘Georgia-06G’ under different tillage systems (Trials 9, 21).

Cultivar	Year[e]	Tillage System	y_{max}[a]	sAUDPC[b]	Onset
Georgia-06G[d]	2013	Reduced	5.05 b	2.06 b	46.33 a
		Conventional	15.65 a	6.03 a	38.42 b
	2014	Reduced	14.50 b	8.59 b	54.37 a
		Conventional	21.89 a	14.34 a	44.88 b

[a]Incidence is the percentage of visible tissue exhibiting TSWV symptoms. Mean values were calculated from three or more replicates for each cultivar.
[b]Means are compared within column by year. Means with the same letter do not significantly differ using Fisher’s Protected LSD ($p \leq 0.05$).
[c]Onset of disease valued as days after planting (DAP).
[d]Tier 2 cultivar.
[e]Year interaction (<.0001), row pattern interaction (p = 0.1192)

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary and Conclusions

Spotted wilt has been a major pest of both peanut and tobacco in the eastern United States since its introduction in the 1980's (Kucharek, et al., 1990; Hagan and Weeks, 1998). No single management option is 100% effective, but with multiple tactics, disease incidence can be greatly reduced. In North Carolina, a predictive model (TTRF) was developed for use in tobacco (Chappell, et al., 2013). TTRF predicts thrips vector population dynamics and provides an expected spotted wilt risk based on weather factors. With this management model, growers can adjust planting date and provide chemical treatment to fields in which heavy spotted wilt pressure is predicted. For peanut, a risk index was developed in Georgia containing cultural and chemical controls, along with varietal resistance, used to mitigate spotted wilt incidence (Brown, et al., 1996; Brown, et al., 2005). Growers calculate a relative risk level (low, medium, or high) and adjust their management tactics to reach a suitable risk to spotted wilt.

Chapter 2 shows the use of TTRF in Georgia tobacco for spotted wilt management. Resistance to TSWV is not commercially available to tobacco producers, therefore, cultural and chemical practices are necessary to manage spotted wilt. A significant correlation was found between the weather factors built into the TTRF and spotted wilt incidence in Georgia. Validation of TTRF showed efficacy with 80% of the dataset (excluding year 2013 for over-predictions) and mean error for the model was just over 10%. These results indicate this model could be useful in Georgia, as incidence in some cases reach high percentages. Studies are currently being evaluated to improve the predictive power of TTRF for use in Georgia tobacco; primarily through testing additional weather factors that may impact thrips activity and spotted wilt in Georgia.

Chapter 3 demonstrates the predictive power of an integrated model for spotted wilt management in southeast United States peanut. This model, Peanut Rx 2.0, combines a predictive model (TTRF) and risk index (Peanut Rx). Peanut Rx describes disease risk by certain risk factors, whereas TTRF predicts disease pressure. By integrating these two models, disease management can be improved. Peanut Rx 2.0 was constructed and explained six times the variability of Peanut Rx alone. These results show the strength of such a model in improving disease management in southeast peanut. It is important to note that while these results are promising; this experiment was using the standard format of both Peanut Rx and TTRF. Future studies will evaluate additional weather factors and risk rankings and determine their usefulness in building a more robust Peanut Rx 2.0. Peanut growers will be able to improve management by identifying a predicted amount of disease, which will subsequently allow them to determine the best production practices to limit spotted wilt incidence.

Chapter 4 examines the impact of other production practices on minimizing spotted wilt with the introduction of peanut genotypes with increased field resistance. Peanut cultivars were placed into tiers based on Peanut Rx risk point values, tier 1 having the highest risk points and tier 3 having the lowest. Significant reductions in spotted wilt incidence were observed between tier 1 standard ‘Georgia Green’ and tier 2 standard ‘Georgia-06G’. When compared to ‘Georgia Green’, ‘Georgia-06G’ displayed variable results. These results should be interpreted with knowledge that many of the experiments based on historical data were conducted under much heavier disease pressure than the past few years. From data collected in 2013 and 2014, significant differences in AUDPC and y_{max} were observed in both tier 2 and tier 3 varieties, but were variable in many instances across tier and production practice. Reductions in disease continued to occur when using production practices listed by Peanut Rx that are known to mitigate spotted wilt disease, albeit many reductions were only nominal. Tier 3 'Georgia-12Y' had significant delays in disease onset compared to more susceptible varieties, which possibly contributed to lower disease progress and final disease intensity. y_{max} and AUDPC did not differ on mean separation. Therefore, using either method of disease quantification is appropriate for spotted wilt analysis. These results conclude that as breeding programs select the most field resistant varieties, management practices targeted at minimizing spotted wilt disease in peanut may have lesser effects due to less disease pressure. This could aid growers by providing opportunities to use more cost-effective management practices with less concern for increased crop losses from heavy spotted wilt pressure.

The results presented in this study reveal the complexity of the TSWV pathosystem in both peanut and tobacco. Spotted wilt has been a troublesome pest in the southeast United States since its introduction almost three decades ago. Multiple management tactics are necessary for adequate spotted wilt control. No previous method of disease prediction has been used in the southeast, but this study shows how TTRF and Peanut Rx 2.0 can be placed into current management practices. Lastly, peanut has an inherited ability to resist TSWV symptom expression, allowing the plant not to be affected by yield. This is a useful tool and these results conclude that much of the management may be considered flexible instead of necessary. However, spotted wilt is still considered a serious pest, and can cause high incidence and yield loss in even resistant varieties. It is our hope that this work can benefit those looking to successfully manage spotted wilt in both peanut and tobacco in the southeast.

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