ABSTRACT

FRYE, JEFFREY WAYNE. Efficacy of Novel Nematicide Seed Treatments for the Control of *Heterodera glycines* in Soybean Production. (Under the direction of Stephen R. Koenning).

Heterodera glycines Ichinohe, soybean cyst nematode (SCN), is the most damaging pathogen of soybean [*Glycine max* (L.) Merr.] in the United States. SCN juveniles are small thread-like, nonsegmented, microscopic worms that penetrate soybean root systems to establish a parasitic relationship that diverts essential plant nutrition to the feeding site. Adult females become pyriform while the males are vermiform. SCN suppresses growth and yield, but because rotation may be unattractive to growers, resistant cultivars may be unavailable, and effective safe alternatives are currently lacking, new control tactics for SCN management are needed. Currently the only non-fumigant nematicide registered for soybean is aldicarb. Aldicarb is highly toxic and is under review by the EPA for groundwater contamination and may not be available in the future. Two chemical seed treatments for management of plant-parasitic nematodes are Avicta (Syngenta Crop Protection) and Aeris (Bayer Crop Sciences). Avicta is a fermentation product (abamectin) derived from an actinomycete and Aeris is a mixture of the neonicotinoid insecticide imidacloprid and thiodicarb, a carbamate insecticide/nematicide. Both are currently registered for use as a seed treatment on cotton. Objectives for the current project were to evaluate the efficacy of both Avicta and Aeris as seed treatments on soybean for management of the soybean cyst nematode. In 2007 and 2008 field trials and microplot experiments were initiated to evaluate the efficacy of these seed treatments against SCN. Three rates of each seed treatment were applied, 0.10, 0.15, and 0.20 mg a.i/seed abamectin, and 0.20, 0.28, 0.36 mg a.i./seed imidicloprid+thiodicarb and compared to an untreated control and an in-furrow rate, 1.17 kg a.i./ha, of aldicarb. SCN populations were not reduced at the end of the growing season and that there were only limited yield benefits seen with either the Avicta or Aeris product at the three different rates.

Population densities of the soybean cyst nematode in field studies lowest (275 eggs/500cm^3 soil) at the Chowan County location to highest (4663 eggs/500cm^3 soil) at the Scotland County location. Highest yields were seen at the Scotland County location which

was more than likely due to soil nutrients and environmental conditions at that location since the seed treatments did not lower infection rates or increase yield on the susceptible cultivars. $Pm_{(28\ DAP)}$ were not lowered with any of the rates of abamectin or imidacloprid+thiodicarb on any of the cultivars with the exception of the cv. NK S76-L9 at the Scotland County location, suggesting that the seed treatments were either not effective against the SCN or did not move with the root system in order to give adequate protection. At the Lenoir County location increasing rates of abamectin and imidacloprid+thiodicarb gave increasing yields on the cv. Fowler, and abamectin on the cv. Hutcheson. Other locations where similar results were seen were in Scotland County for both abamectin and imidacloprid+thiodicarb on the cv. Hutcheson, Scotland County for imidacloprid+thiodicarb on both the cv. NC Raleigh and NK S76-L9 and abamectin on cv. NC Raleigh. However, the only significant difference was seen at the Scotland County location with the abamectin treatment on the cv. NC Raleigh where increasing rates also gave increasing $Pm_{(28\ DAP)}$ values which leads to possible host tolerance being responsible for maintaining yield since the low and mid rates were not significantly different from the untreated control with respect to yield or $Pm_{(28\ DAP)}$ values.

Our current research suggests that host status is the most influential effect on the SCN and that the seed treatments are either short lived in the soil or are not moving with the root system. Rapid germination seen in soybean can push the seed coat out of the soil in as little as 72 hours after planting as was seen in greenhouse and microplot studies. A majority of the seed treatment was left on the seed coat where the chemicals could have been degraded by ultra-violet rays from the sun.

Efficacy of Novel Nematicide Seed Treatments for the Control of *Heterodera glycines* in Soybean Production

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Plant Pathology

Raleigh, North Carolina

2009

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DEDICATION

I dedicate this work to my parents Richard and Brenda whom have supported me in all of my endeavors no matter how absurd they were. To my father whom has supported me financially throughout my educational career and my mother who kept telling me it was never too late to return to school. To my grandparents who instilled in me their work ethics, pride and integrity. To my loving wife, Karen, who has supported and encouraged me to follow my dreams and patiently waited.

BIOGRAPHY

Jeffrey Wayne Frye was born on August 16, 1975 at the Moore Regional Hospital in Moore County, North Carolina. He grew up in the small town of West End, NC on a tobacco farm and recently lives 500 yards from his home place. He graduated from Union Pines High School in 1993 and began full-time work with his uncle, Ronnie Williams, installing landscape and irrigation. He remained at this job until 1997 when he began his own construction business under the name Frye Grading and Drainage. After 5 years he returned school part time at Sandhills Community College in Pinehurst in 2002. He then transferred to North Carolina State University in 2004 and received a Bachelors' of Science degree in Biochemistry in 2007. During his undergraduate studies he worked with the plant pathology department as a lab technician in the nematology lab. Following graduation in 2007, he began pursuing his masters' degree in the Department of Plant Pathology under the direction of Dr. Stephen R. Koenning. His research focused on the control of plant parasitic nematodes affecting soybean.

He currently remains in his home town of West End and lives with his wife, Karen Frye, and stepson Matthew Key. He enjoys farming and is known for his over zealous gardening practices.

ACKNOWLEDGMENTS

There are numerous people responsible for my accomplishments…

I would like to thank my major advisor, Dr. Stephen R. Koenning, for his guidance in getting me off to a good start and then allowing me to initiate my own decisions about how to conduct my research. I would also like to thank my committee members, Dr. Eric Davis and Dr. Barbara Shew, for their input and suggestions and especially for graciously talking with me when I would pop in unannounced, which was most of the time.

Thanks to the hardworking technicians, Roger N. Taylor, Jackie Ward, Abigail Capps, Jason Greene, and Jeff Spivey, for all of their help in the fields and the lab. Without their hard work this would not have been possible. A special thanks to my best friend Jason who helped me keep my sanity and kept the entire lab content with his daily insanity.

I would like to thank my family whom supported me through all of my educational experiences and encouraged me not to give up. To my wife, who I have shared this whole experience with, for helping me keep life in order and reminding me to keep my eyes on the big picture.

To my sister, Robin Thomas, for giving me two wonderful nieces, Sarah and Nora, that inspired me throughout my college experience. Whenever things got tough I just looked at their beautiful faces and it reminded that I was setting examples for them to follow and that having a college degree would be a means for me to support their own endeavors someday.

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CHAPTER 1:

Introduction & Literature Review

Section 1. History and Distribution

In order to make assumptions on the origin of the soybean cyst nematode (SCN), *Heterodera glycines* Ichinohe, first we must look at the history of soybean (*Glycine max* [L.] Merr.) cultivation. Many of the cultural practices utilized in the production of soybean are directly related to the dissemination of the soybean cyst nematode. Domestication of soybean from a wild plant to a cultivated crop was believed to occur around 3500 BC in northern and central China (Riggs et al., 2004). Importation of cultivated soybean into Korea, Japan and Russia began about 2300 years ago. Soybean was not introduced into North America until the late eighteenth century (Hymowitz, 1990). Soybean seed were transported in from many countries, mainly Japan and China, and distributed throughout the United States to many of the Agricultural Experiment Stations in the late 1800's and early 1900's (Riggs et al., 2004). From the 1950's to the 1980's soybean plantings expanded rapidly and currently the top 5 soybean producing states are in the "Corn Belt" of the USA (http://www.nass.usda.gov/QuickStats/index2.jsp).

The soybean cyst nematode is believed to have evolved with the production of the soybean, so the probable origin of the nematode is considered to be China (Riggs et al., 2004). The earliest report of damage to soybean caused by the soybean cyst nematode in China occurred in 1899 (Liu et al., 1997). A disease referred to by farmers as "fire burned seedlings" was known to occur many years prior to the release of the before mentioned report (Riggs et al., 2004). Numerous detections followed the 1899 report in China including Japan in 1915, Hokkaido in 1921, Niigata in 1946, Korea in 1936 and all soybean producing areas of South Korea today. The most recent discovery of soybean cyst nematode occurred in Zhejiang, China which makes it the most southern region infested in China with soybean cyst nematode (Zheng et al., 2009). The first report of soybean cyst nematode in the USA occurred in a bulb growing field in Wilmington, NC in 1954 (Winstead et al., 1955). Soil and debris brought over on these flower bulbs from Japan are the probable cause of dissemination into North Carolina. By 1958 over 15,000 acres in the United States were known to be infested with soybean cyst nematode (Christie, 1959). Surveys, prompted by discovery of the soybean cyst nematode in North Carolina, detected its presence in Tennessee (Epps, 1956), Missouri (Hegge, 1957), Arkansas, Kentucky and Mississippi (Spears, 1957), Virginia (Anonymous, 1961), and one county in Illinois (Spears, 1964). Reports of SCN increased rapidly over the next three decades. In 1965 eight states reported SCN populations, which grew to 15 states by 1976, 24 states by 1986 (Noel, et al., 1996), and the most current distribution map shows 33 states reporting populations of soybean cyst nematode (Figure 1). Rapid dispersal of the nematode can be seen in the state of Arkansas where SCN was detected in one county in 1957, 3 counties by 1960, 8 total counties in 1964 and another 24 counties had SCN infested fields by 1969 (Riggs, 1977). The spread of the soybean cyst nematode throughout the USA is assumed to be partly due to the use of *Bradyrhizobium* soil inoculations. W. P. Brooks showed in 1893 that dusting soybean with soil from 3 soybean cultivars from Japan proved beneficial for soybean growth (Hymowitz, 1990). Introduction through these infected seed lots during the 18th and 19th century throughout the United States is a probable cause for dissemination of the soybean cyst nematode over such an extensive area.

Once the soybean cyst nematode was established in the USA dispersal within the country was aided by many factors. In 1924 there were 181,300 hectares of planted soybean in the US, by 1974 soybean production had grown to 21.3 million hectares (Riggs, 1977). The most common dispersal method of the nematode is through infested soil moved to uninfested areas by humans and animals. The increase in production of soybean in the early 1900’s meant that new land was being cultivated and equipment was towed long distances from infested fields to uninfested fields. A small amount of soil adhered to machinery, field workers shoes or animals could potentially transport thousands of cyst nematodes to an uninfested field. At the time of the nematodes greatest expansion in the US sanitation practices were not utilized as they are or should be today. Therefore, machinery and other field utensils more than likely were the greatest factor in the dispersal of this pathogen once it was established in the US. Also, Epps showed that cysts could survive passage through the intestinal tract of blackbirds and this is probably true for many bird species (Riggs et al., 2004). This could explain the nematodes dispersal along routes of migratory birds. Other modes of dispersal are windblown soils, flooded fields and movement of rain water, and contamination of soybean used for seed with infested soil from a previous harvest.

Currently soybean cyst nematode is found in all soybean producing areas in the US (Figure 1) and is the most damaging pathogen of soybean worldwide (Koenning, 2004).

Section 2. Importance of the Soybean Cyst Nematode

The soybean cyst nematode causes more yield loss of soybean than any other soybean disease (Koenning, 2006). An estimated 12.05 million metric bushels of soybean yield was lost due to the soybean cyst nematode in 2006 for 16 southern soybean producing states in the US (Koenning, 2006). In the USA crop loss assessments ranged from 5 to nearly 10% yield loss from 1996 to 2002 (Monson et al., 2004). Yield losses of 30% have been observed in Iowa fields heavily infested with SCN without any noticeable above ground symptoms, such as plant height and chlorosis, on resistant or susceptible cultivars (Niblack et al., 2004). Population densities as low as 50-100 eggs/100cm^3 can cause severe yield loss (Kraus et al., 1996). With the low input costs associated with soybean production, the increasing market price/bushel, the use of soybean in biodiesel, and the increasing demand for soybean meal world-wide, more growers are producing soybean. With this increased production comes increased disease pressure and increased population densities due to shorter rotation schedules of the soybean cyst nematode. A short life cycle of 28 days accounts for an exponential growth in SCN populations within one growing season.

While there are resistant cultivars available, all resistance in the more commonly used roudup-ready soybean comes from the same gene or parental line which limits its' use. A field population of SCN is heterogeneous with one race or HG-type (*Heterodera glycines* – type) predominating. While many of the newer soybean cultivars have resistance to some of the HG-types, no current cultivar is resistant to all HG-types. Some HG-resistant cultivars lack important agronomic qualities, the biggest being lower yield potential (Koenning, 2004).

However, the use of resistant cultivars as the sole management tactic will cause a race shift in the population by selecting for nematode populations that can overcome specific resistance genes (Young, 1984, 1992). Resistant cultivars and long-term efficacy of those cultivars are complicated by many factors that will be addressed in the management section of this paper. Although host range for the SCN is relatively narrow, it has many weed hosts that are commonly found in the United States including sickle pod (*Aeschynomene virginica*), old field toadflax (*Linaria Canadensis*), common lespedeza (*Lespediza striata*), and henbit (*Lamium amplexicanle*) (Riggs, 1977). Sowing covercrops and the use of Roundup-Ready soybean can aid in controlling cyst populations early in the growing season by keeping weed host of the SCN from emerging. Unfortunately the only Roundup-Ready cultivars currently available have the same source of resistance adapted from PI 88788.

Section 3. Management

Among the most effective form of management of *H. glycines* in soybean is rotation with non-host crops and/or resistant and susceptible cultivars. The use of conservation tillage has shown to be variable. (Koenning et al., 1995; Niblack, 1999). In an 8 yr. study performed by Koenning et al., no-till practices reduced final egg and juvenile population densities but effects on yield were maximized by a rotation with 2 yr. of corn followed by soybean. With the low value of many of the non-host crops that will fit into a cropping system growers are reluctant to use them, however, with the increased use of biofuels corn prices are increasing, making it a much more attractive non host crop. Much focus has been put on the use of nematicides and soybean cultivars that are resistant to the nematode. Many of the current nematicides are of very limited use due to the toxicity in the environment, human health concerns and increased input costs to the grower (Xiao, et al., 2008). Continuous use of a resistant cultivar can result in a change in the nematode population to the point that resistance is lost (Young, 1992). Many growers are not aware or are uneducated about the concept of a race shift and how sources of resistance should be rotated to slow this process down.

i. Chemical Control

Control of plant parasitic nematodes with nematicides has been successful in the past. In the 1940's Carter (1943) showed the benefits of managing plant parasitic nematodes in pineapple fields and vegetable crops with a mixture of 1,2-dichloropropane-1,3-dichloropropene (D-D).

Many chemical nematicides were discovered during this time period including ethylene dibromide (EDB), 1,2-dibromo-3-chloropropane (DBCP), trichlornitromethane (chlorpicrin), methyl bromide and aldicarb (Riggs et al., 1998). Many of these nematicides did not fit into the principles of sustainable agriculture because they were not rapidly biodegradable in the soil (Kraus et al., 1996). Health and environmental concerns involved in the handling and deployment of most of these effective and inexspensive nematicides have resulted in many of them being taken off of the market and many more may be lost in the near future. Aldicarb (Temik 15G, Bayer Crop Science, Research Trangle Park NC) and 1,3-dichloropropene (Telone II) have been used to lower initial population densities of plant-parasitic nematodes, however, their use is not generally recommended for control of SCN due to the costs of product and those involved with extra labor or specialized equipment unless population densities are extremely high. Aldicarb is very effective when applied properly, but its' activity is dependent on soil texture and soil moisture. Aldicarb is also rapidly degraded in the soil by many microbes. An immediate rain following application of aldicarb will cause the nematicide to be washed away from the developing root zone and thus protection to the plant is limited. Multiple application rates and times have given good control, but cannot be justified economically for use in soybean production.

Sensitivity of plant parasitic nematodes to abamectin showed that the nematodes were only temporarily paralyzed and were able to recover once removed from the nematicide treatment (Fraske, et al., 2006). Kraus et al. (1996) experimented with compounds that could stimulate or inhibit hatching of the SCN eggs. The naturally occurring root exudate Glycinoeclepin A has been isolated from kidney bean roots and is known to stimulate egg hatch. However, only milligrams of the compound could be isolated from thousands of kilograms of roots. Analogs of this compound were synthesized and it was found that many of these analogs either inhibited or stimulated egg hatch. Due to the cost of extraction methods and synthesizing of the compounds the research was abandoned (Dr. Greg Tylka, *personal communication*).

ii. Cultural Practices

Effective control of the SCN is obtained through Integrated Pest Management (IPM) practices. Essential parts of IPM are cultural practices such as rotation schedules, planting date, early maturing cultivars, blends and conservation tillage. It is considered that a small portion of the eggs in the cyst female hatch spontaneously and infect existing plant roots, a higher proportion hatch in response to environmental cues such as soil moisture and temperature and hatch the next growing season and the remaining eggs may lie dormant for years in a diapause state (Niblack). Many researchers have looked at the effects of planting date on disease caused by the SCN and found that by delaying the planting date infection rates were considerably lowered at the end of the first life cycle (28 DAP). This is due to the portion of the eggs that hatch in response to environmental cues can not find suitable host tissue and juvenile mortality is significantly decreased within 30 to 60 days after emergence. Also, the use of early maturing soybean cultivars shortens the season which does not allow SCN populations to build up by limiting the number of generations in a season and this will lower the damage potential for the subsequent crop (Koenning et al., 1996). Use of early maturing cultivars has been proposed as a management tactic for the SCN. The reasoning behind this is that earlier maturing cultivars decrease the amount of time for SCN reproduction and will lower final population densities. In a 1993 study in Southeastern Kansas, however, yield loss and population densities were not effected by planting date or maturity groups and the researchers concluded that these were not viable practices for controlling the SCN population densities in Kansas (Todd, 1993).

Seed treatments are becoming more popular due to their ease of use and low concentration of chemical used per hectare. With the lowered chemical use comes the benefit of lower control costs for the grower. Use of treated seed can reduce chemical use by 99.4% compared to aerial applications and 88% compared to a banded in-furrow treatment. Seeds are coated with a small amount of a chemical or a combination of chemicals including fungicides, insecticides and nematicides. All treated seed must also be coated with a colorant so the grower can see if a seed is treated or untreated. Once the seed is planted the chemical, either systemic or contact, should move with the root zone and give early season protection for the emerging seedling. Problems with ability of a chemical to move through the soil, high affinity for soil particles, and rapid degredation by soil microbes are limiting factors for the use of seed treatments. Use of seed treatments in cotton production against plant-parasitic nematodes have been successful in the past by reducing root galling severity against *Meloidigyne incognita* and reducing populations of *Rotylenchus reniformis*. However, the use of treated seed for control of SCN is unknown. One foreseeable complication with the efficacy of seed treatments for control of the SCN is that unhatched eggs inside the protective cuticle of the cyst respond to root exudates and hatching may not occur until the nematicide seed treatment has dissipated from the root zone. Efficacy of seed treatments may also be dependent on soil moisture and texture.

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CHAPTER 2:

Efficacy of Novel Nematicide Seed Treatments for the Control of *Heterodera glycines* in Soybean Production.

Introduction:

The most economically important pathogen to soybean (*Glycine max* [L.] Merr.) is the soybean cyst nematode (SCN), *Heterodera glycines* Ichonohie. Losses associated with the SCN from 2003 to 2005 in the United States exceeded 8.3 million metric tonnes (Wrather et al., 2006). The life cycle of the SCN can be completed in 24 to 30 days under optimum conditions. The cyst nematodes are characterized by the tanning of the female cuticle following death to encapsulate viable eggs. The cyst provides protection for the 200-400 eggs contained inside. A majority of the unhatched eggs remain in cyst until favorable conditions arise. In North Carolina early spring temperatures are adequate for the second stage juveniles (J2's) to hatch. If a suitable host is present then the J2's will penetrate near the root tip, migrate intracellularly, and establish feeding sites in or near the vascular cylinder. The most effective management practices for control of SCN are rotation with non-host crops or the use of resistant cultivars if available (Niblack et al., 1993). Repeated use of resistant cultivars with the same source of single-gene resistance can result in a change in the frequency of pathotypes (commonly referred to as a race shift) in the population rendering the resistant cultivar ineffective (Young, 1984; Schmitt, 1991; Young, 1992). The use of non-host crops in rotation is limited by the cropping system and the value of non-host crops that are available. Use of chemical control has been limited in soybean production due to the low cash value of the crop. The most cost effective chemical controls are no longer labeled for use in the US due to high mammalian toxicity and environmental concerns. Aldicarb (Temik 15G, Bayer Crop Sciences, Research Triangle Park, Raleigh NC) is a granular nematicide that can give adequate control if population densities of the SCN are low to moderate, however, it has hazards associated with handling and is restricted to certain soil types (Koenning, personal communication). Fumigant nematicides offer fair to excellent control, but require specialized equipment, extra labor costs, and performance depend on soil types and moisture. The expense associated with fumigant cost, waiting periods, and applications are considered economically restrictive in soybean production.

The use of nematicide treated seed is attractive because there are no increased costs associated with planting, there are fewer hazards associated with handling, and smaller amounts of nematicide can be used per acre. Faske and Starr (2007) investigated the efficacy of abamectin as a seed treatment against root-knot nematode (RKN), *Meloidigyne incognita*, and the reniform nematode, *Rotylenchus reniformis*, in cotton production. They found that effectiveness of the seed treatment was greatest at short taproot lengths, and that as the taproot length increased the concentration of abamectin decreased. Most of the abamectin remained on the seed coat and was not transported to the root system. In another study, severity of root galls caused by *Meloidigyne incognita* was lower with abamectin-treated seed, but population densities remained high (Phipps et al., 2006).

Imidacloprid as a seed treatment for nematode management has been used in the form of Gaucho® (Bayer Crop Sciences). When tested in combination with a band application of Temik 15G, root gall severity caused by the root knot nematode was reduced, but this was not seen when the imidacloprid seed treatment was used alone (Phipps et al., 2006).

It is unknown if nematicide seed treatment will have any effect on cyst nematodes or their damage to soybean. The objectives of the current research were to determine the efficacy of seed treatments (i) for the control of the soybean cyst nematode population densities, (ii) suppresion of root penetration, and (iii) increased yield potential.

Materials and Methods:

Section 1: Field experiments

Field plots: Locations in Hoke, Wilson, and Lenoir Counties in 2007 and Scotland, Chowan, Perquimmans, and Edgecombe Counties in 2008 that were planted in soybean the previous year were selected based on presence of SCN. Two fields in 2008 in Scotland County were heavily infested with 1300 to 5000 cysts/500cm^3 soil and a third field in Scotland County and a field in Perquimans County had levels of SCN that were at undetectable levels. Soybean cultivars in either maturity group V (SCN susceptible

Hutcheson, or resistant Fowler [resistant to races 1,2,3,5 of SCN]) or maturity group VII (SCN susceptible NC Raleigh, or resistant NK S76-L9 [resistant to races 3,14 of SCN]) were paired by maturity group within an experiment. Plots were arranged in a split plot design with resistant and susceptible cultivars as whole plots and seed treatments as sub-plots with six replications in 2007 and eight replications in 2008. Soybean seeds were treated with Avicta (abamectin) or Aeris (Imidacloprid + Thiodicarb) at three different rates by Syngenta Corporation or Bayer Crop Sciences respectively Seed treatment rates were 0.10, 0.15 and 0.2 mg ai/ seed for the abamectin treatments, 0.12, 0.24 and 0.36 mg ai/seed for the imidacloprid+thiodicarb treatments All seed treatments were compared to an untreated control and an in-furrow planting application of aldicarb at 1.17 kg ai/ha.

Plots were four rows 7.6-m long and 0.925-m row spacing with 3-m long alleys between plots. All plantings occurred in late May or early June. Soil samples for assays were obtained in a zig-zag pattern at pre-plant (Pi), and at harvest (Pf) from the middle two rows. Eight to ten 2.5-cm diam. soil cores were taken to a depth of approximately 15-cm. Soil from each plot was then bagged and labeled and placed in a cooler for transport. Samples from individual plots were thoroughly mixed and a 500-cm^3 subsample was assayed by elutriation and centrifugation methods (Byrd et al., 1976; Jenkins, 1964). Juveniles and cysts were then counted under a dissecting microscope at 100X and 40X magnification respectively. Cysts were crushed with a Tenbroeck homogenizer (Fisher Scientific, Pittsburgh PA). Eggs were collected, diluted 50X, stained and visually counted under a dissecting microscope at 40X magnification.

At 28 days after planting ($Pm_{(28\ DAP)}$) three plant root systems were taken from the middle two rows of each plot to determine cysts per root system ($Pm_{(28\ DAP)}$). Root systems were soaked in a bucket of water to release soil from the root system and then blasted under high pressure water on nested 20um over 60um sieves to release the cysts from the roots. Each sample was then examined at 40X magnification under a dissecting microscope to quantify cysts per plant. Soil from each location was assayed using a Lamotte Soil Texture Unit (Lamotte Company, Charlestown, Maryland) to determine the composition of the soils.

Plant Assessments

At selected locations in both years a measurement of plant height and canopy closure were obtained at midseason to assess phytotoxicity associated with the treatments. Three plants from the middle two rows were arbitrarily chosen as representative of the entire plot and height of the plant and width of the canopy were measured. In 2008 additional data were recorded on stand counts by selecting two 1-meter lengths in the two middle rows and counting the number of plants. Yield was determined by combining the center two rows of each plot harvested in late October or early November.

Data analysis

All data were analyzed using the PC/SAS program (SAS Institute, Cary, NC). Statistical analysis was done using the PROC GLM method for a split plot design. Nematode numbers were transformed $\log_{10}(x + 1)$ prior to analysis to standardize the variance. Nontransformed numbers are presented in tables for clarity. The Waller Duncan k-ratio *t* test (k-ratio = 50) was used for mean separation of treatments and split-factorial contrasts for treatment comparisons. A reproductive factor (Rf) was calculated for analysis using the following formula:

Rf = [(Final egg population densities)/(Initial egg population densisties)]

Section 2: Microplot and Greenhouse experiments

Microplot time-course studies: The microplot experiment was performed in 2007 at the Central Crops Research Station in Clayton, NC. Microplots were 1-m X 1-m square plots previously infested with SCN race 2. Soil was assayed by collecting 4 soil cores 2.5-cm-diam. approximately 15-cm deep. A total of 144 microplots were sampled and a 250 cm^3 subsample of soil from each plot was elutriated and centrifuged to isolate cysts from the soil (Byrd et al., 1976; Jenkins, 1964). Cysts were crushed with a Ten_broeck homogenizer (Fisher Scientific, Pittsburgh, PA). Eggs were collected, stained with acid fucshin and enumerated. Based on this data, twenty plots were selected with similar SCN population densities. Treatments of each microplot were, two rates of imidacloprid+thiodicarb treated seed,0.12 or 0.36 mg a.i./seed, two rates of abamectin treated seed,0.10 and 0.20 mg a.i./seed, and two untreated checks. All seed treatments were applied by their respective companies.

Twenty seeds of each treatment were planted in each microplot. One plant root system from each of the six treatments was removed from 10 of the plots for staining (Byrd, et al., 1983) and visually quantifying juveniles, adult males and adult females per root system at 8, 14, 21 and 28 days after planting. The remaining ten plots were left undisturbed until harvest so yield data could be obtained. Plots were irrigated as needed. Plants were harvested by hand and thrashed.

All statistics were analyzed using PC/SAS software and the PROC GLM procedure (SAS Institute, Cary, NC).

Results:

Section 1: Field experiments

Wilson County, 2007, (MG V): Cysts per plant at 28 DAP, ($Pm_{(28\ DAP)}$), were different (P = .0019) between the resistant cv. Fowler and the susceptible cv. Hutcheson. $Pm_{(28\ DAP)}$ counts were 3 cysts/plant for Fowler and 12 cysts/plant for Hutcheson (Table 2). Treatment with aldicarb did not reduce $Pm_{(28\ DAP)}$ counts. On the cv. Hutcheson, the abamectin or imidacloprid+thiodicarb treatments gave lower $Pm_{(28\ DAP)}$ counts, although differences were not significant, suggesting that the aldicarb was not able to move through the soil profile early in the season due to low moisture in the ground. Reproduction was greatest on the resistant cultivar where population densities increased by a factor of 3.49 and an increase of 2.18 was seen on the susceptible cultivar (Table 2). This data suggests that the source of resistance found in the cv. Fowler was not effective at this location. Seed treated with abamectin or imidacloprid+thiodicarb did not lower $Pm_{(28\ DAP)}$ or Pf counts at this location for either the resistant or susceptible cultivar. Yields were different between cultivars with the cv. Fowler yielding 1612.37 kg/ha compared to 1443.36 kg/ha for the cv. Hutcheson, but yield was not affected by seed treatments on either cultivar (Table 2).

Plant growth measurements were not affected by either the abamectin or imidacloprid+thiodicarb seed treatments, but plant heights were lowered with the use of in-furrow aldicarb (Table 3). A plant height of 39.37 cm was seen on the cv. Hutcheson with in-furrow aldicarb which was significantly lower ($P < .05$) than all other treatments. The plant heights for imidicloprid+thiodicarb susceptible treated seed were 47.41, 43.60, and 43.69 cm for the low, mid, and high rates respectively. The abamectin-treated Hutcheson seed had plant heights of 43.18, 45.72, and 44.87 cm for the low, mid, and high rates respectively with a plant height of 44.03 cm for the susceptible untreated control. This effect was also seen on the cv. Fowler ($P < .06$). Canopy closure was not affected by any of the seed treatments (Table 3).

Lenoir County*, 2007, (MG V)*: This location was a loamy soil populated with race 5 SCN (Table 1). Mean $Pm_{(28\ DAP)}$ differed ($P = .0003$) by cultivar with 1 cyst/plant on the cv. Fowler and 5 cysts/plant on cv. Hutcheson (Table 2). Treatment contrasts showed that the aldicarb treatment lowered $Pm_{(28\ DAP)}$ counts by 2 cysts/plant vs. the imidacloprid+thiodicarb treatments ($P = .0807$) and 8 cysts/plant vs. the untreated control ($P = .0686$). Plant height was affected by cultivar with cv. Fowler (84.36 cm) being greater ($P = .0119$) than cv. Hutcheson (80.96 cm) (Table 3). Imidacloprid+thiodicarb reduced canopy closure by 10% campared to abamectin treated seed and 4% compared to aldicarb. This was likely due to the higher $Pm_{(28\ DAP)}$ counts seen on the imidacloprid+thiodicarb treatments and not phytotoxic effects. Reproduction was least ($P = .0220$) on the cv. Fowler where mean population densities increased by a factor of 1.10 compared to and increase of 4.50 on the cv. Hutcheson. A 24% increase was also seen in yield with the cv. Fowler. Fowler yielded 1644.86 kg/ha and Hutcheson yielded 1252.59 kg/ha (Table 2). There were no effects on individual cultivars by the seed treatments.

Scotland County, 2008, MG V: This site had the highest Pi of any of the sites tested (Table 1). Race 1 SCN population densities for the field were 5,146 eggs/500 cm^3 soil at planting. Main effects were determined by cultivar selection. $Pm_{(28\ DAP)}$ counts differed ($P =$

.0004) between cultivars with 1 cyst/plant seen on the cv. Fowler and 15 cysts/plant on the cv. Hutcheson. On the cv. Hutcheson, the imidacloprid+thiodicarb treated seed had greater (P = .0983) $Pm_{(28\ DAP)}$ counts than the aldicarb treatment where there were 13, 15, and 24 cysts/plant for the low, mid, and high rates compared to 2 cysts/plant for the aldicarb treatment. Other $Pm_{(28\ DAP)}$ counts were 9, 13, and 25 cysts/plant for the low, mid, and high rates of abamectin treated seed and 20 cysts/plant on the untreated control. Pf was also different (P < .0001) between cultivars with 1,909 eggs/500 cm^3 soil and 22,894 eggs/500 cm^3 soil for Fowler and Hutcheson respectively (Table 2). However, reproduction was least on the untreated control for the cv. Hutcheson. This suggests that seed treatments were uneffective on the susceptible cultivar at this location. Rf for the untreated control was 3.83 and differed (P = .0861) compared to the imidacloprid+thiodicarb treated seed with Rf's of 11.50, 15.51, and 16.95 for the low, mid and high rates respectively. The use of abamectin increased stand counts (P = .0031, .0161, .0037) on Fowler and Hutcheson compared to aldicarb, imidicloprid+thiodicarb, and the untreated control (Table 2). Percent stand for the abamectin treated seed were 98% for the low rate, and 100% for the mid rate and high rate of treatment compared to 84% for aldicarb, 84% for the untreated control, and 91, 82, and 98% for the low, mid and high rate of imidacloprid+thiodicarb treatments (Table 3). This data suggests that the abamectin gave early (< 5 days) protection for the root system, although, this did not affect yield where the untreated control yielded the highest with 4143.26 kg/ha. The increased stand count seen with the abamectin treatments would however support higher populations of SCN throughout the season which could have been the factor for yield increases not being seen. Plant height and canopy closure were affected only by cultivar selection and not treatments.

Scotland County, 2008, MG VII: The second Scotland County location was in the same field as the previous one with the only difference being in cultivar maturity groups (MG). At this location the two cultivars were NKS76-L9 (SCN resistant race 3, 9, and14) and NC Raleigh (SCN susceptible). Mean initial population densities were 1,310 eggs/500 cm^3 soil. $Pm_{(28\ DAP)}$ counts differed (P = 0.0692) among treatments (Table 1). The highest $Pm_{(28\ DAP)}$, 17 cysts/plant, was seen on the imidacloprid+thiodicarb low rate treatment followed by the high rate imidacloprid+thiodicarb treatment with 13 cysts/plant, the mid and high rate abamectin treatments had 10 cysts/plant which were significantly different from the 7 cysts/plant seen on the low rate abamectin treatment, 8 cysts/plant on the mid rate imidacloprid+thiodicarb treatment, 5 cysts/plant on the untreated control and 4 cysts/plant with the in-furrow aldicarb (Table 2). The resistance in cv. NKS76-L9 was ineffective at this location since the SCN population was primarily composed of race 1 SCN, therefore no differences were seen in the $Pm_{(28\ DAP)}$ counts between cultivars. However, final population densities were different (P = 0.0593) for cv. NC Raleigh with the high rate of abamectin treated seed having a Pf of 12,950 eggs/500 cm^3 soil followed by the low and mid rates of abamectin treated seed with 8,188 and 5,938 eggs/500 cm^3 soil compared to 4,388 eggs/500 cm^3 soil for the untreated control, and 4700 eggs/500 cm^3 soil with the aldicarb. The lowest Pf was seen with the imidacloprid+thiodicarb mid rate treatment with 3,688 eggs/500 cm^3 soil. Yields were different between cultivars but not treatments (Table 2). NC Raleigh gave a 11% increase in yields over cv. NKS76-L9. This data suggests that cv. NC Raleigh was tolerant since SCN population densities were equivalent for both NC Raleigh and NKS76-L9 at this location and the 2007 location and yields were significantly higher for the cv. NC Raleigh at both locations. The $Pm_{(28\ DAP)}$ counts were also equivalent at both locations suggesting that the NKS76-L9 was moderately susceptible to the SCN populations present at these locations. No plant growth measurements were taken at this location.

Chowan County, 2008, MG V: The Chowan County location was an Augusta Fine Sandy Loam infested with a population of SCN Race 2. Mean Pi for the field was 930 eggs/500 cm^3 soil (Table 1). $Pm_{(28\ DAP)}$ counts were not different between cultivars which suggests that the source of resistance in the cv. Fowler was not effective to the SCN Race 2 population in the field. However, Pf counts were different (P = 0.0063) between cv. Fowler and Hutcheson with 6,597 and 12,826 eggs/500 cm^3 soil respectively. Although Fowler had a higher mean yield than Hutcheson, 2091.36 kg/ha compared to 1944.68 kg/ha, it was not significantly different (Table 2).

On cv. Hutcheson $Pm_{(28\ DAP)}$ counts were lower for the the aldicarb (*P* = .0778) and imidacloprid+thiodicarb (*P* = .0155) treatments when compared to the abamectin treatment. There was 1 cyst/plant for the aldicarb treatment and all rates of the imidacloprid+thiodicarb treatments and 8, 2, and 3 cysts/plant for the low, mid, and high rates of abamectin, but Pf's were not different probably due to limited reproduction on abamectin treated seed because of extensive root damage from the higher $Pm_{(28\ DAP)}$ counts.

Reproduction on cv. Fowler was lowered (*P* = 0 .0619) with the use imidacloprid+thiodicarb compared to the untreated control. A Rf of 26.92 was seen on the untreated control which again is a result of the ineffective resistance by Fowler to this SCN population. Rf for the imidacloprid+thiodicarb treatment still increased by a factor of 10 for the low rate, and 8 for the mid and high rates. No plant growth measurements were taken at this location.

Scotland County, 2008, MG V: There was a third location in Scotland County in 2008 which had undetectable levels of the SCN. Soil samples were taken and evaluated at this location at pre- and post-harvest and no SCN were detected. $Pm_{(28\ DAP)}$ samples were also taken at this location and no cysts were found. Plant growth measurements, however, were taken including stand count, plant height, canopy closure as well as yield.

Differences were seen only between cultivars for plant height and yield. Cultivar Fowler had an increased plant height (*P* = .0207) of 40.74 cm compared to 39.64 cm for Hutcheson (Table 3). Fowler also yielded more (*P* = .0446) with 3316.18 kg/ha and 3091.43 kg/ha for Hutcheson. No effects were seen with different treatments (Table 2).

Perquimans County, 2008, MG VII: SCN populations were below threshold levels at this location which had a Tomotley fine sandy loam (Table 1). The only data collected at this were stand count, plant height, canopy closure and yield. Stand count was improved with the use of abamectin treated seed compared to aldicarb and imidacloprid+thiodicarb, but stand counts were above 92% for all treatments (Table 3). A yield increase was seen with the use of imidicloprid+thiodicarb compared to abamectin treated seed (*P* = .0635) and in-furrow application of aldicarb (*P* = .0149). Imidacloprid+thiodicarb treatments increased yields by

733.66 kg/ha compared to abamectin treatments and 456.63 kg/ha compared to aldicarb (Table 2).

Canopy closure on cv. NKS76-L9 was greatest with the use of in-furrow aldicarb. Percent canopy closure was 34% for the aldicarb treatment compared to 29% for the high rate of imidacloprid+thiodicarb treatment and 33% for the mid rate of abamectin treatment. The untreated control had a 30% canopy closure (Table 3).

The only effect evident for cv. NC Raleigh was seen with yield. Use of imidacloprid+thiodicarb gave the highest yields of 2707.25, 2377.75, and 2538.43 kg/ha for the low, mid, and high rates of treatment respectively (Table 2). Yields for the abamectin treated seed were 22% lower than that of the imidacloprid+thiodicarb treated seed.

Section 2: Microplot and Greenhouse experiments

Microplot Experiments

The first plants were removed at 8 DAP with J2's per root system ranging from 71 to 40 (Table 5) The highest rate of the abamectin treatment had the largest infection rate at 71 J2's/plant followed by the low rate of imidicloprid+thiodicarb with 65 J2's/plant. The high rate of imidicloprid+thiodicarb had the lowest infection rate with 40 J2's/plant. None of the treatment means were significantly different from each other under the ANOVA test with alpha=50. At 14 DAP all treatments had lower J2 infection rates than at 8 DAP with abamectin high rate having the largest number of infections at 39 J2's/plant and 86 developing cysts/plant which was significantly different where P = 0.0693 and 0.0419 respectively (Table 5). The high rate of imidicloprid+thiodicarb was not significantly different from the abamectin treatment for numbers of developing cysts/plant at 14 DAP. The low rate of abamectin had the lowest number of both J2's and developing cysts/plant at 10 and 31 respectively. At 21 DAP the high rate of abamectin had the largest number of infections/plant with a total of 123 J2's and cysts/plant. Again the lowest infection rate at 21 DAP was the low rate of abamectin with 52 J2's and cysts/plant. There were 80 and 59 J2's and cysts/plant for the high rate and low rate of imidicloprid+thiodicarb respectively. By 28 DAP secondary infections were occurring.

Cyst/root system ranged from 4 to 1 with the untreated check having the highest number of cysts and the low rate of abamectin having the lowest number of cysts. J2's/root system ranged from 86 J2's/plant for the high rate of imidicloprid+thiodicarb and 52 J2's/plant for the low rate of abamectin. No significant differences were seen past 14 DAP. Yield data for the treatments were not significantly different at the end of the season on the 10 microplots that were left undisturbed. The highest yield was for the high rate of imidicloprid+thiodicarb with 29.1 bu/acre followed by the untreated check with 26.3 bu/acre and the low rate of imidicloprid+thiodicarb with 25.4 bu/acre. The highest rate of abamectin treatment yielded 23.5 bu/acre and 19.7 bu/acre for the low rate of abamectin treatment (Table 5).

Conclusions:

Field Studies:

Increasing awareness of damage caused by the SCN has prompted investigators to look at several different management strategies over the years. While crop rotation is the most effective management practice (Koenning et al., 1995) it is not always used due to market prices of non-host crops or poor agronomic qualities of resistant cultivars such as yield. The use of nematicides to control SCN, while they may be effective are not registered for soybean or are not economical. Due to environmental concerns and worker welfare their use is avoided when possible. Applying pesticides as a seed treatment has become a popular area of research because of the lowered risks and hazards associated with the handling and implementation associated with its use and its economic feasibility.

Initial population densities of the soybean cyst nematode in the field studies ranged from low (275 eggs/500cm^3 soil) at the Chowan County location to high densities (4663 eggs/500cm^3 soil) at the Scotland County location. Oddly enough the highest yields were seen at the Scotland County location which is more than likely due to soil nutrients and environmental conditions at that location since the seed treatments did not lower infection rates or increase yield on the susceptible cultivars. $Pm_{(28\ DAP)}$ were not lowered with any of the rates of abamectin or imidacloprid+thiodicarb on any of the cultivars with the exception of the cv. NK S76-L9 at the Scotland County location, suggesting that the seed treatments were either not effective against the SCN or did not move with the root system in order to give adequate protection. Poor mobility of the seed treatments may be due to the chemical affinity to organic material in the soil or low soil moisture at planting time. At the Lenoir County location increasing rates of abamectin and imidacloprid+thiodicarb gave increasing yields on the cv. Fowler, and abamectin on the cv. Hutcheson. Other locations where similar results were seen were in Scotland County for both abamectin and imidacloprid+thiodicarb on the cv. Hutcheson, Scotland County for imidacloprid+thiodicarb on both the cv. NC Raleigh and NK S76-L9 and abamectin on cv. NC Raleigh. However, the only significant difference was seen at the Scotland County location with the abamectin treatment on the cv. NC Raleigh where increasing rates also gave increasing $Pm_{(28\ DAP)}$ values which leads to possible host tolerance being responsible for maintaining yield since the low and mid rates were not significantly different from the untreated control with respect to yield or $Pm_{(28\ DAP)}$ values. Reproduction was only affected at the Chowan County location with increasing rates of abamectin on the cv. Hutcheson, but the treatment with the lowest Rf also had the highest Pi which limited proportional increase for that treatment and population densities still increased by a factor of 4.60.

Use of seed treatments for control of plant-parasitic nematodes is a novel idea, however, as seen with many studies in different cropping systems there is a lot of variability and inconsistencies associated with their use. Future work should focus on the soil environment and how it affects the efficacy of these nematicide seed treatments. Possibilities are that these seed treatments may be beneficial for certain regions and soil types or under controlled conditions such as irrigated fields. Our current research suggests that host status is the most influential effect on the SCN and that the seed treatments are either short lived in the soil or are not moving with the root system. Rapid germination seen in soybean can push the seed coat out of the soil in as little as 72 hours after planting as was seen in greenhouse and microplot studies. A majority of the seed treatment was left on the seed coat where the chemicals could have been degraded by ultra-violet rays from the sun.

Microplot studies:

In microplot and greenhouse studies that were performed data suggested that there were minimal advantages associated with the use of abamectin or imidicloprid+thiodicarb as a seed treatment for the management of SCN. While yield was increased with the highest rates of abamectin or imidicloprid+thiodicarb when compared to the lower rates of each nematicide, the increase was not significantly different compared to the untreated control. Soil physical and chemical properties as well as soil moisture must be factors driving the effectiveness of these seed treatments as well as other chemical treatments.

Although abamectin seed treatments have shown to be effective in cotton production (Phipps et. al., 2006; Faske et al., 2007), our current research has not shown any benefits for soybean production and control of the SCN. Hatching of SCN occurs in three different ways; (i) approximately 1/3 of the eggs hatch in response to environmental changes in soil temperature and moisture, (ii) 1/3 hatch due to chemical cues of root exudates, and (iii) the remainder may lie dormant for an extended period of time. We hypothesize that many of the eggs may not hatch until after the seed treatment has diffused away from the infection zone. An alternative explanation is that due to the rapid germination of soybean under specific moisture conditions the seed treatment will get pushed out of the soil on the seed coat placing the chemical outside of the infection court.

Future work in this area will need to be studied with infection by freshly-hatched J2's to observe the toxicity against unprotected cyst nematode juveniles. More work should also be done to obtain data on the effects of differing soil types and moisture. We can only speculate that soybean seed treatment for SCN management will only work in a specific market and results across regions could only give inconsistent results.

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Table 1: Location, year, soil type, maturity group (MG), *Heterodera glycines* race, planting date, cultivar, eggs/500 cm^3 soil preplant (Pi) and standard deviation (SD) of the mean density.

Location	Year	Soil Type	MG	Race	Planting Date	Pi	SD
Wilson	2007	Norfolk Loamy Sand	V	4	May 21,2007	1176	1184
Lenoir	2007	Portsmouth Loam	V	5	May 16,2007	3423	4833
Chowan	2008	Augusta Fine Sandy Loam	V	2	May 30, 2008	930	873
Scotland	2008	Noboco Loamy Sand	V	2	June 16, 2008	5146	5746
Scotland	2008	Noboco Loamy Sand	VII	1	June 16, 2008	1310	1976
Scotland	2008	Norfolk Loamy Sand	V	NA	June 17, 2008	nd[a]	nd
Perquimans	2008	Tomotley Fine Sandy Loam	VII	NA	June 18, 2008	nd	nd

[a]nd = none detected at pre-plant sampling date.

Table 2: Location, treatment, cultivar, rate, female cysts/plant 28 DAP ($Pm_{(28\ DAP)}$), eggs/500 cm^3 soil at harvest (Pf), reproductive factor (Rf), Yield (kg/ha), and standard deviation (SD) of the mean.

Location	Treatment	Cultivar	Rate	$Pm_{(28\ DAP)}$	Pf	Rf	Yield (kg/ha)
Wilson	Avicta	Fowler	0.00	2a	1183 a	1.31 a	1587 ab[x]
			0.10	2a	900 a	3.23 a	1809 a
			0.15	2a	800 a	2.38 a	1500 b
			0.20	4a	1167 a	2.30 a	1638 ab
			Pr > F	**0.8318**	**0.9712**	**0.5461**	**0.1172**
	Aeris	Fowler	0.00	2a	1183 a	1.31a	1587 a
			0.12	3a	1100a	2.68a	1673 a
			0.24	3a	750a	2.64a	1551 a
			0.36	3a	950a	2.05a	1538 a
			Pr > F	**0.9883**	**0.7007**	**0.5183**	**0.5426**
	Avicta	Huctheson	0.00	13 a	450 b	1.04 a	1383 a
			0.10	13 a	933 ab	1.03 a	1424 a
			0.15	15 a	650 b	1.08 a	1489 a
			0.20	16 a	1383 a	2.20 a	1356 a
			Pr > F	**0.9631**	**0.0632**	**0.3135**	**0.7187**
	Aeris	Hutcheson	0.00	13 a	450 b	1.04 a	1383 a
			0.12	13 a	850 ab	3.12 a	1538 a
			0.24	11a	1100 a	4.53 a	1435 a
			0.36	8a	580 b	0.67 a	1552 a
			Pr > F	**0.8482**	**0.0795**	**0.2383**	**0.3812**
Lenoir	Avicta	Fowler	0.00	0.94a	1000a	2.57ab	1560 a
			0.10	0.17b	433a	0.57b	1391 a
			0.15	0.60ab	1380a	3.56a	1650 a
			0.20	0.22b	683a	0.68b	1711 a
			Pr > F	**0.0493**	**0.2122**	**0.0881**	**0.4264**
	Aeris	Fowler	0.00	1a	1000a	2.57a	1559 a
			0.12	2a	583a	3.82a	1600 a
			0.24	1a	433a	1.24a	1641 a
			0.36	0a	633a	1.74a	1947 a
			Pr > F	**0.4083**	**0.9074**	**0.7202**	**0.5162**
	Avicta	Hutcheson	0.00	7a	3050a	2.29a	1307 a
			0.10	9a	3117a	2.08a	1199 a
			0.15	5a	1567a	5.25a	1207 a
			0.20	3a	1740a	3.22a	1351 a
			Pr > F	**0.2435**	**0.9731**	**0.7157**	**0.8451**
	Aeris	Hutcheson	0.00	7a	3050a	2.29a	1307 a
			0.12	6a	3150a	5.49a	1096 a
			0.24	4a	3917a	7.13a	1337 a
			0.36	7a	1983a	3.80a	1210 a
			Pr > F	**0.8413**	**0.8276**	**0.3357**	**0.5479**

Table 2: Continued.

Chowan	Avicta	Fowler	0.00	0.38a	4186a	26.92a	2024 a
			0.10	0.10a	3113a	6.76a	2063 a
			0.15	2.79a	2900a	8.38a	2276 a
			0.20	2.38a	7625a	25.19a	2053 a
			Pr > F	**0.3344**	**0.1639**	**0.4878**	**0.3063**
	Aeris	Fowler	0.00	0.38a	4186a	26.92a	2024 a
			0.12	3.89a	1700a	2.34a	2115 a
			0.24	5.13a	3813a	5.78a	1983 a
			0.36	0.96a	2388a	9.55a	2182 a
			Pr > F	**0.6391**	**0.4151**	**0.5082**	**0.6995**
	Avicta	Hucheson	0.00	3a	8813a	24.11a	1770 a
			0.10	8a	10286a	25.35a	1696 a
			0.15	2a	3175a	9.48ab	2133 a
			0.20	3a	3600a	4.60b	1897 a
			Pr > F	**0.3570**	**0.1291**	**0.0669**	**0.3186**
	Aeris	Hucheson	0.00	3.13a	8813a	24.11a	1770 a
			0.12	1.00a	6300a	20.17a	2072 a
			0.24	1.21a	3088a	14.00a	2019 a
			0.36	0.79a	11275a	37.84a	2006 a
			Pr > F	**0.5568**	**0.2219**	**0.4107**	**0.7609**
Scotland	Avicta	Fowler	0.00	0.38a	688a	1.37a	4143 a
			0.10	6.33a	1513a	2.26a	4088 a
			0.15	0.33a	2425a	2.90a	3584 b
			0.20	0.38a	975a	1.03a	3785 b
			Pr > F	**0.4472**	**0.3775**	**0.7297**	**0.0060**
	Aeris	Fowler	0.00	0.38a	688a	1.37ab	4143 a
			0.12	0.52a	950a	3.49a	3879 b
			0.24	0.29a	288a	0.24b	3861 b
			0.36	0.38a	425a	0.15b	3771 b
			Pr > F	**0.9578**	**0.3952**	**0.1529**	**0.0463**
	Avicta	Hucheson	0.00	16ab	7171a	3.83b	3480 a
			0.10	9b	12463a	9.60ab	3413 a
			0.15	13b	13250a	13.62a	3582 a
			0.20	25a	13575a	5.05b	3590 a
			Pr > F	**0.0314**	**0.3968**	**0.1103**	**0.8049**
	Aeris	Hutcheson	0.00	16a	7171a	3.83a	3480 a
			0.12	13a	16638a	11.50a	3364a
			0.24	15a	7488a	15.51a	3606a
			0.36	12a	7586a	16.95a	3743a
			Pr > F	**0.9854**	**0.1267**	**0.4564**	**0.4095**
Scotland	Avicta	NC-Raleigh	0.00	7ab	4388a	18.52a	3887c
			0.10	3b	8188a	14.14a	3700c
			0.15	8ab	5938a	8.00a	4221b
			0.20	14a	12950a	19.88a	4359a
			Pr > F	**0.1282**	**0.6792**	**0.7758**	**0.0370**

Table 2: Continued.

	Aeris	NC-Raleigh	0.00	7a	4388a	18.52a	3887a
			0.12	21a	4629a	11.10a	3677a
			0.24	9a	3688a	14.37a	3898a
			0.36	14a	5400a	7.01a	4170a
			Pr > F	**0.3527**	**0.9675**	**0.6961**	**0.4495**
	Avicta	NK S76-L9	0.00	3b	5613a	27.03a	3570a
			0.10	10ab	4788a	7.05a	3543a
			0.15	12a	5550a	6.06a	3726a
			0.20	3b	2983a	25.21a	3642a
			Pr > F	**0.0914**	**0.8105**	**0.4564**	**0.7991**
	Aeris	NK S76-L9	0.00	3a	5613b	27.03a	3570a
			0.12	15a	1988b	5.20a	3472a
			0.24	6a	6775ab	11.97a	3519a
			0.36	15a	14400a	19.36a	3529a
			Pr > F	**0.2858**	**0.0860**	**0.4912**	**0.9756**
Scotland	Avicta	Fowler	0.00	-	-	-	3136a
			0.10	-	-	-	3517a
			0.15	-	-	-	3191a
			0.20	-	-	-	3431a
			Pr > F	**NA**	**NA**	**NA**	**0.3271**
	Aeris	Fowler	0.00	-	-	-	3136b
			0.12	-	-	-	3299ab
			0.24	-	-	-	3063b
			0.36	-	-	-	3664a
			Pr > F	**NA**	**NA**	**NA**	**0.0413**
	Avicta	Hucheson	0.00	-	-	-	3160a
			0.10	-	-	-	2693a
			0.15	-	-	-	3089a
			0.20	-	-	-	3173a
			Pr > F	**NA**	**NA**	**NA**	**0.8228**
	Aeris	Hutcheson	0.00	-	-	-	3160a
			0.12	-	-	-	3258a
			0.24	-	-	-	3085a
			0.36	-	-	-	2936a
			Pr > F	**NA**	**NA**	**NA**	**0.4344**
Perquimans	Avicta	NC-Raleigh	0.00	-	-	-	2197a
			0.10	-	-	-	2058a
			0.15	-	-	-	2180a
			0.20	-	-	-	2025a
			Pr > F	**NA**	**NA**	**NA**	**0.9305**
	Aeris	NC-Raleigh	0.00	-	-	-	2197a
			0.12	-	-	-	2712a
			0.24	-	-	-	2382a
			0.36	-	-	-	2543a
			Pr > F	**NA**	**NA**	**NA**	**0.4100**

Table 2: Continued.

	Avicta	NK S76-L9	0.00	-	-	-	2052a
			0.10	-	-	-	2027a
			0.15	-	-	-	2202a
			0.20	-	-	-	2286a
			Pr > F	**NA**	**NA**	**NA**	**0.7407**
	Aeris	NK S76-L9	0.00	-	-	-	2052b
			0.12	-	-	-	1981b
			0.24	-	-	-	2010b
			0.36	-	-	-	2631a
			Pr > F	**NA**	**NA**	**NA**	**0.0903**

x: Values followed by the same letter are not significantly different.

Table 3: Measurement of plant growth factors by location, treatment, cultivar, rate, plant height in cm, % canopy closure, % stand count.

Location	Treatment	Cultivar	Rate	Plant Height (cm)	Canopy Closure (%)	Stand Count (%)
Wilson	Abamectin	Fowler	0.00	46.14	50	nt[a]
			0.10	49.53	50	nt
			0.15	43.18	47	nt
			0.20	44.45	47	nt
			Pr>F	**0.1985**	**0.3860**	
	Imidacloprid+ thiodicarb	Fowler	0.00	46.14	50	nt
			0.12	41.15	48	nt
			0.24	45.30	49	nt
			0.36	44.45	41	nt
			Pr>F	**0.2070**	**0.1964**	
	Abamectin	Huctheson	0.00	44.03	47	nt
			0.10	43.18	49	nt
			0.15	45.72	49	nt
			0.20	44.87	47	nt
			Pr>F	**0.5880**	**0.7182**	
	Imidacloprid+ thiodicarb	Hutcheson	0.00	44.03	47	nt
			0.12	47.41	49	nt
			0.24	43.60	47	nt
			0.36	43.69	49	nt
			Pr>F	**0.2061**	**0.8660**	
Lenoir	Abamectin	Fowler	0.00	83.40	85	nt
			0.10	83.82	86	nt
			0.15	87.88	90	nt
			0.20	86.78	87	nt
			Pr>F	**0.4320**	**0.7516**	
	Imidacloprid+ thiodicarb	Fowler	0.00	83.40	85	nt
			0.12	81.28	81	nt
			0.24	81.28	82	nt
			0.36	85.51	88	nt
			Pr>F	**0.6547**	**0.0678**	
	Abamectin	Hutcheson	0.00	81.70	83	nt
			0.10	78.74	85	nt
			0.15	80.43	88	nt
			0.20	81.28	84	nt
			Pr>F	**0.6918**	**0.8089**	
	Imidacloprid+ thiodicarb	Hutcheson	0.00	81.70	83	nt
			0.12	80.86	84	nt

Table 3: Continued

			0.24	81.70	79	nt
			0.36	79.16	86	nt
			Pr>F	**0.8777**	**0.6337**	
Scotland	Abamectin	Fowler	0.00	43.82	63ab	99
			0.10	44.04	60b	100
			0.15	45.09	62b	100
			0.20	46.86	66a	100
			Pr>F	**0.0476**	**0.0200**	**ns**[b]
	Imidacloprid+ thiodicarb	Fowler	0.00	43.82	63	99
			0.12	43.05	62	100
			0.24	44.83	61	97
			0.36	44.20	61	100
			Pr>F	**0.5455**	**0.6640**	**ns**
	Abamectin	Hucheson	0.00	42.56	60	100
			0.10	40.42	58	100
			0.15	42.61	61	100
			0.20	41.53	59	100
			Pr>F	**0.3332**	**0.3332**	**ns**
	Imidacloprid+ thiodicarb	Hutcheson	0.00	42.56	60	100
			0.12	40.29	59	100
			0.24	42.48	59	100
			0.36	42.82	60	100
			Pr>F	**0.5314**	**0.9475**	**ns**
Scotland	Abamectin	Fowler	0.00	16.18	21	100
			0.10	16.25	21	100
			0.15	15.68	20	100
			0.20	16.11	21	100
			Pr>F	**0.5383**	**0.4664**	**ns**
	Imidacloprid+ thiodicarb	Fowler	0.00	16.18	21	100
			0.12	16.16	20	100
			0.24	15.41	20	100
			0.36	16.54	22	100
			Pr>F	**0.2807**	**0.3994**	**ns**
	Abamectin	Hucheson	0.00	15.23	20	100
			0.10	15.39	20	100
			0.15	15.70	21	100
			0.20	16.18	21	100
			Pr>F	**0.1771**	**0.9324**	**ns**
	Imidacloprid+ thiodicarb	Hutcheson	0.00	15.23	20	100
			0.12	15.59	20	100
			0.24	16.08	21	100
			0.36	15.11	19	100

Table 3: Continued.

			Pr>F	**0.4579**	**0.3014**	**ns**
Perquimans	Abamectin	NC-Raleigh	0.00	9.50	12	99
			0.10	9.95	13	100
			0.15	9.33	12	95
			0.20	9.57	12	100
			Pr>F	**0.9179**	**0.6927**	**ns**
	Imidacloprid+ thiodicarb	NC-Raleigh	0.00	9.50	12	99
			0.12	10.08	13	100
			0.24	9.67	12	100
			0.36	9.14	11	98
			Pr>F	**0.6415**	**0.3789**	**ns**
	Abamectin	NK S76-L9	0.00	8.50	11	98
			0.10	8.48	11	100
			0.15	9.12	12	100
			0.20	8.34	10	100
			Pr>F	**0.3842**	**0.1502**	**ns**
	Imidacloprid+ thiodicarb	NK S76-L9	0.00	8.50	11	98
			0.12	8.09	10	83
			0.24	8.24	10	94
			0.36	8.67	11	95
			Pr>F	**0.8591**	**0.8424**	**ns**

[a] nt = data not taken in 2007.
[b] ns = No significant differences.

Table 4: Anova table for 2007 and 2008 fields giving p-values for number of female cysts per root system, yield (kg/ha), and reproductive factors.

Anova table with p-values for number of female cysts per plant at 28 days after planting, Yield, and Reproductive Factors.

			Female Cysts per root system			Yield			Reproductive Factor		
Location	**Year**	**Maturity Group**	**Rep**	**Cultivar**	**Treatment**	**Rep**	**Cultivar**	**Treatment**	**Rep**	**Cultivar**	**Treatment**
Wilson	2007	V	0.4085	<.0001	0.7457	<.0001	0.0003	0.4755	0.6883	0.0818	0.4574
Lenoir	2007	V	0.5974	<.0001	0.2456	0.2999	<.0001	0.7139	0.0051	0.0002	0.1633
Scotland	2008	V	0.3597	<.0001	0.6001	0.0354	<.0001	0.7119	0.2553	<.0001	0.6316
Scotland	2008	VII	0.0149	0.8423	0.0692	0.7543	<.0001	0.0925	0.5290	0.8994	0.3909
Chowan	2008	V	0.0015	0.6400	0.7498	0.0070	0.0703	0.5826	0.0346	0.0680	0.6047

Table 5: Number of Second Stage Juvenile infections per root system at 8, 14, 21, and 28 DAP and Yield.

Treatment (mg a.i./seed)	Number of second stage juveniles at 8, 14, 21, and 28 DAP				
	8 DAP	**14 DAP**	**21 DAP**	**28 DAP**	**Yield (bu/acre)**
Untreated Contol	53.25 a	18.85 b	65.74 a	56.42 a	29.56 a
Thiodicarb 0.12	65.13 a	19.50 b	55.38 a	70.88 a	28.51 a
Thiodicarb 0.36	39.5 a	18.90 b	77.80 a	85.80 a	32.71 a
Abamectin 0.10	42.1 a	10.40 b	44.90 a	52.10 a	22.21 a
Abamectin 0.20	70.7 a	39.30 a	116.70 a	67.70 a	26.41 a
p-val	**0.5633**	**0.0693**	**0.4741**	**0.8247**	0.8669

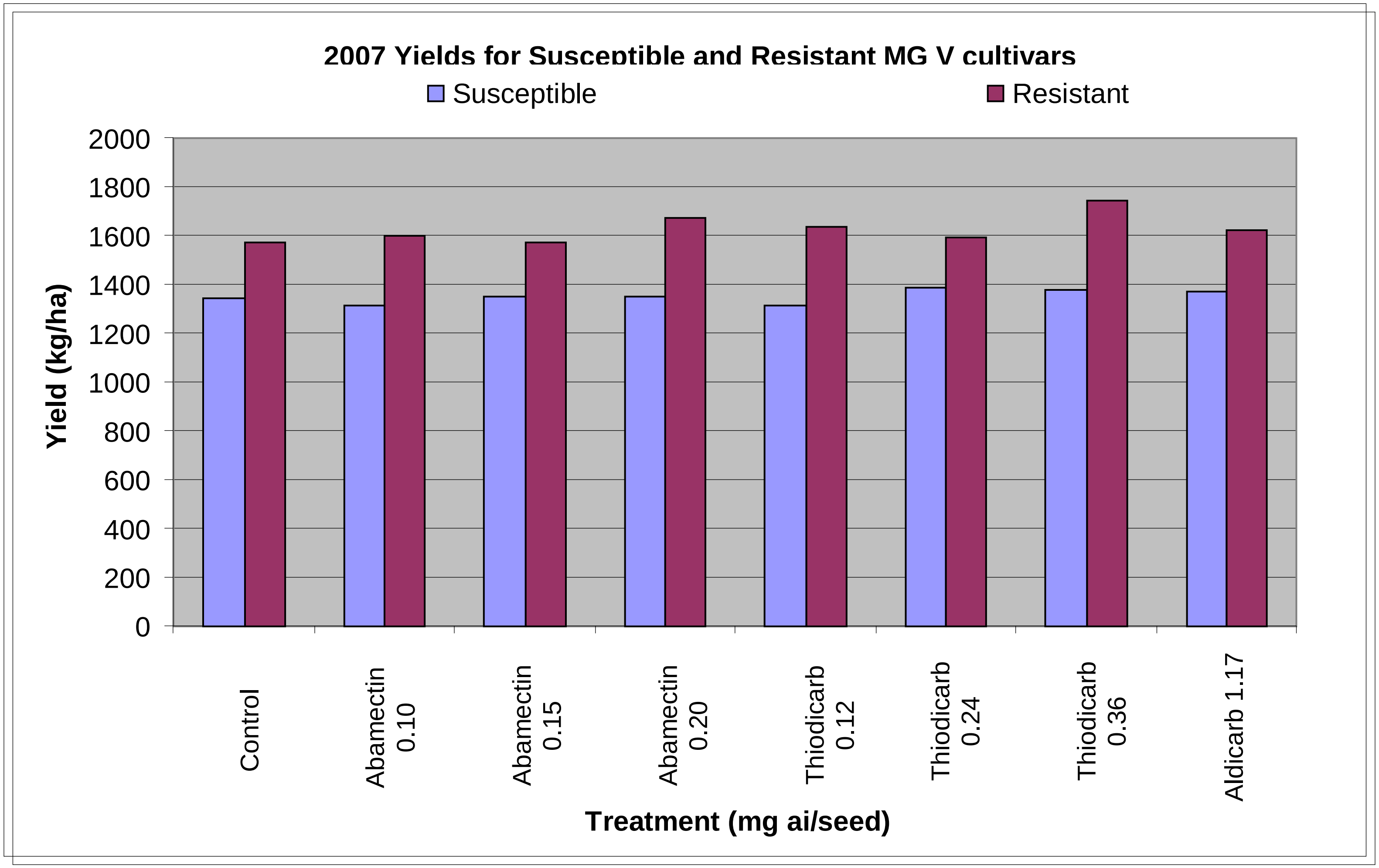

Figure 1: Yield in kg/ha for seed treatments on Maturity Group V Soybean in 2007 on Susceptible and Resistant cultivars in the Lenoir and Wilson County locations combined.

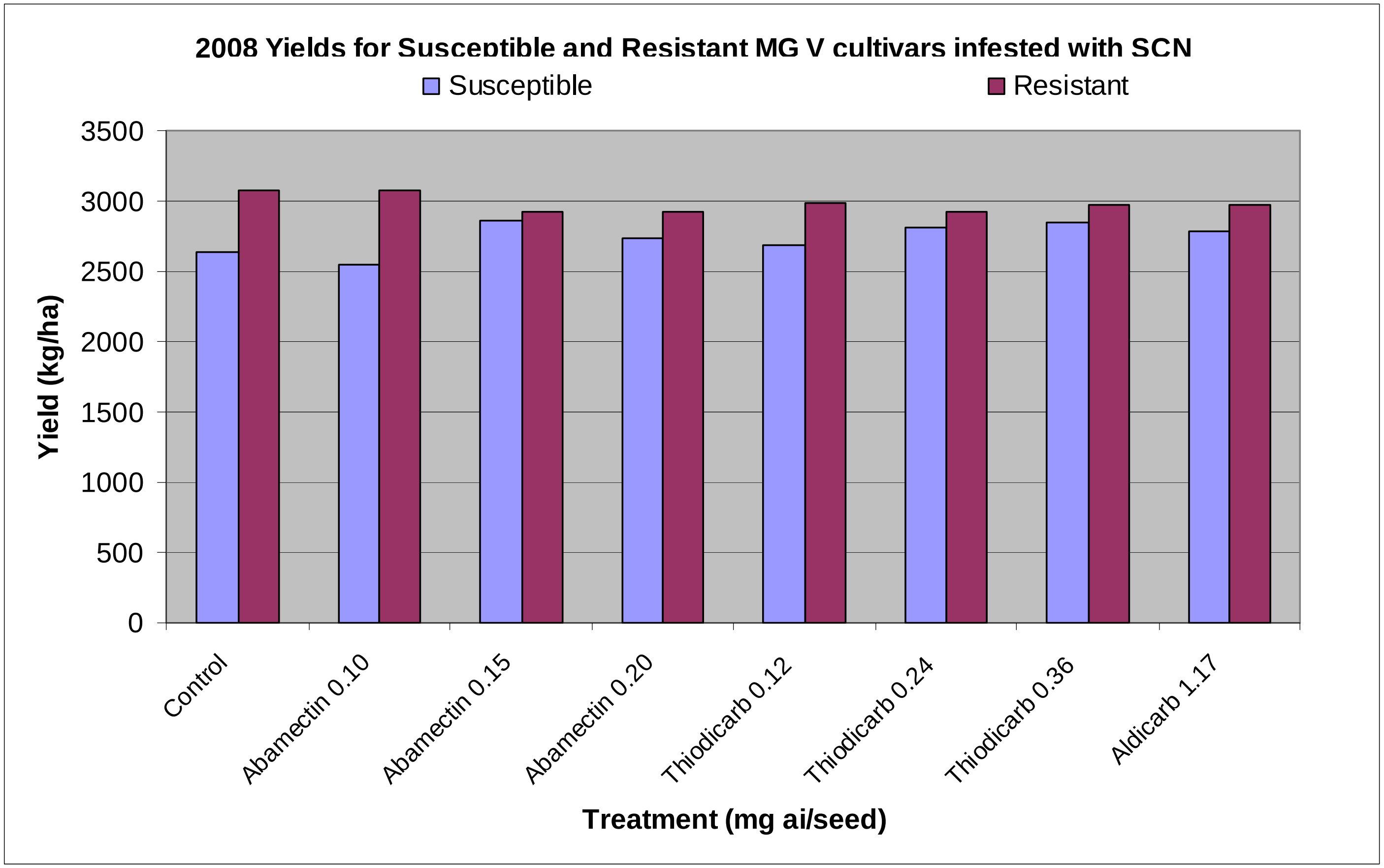

Figure 2: Yield in kg/ha for Maturity Group V Soybean seed treatments in 2008 infested with SCN.

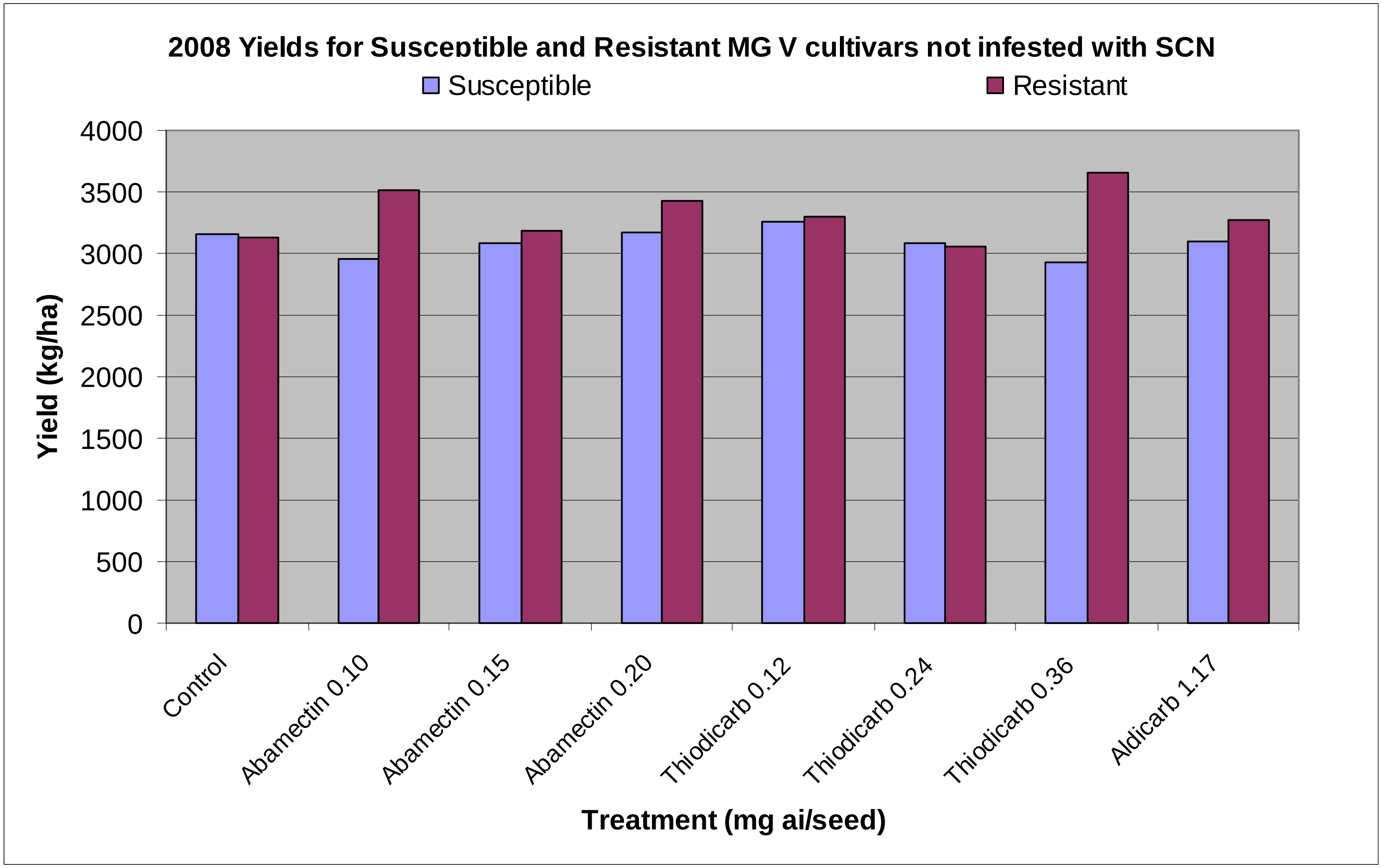

Figure 3: Yields (kg/ha) for Resistant and Susceptible cultivars in 2008 for MG V fields not infested with SCN

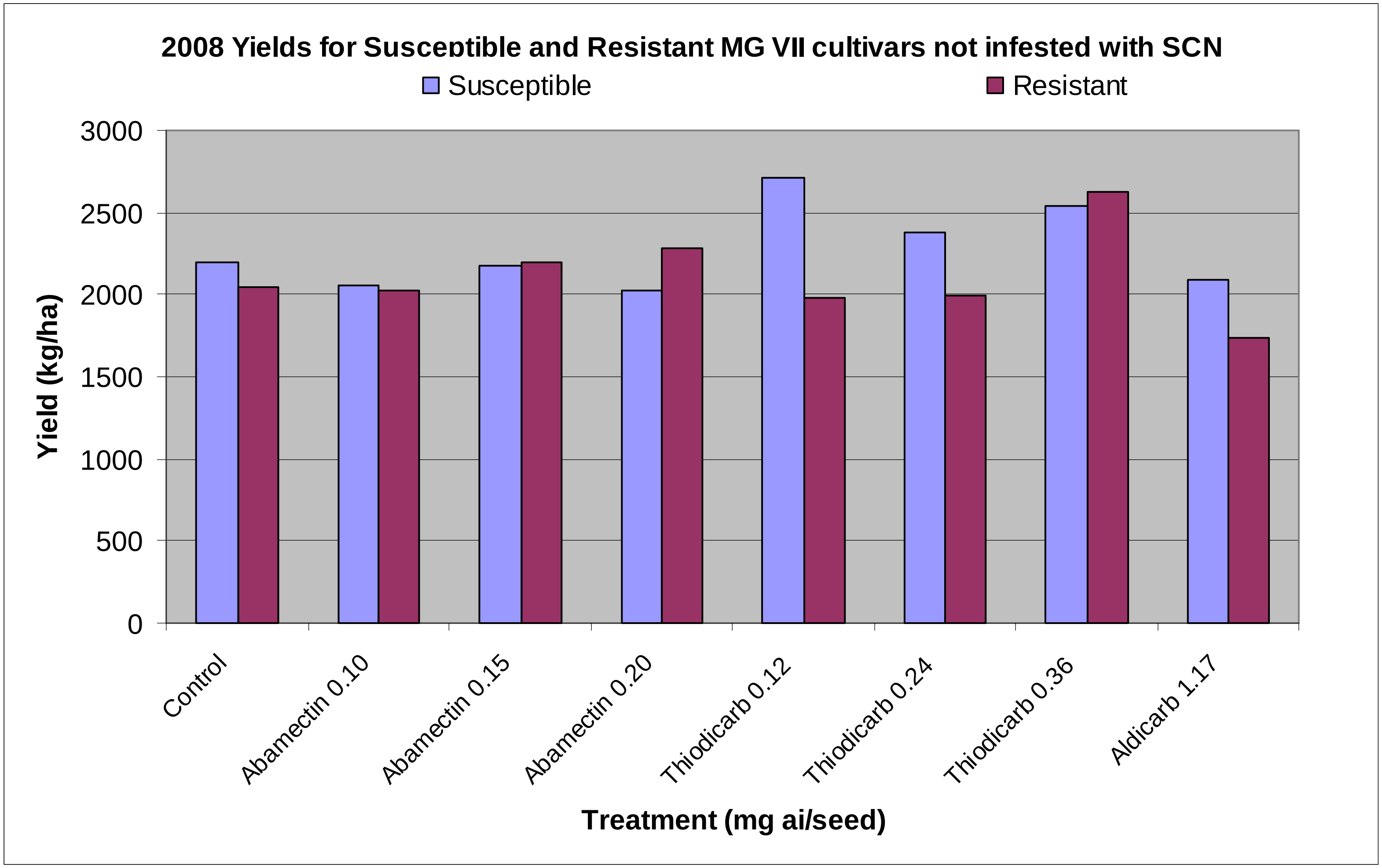

Figure 4: Yields (kg/ha) for Susceptible and Resistant cultivars MG VII in 2008 not infested with SCN.

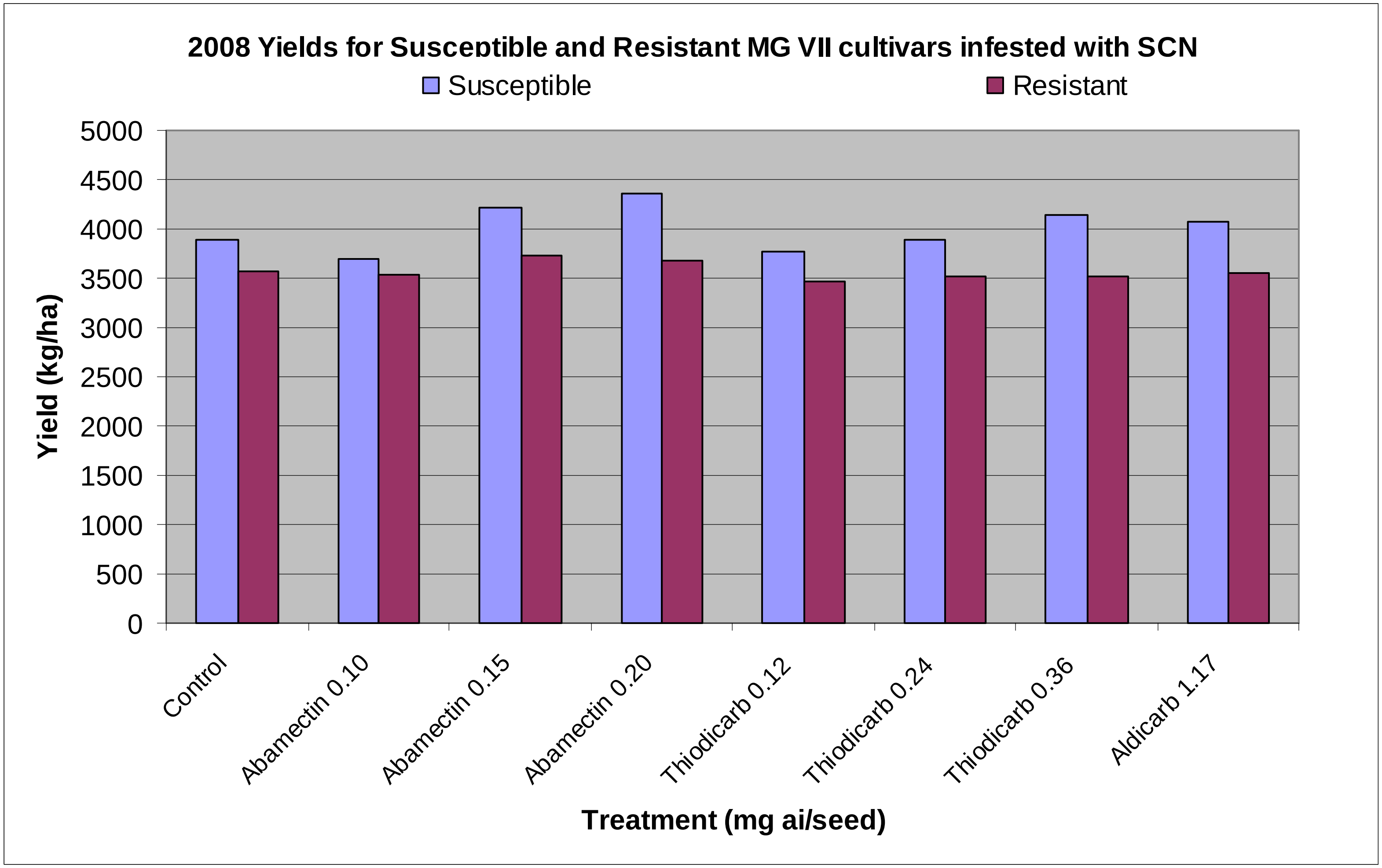

Figure 5: Yields (kg/ha) for Susceptible and Resistant MG VII cultivars infested with SCN.

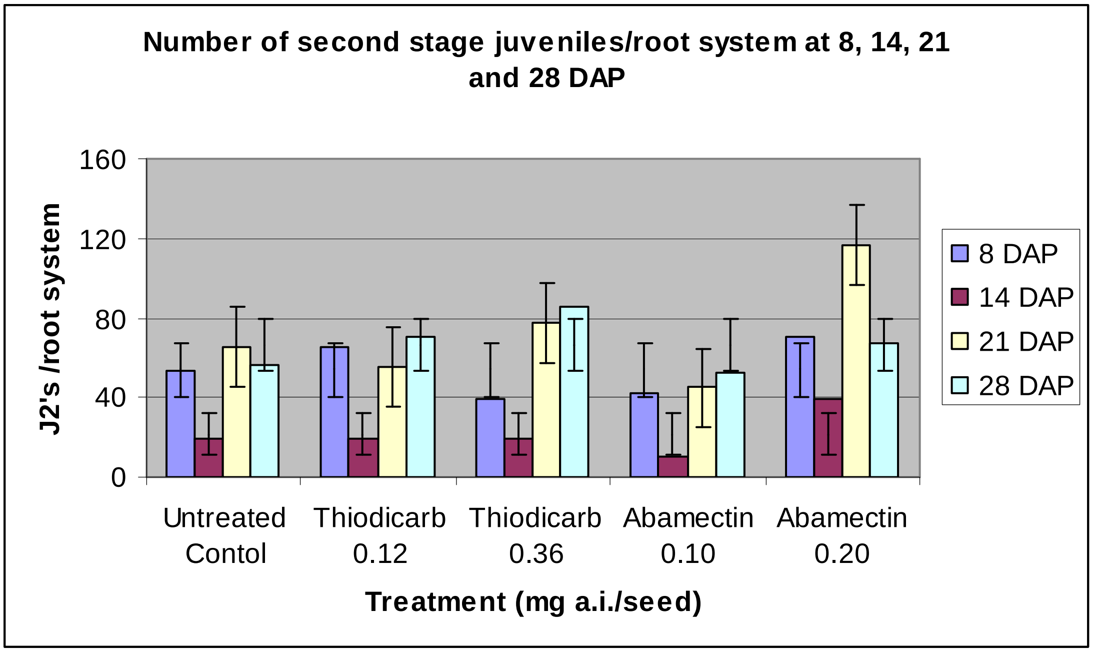

Figure 6: Number of J2's/root system at 8, 14, 21, and 28 DAP for treated seed in 2007 Micro-plot study.

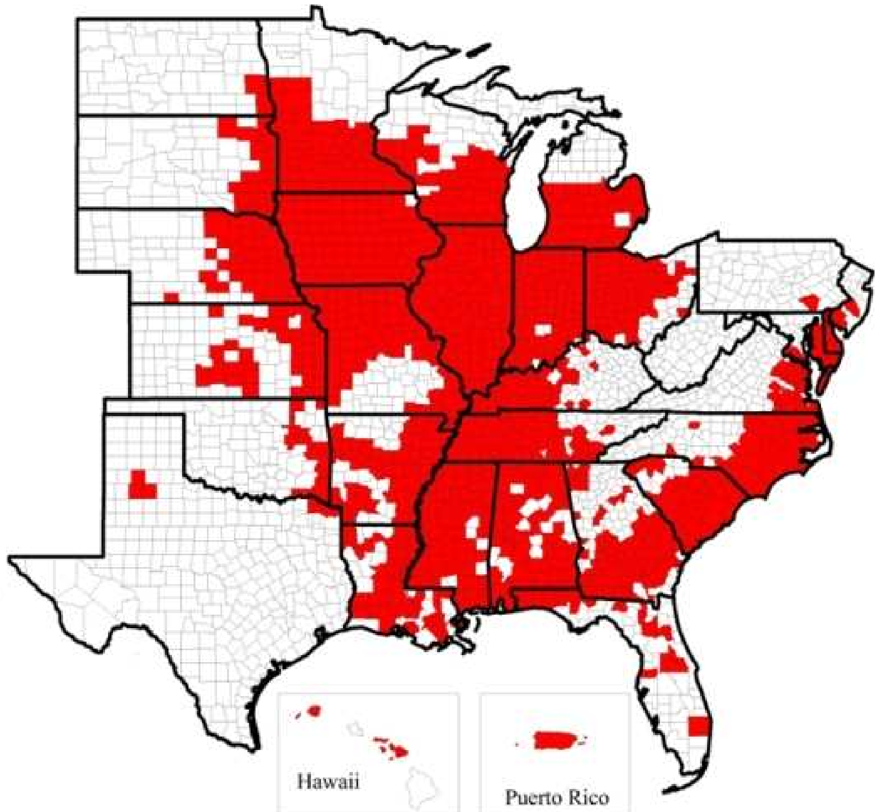

Figure 7: Known distribution of the Soybean Cyst Nematode in 2008.