CHARACTERIZATION OF SOYBEAN CYST NEMATODE DIVERSITY IN KANSAS

by

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Abstract

The soybean cyst nematode (*Heterodera glycines*) (SCN) is an important pathogen of soybean in the United States. Annual yield losses from SCN are estimated to be over $2 billion worldwide. However, SCN virulence or the ability of a nematode to grow on resistant soybean genotypes varies widely among SCN populations. Fortunately there are several genetic sources of resistance to decrease the virulence of the pathogen on soybean. The objectives of this research were to: 1) characterize the genetic diversity of soybean cyst nematode populations in Kansas, 2) determine the frequency of Kansas SCN populations virulent on PI88788, 3) determine which plant introductions used in the HG Type Test provide the best level resistance, and 4) compare the performance of commercial soybean cultivars to the plant introduction from which their SCN resistance was derived. Soil samples were collected from SCN-infested fields across the state. Each soil sample was taken to the greenhouse and planted to a susceptible soybean cultivar to increase SCN population. Following an SCN population increase, a HG Type Test was planted. *H. glycines* field populations were highly variable, not only in population densities, but also in their abilities to develop on soybean genotypes. Collected from a diverse range of environments, ten HG types were identified. About 50% of the *H. glycines* populations were virulent on PI 88788, and most of the populations were virulent on commercial SCN resistant lines which derived their resistance from PI 88788. The commercial lines tended to be more susceptible to SCN than the lines from which they derived their resistance, but few HG populations were virulent on PI 437654 or the commercial line that derived its resistance from PI 437654. These results suggest that

sources other than PI 88788 should be used in the development of *H. glycines* resistant cultivars for Kansas. One possible source of resistance is PI 437654. Information about SCN diversity in Kansas will improve decisions regarding cultivar development and selection for SCN management.

Table of Contents

List of Figures

List of Tables

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Dedication

My college education and Master's project is dedicated to my loved family and friends. My grandparents, Stanley and Magdeline Rzodkiewicz, Sr., and Lewis and Sophia Kukal; My parents, Stanley and Betty Rzodkiewicz; my children, Sara and Jacob; my companion, Lynn; his children, Bilan, Blair, and Brian; my friends Melanie and Kevin, Jim and Jan, and Jianye.

Preface

The research described in this thesis is published to increase the knowledge database of the soybean cyst nematode diversity in Kansas.

CHAPTER 1 - Introduction

Heterodera glycines, commonly known as the soybean cyst nematode (SCN) is a pathogen that infects the roots of soybean [*Glycine max* (L.) Merr.]. SCN is a major pest of soybeans in United States and the world (Guo et al., 2006; Wrather et al., 1994). Soybean yield suppression credited to *H. glycines* resulted in approximately $750 million in losses to U. S. soybean producers each year from 2003 to 2005 (Wrather and Koenning, 2006).

H. glycines was first discovered in the United States in 1954 in North Carolina (Winstead et al., 1955) and has since spread to 26 additional states in the southeast and Midwest (Noel, 1992). Additionally, *H. glycines* has been found in all chief soybean-producing states (Niblack, 1999). *Heterodera glycines* is widely distributed throughout the north-central United States (Riggs, 2004), where past state surveys in the region report from 14% to 63% of fields are infested (Niblack, et al., 1993; Willson, et al., 1996). *Heterodera glycines*, is a significant pest of soybean in Kansas, where it was first reported in 1985 in Doniphan County field (Jardine and Todd, 2001). In individual Kansas fields, crop losses of 35-40% have been observed (Todd, 1993).

The impact of *H. glycines* on soybean yield production in the Midwestern states has been documented (Doupnik, 1993; Niblack et al., 1992; Niblack, 1993). The economic losses due to *H. glycines* infestation cannot be estimated reliably with the information available because losses are dependent on many factors, including environmental conditions, costs associated with management of the nematode, the price

of soybeans, variability in host responses, and impacts from breeding recommendations and cultivar selection by producers.

Plant damage is caused by *H. glycines* when the infective juvenile (J4) stage enters the soybean root, establishes a feeding site and develops into a swollen adult female. Plants infected with high numbers of *H. glycines* females have inadequately developed root systems that cannot utilize nutrients and water efficiently. The outcome may be stunted plants with chlorotic foliage (Agrios, 1997), resulting in fewer pods produced (Smith et al., 2000; Young et al., 1988) on infected plants thus reducing crop yields. *H. glycines* may also decrease the number of nodules formed by nitrogen-fixing bacteria.

Once *H. glycines* is present in the soil, it can be managed to minimize its reproduction and maximize crop yields. Two management practices used to control *H. glycines* reproduction are the use of crop rotation and planting soybean cultivars with SCN resistance. Resistant cultivars decrease nematode reproduction because of an incompatible interaction between the host and parasite. Nematode reproduction typically is not completely prevented, but continues at a reduced rate (Wang, et al., 2000). The rotation of SCN-susceptible soybean with a non-host and SCN-resistant cultivars is currently considered the best method to manage *H. glycines* (Chen et al., 2001a; MacGuidwin et al., 1995;Niblack, 2005; Niblack and Chen, 2004; Young, 1998) because this decreases reproduction of the *H. glycines* and places less selection pressure on the nematode population.

Planting soybean cultivars with increased resistance to *H. glycines* is an effective method to defend against yield losses due to *H. glycines* (Chen, et al., 2001). Plant

breeders' efforts have developed cultivars with genetic resistance derived from plant introductions (PIs). Recently, newly discovered mapping studies have shown that the PIs used as resistant sources in development of cultivars have major resistance genes in common (Concibido et al., 1996; Webb et al., 1995; Arelli et al., 1992). As a consequence, *H. glycines* may overcome these few major resistance genes which are in currently used cultivars.

The sources of *H. glycines* resistance for use in cultivars are limited. Of the more than 100 known sources of resistance (Rao-Arelli et al., 1997), only a few are used for cultivar and germplasm development in the United States (Shannon et al., 2004). Of the sources of *H. glycines* resistance used in cultivars developed in the United States, resistance can be traced to *G. max* 'Peking', PI 88788, PI 90763, PI 437654, and PI 209332. The principal source of *H. glycines* resistance in the Midwestern United States is PI 88788 with a few cultivars released with resistance from PI 90763, PI 437654, and PI 209332. Consistent use of soybean cultivars with the same sources of resistance can lead to adaptation of existing *H. glycines* populations to those cultivars. This continued use of a specific source of resistance may lead to an increase in *H. glycines* populations and virulence and a decrease in soybean yields. Genetically variable *H. glycines* populations can present challenges to both researchers and producers.

Currently, resistant soybean cultivars reduce the ability of *H. glycines* to develop and complete its life cycle. However, limitations of this approach have been noticed. Disease development depends on the genetics of both the soybean cultivar and *H. glycines*. The use of resistant cultivars is constrained by a lack of long-lasting resistance due to the restricted genetic background from which resistance is derived (Diers, et al.,

1997) and the genetic diversity of in *H. glycines* populations (Dong, et al., 1997). The genetic variation within cyst nematode populations (Colgrove, et al., 2002) and environmental factors that affect *H. glycines* reproduction (Avendano, et al., 2004; Palmateer, et al., 2000; Johnson, et al., 1993) can further decrease the resistance of the soybean cultivar.

Early genetic studies on *H. glycines* variability consisted of directional selection experiments on various host differentials. In these studies, selection on a resistant host resulted in a gradual increase in the ability of the nematode population to reproduce on that host (McCann et al., 1982; Young, 1982). In 1934, an early example in the recognition of genetic diversity occurred with the placement of *H. glycines* as a subspecies of *H. schachtii* (Fujita et al., 1934). After this, reports of populations of *H. glycines* from North Carolina differed from Tennessee populations in that those from North Carolina developed on the soybean Plant Introduction (PI) 88788 but those from Tennessee did not (Ichinohe, 1952; Ross, 1962). The verification of genetic diversity among populations continues to accumulate (Anand, et al. 1994; Niblack, et al., 1993) together with evidence of diversity within populations (Colgrove, et al., 2002; Zhang, et al., 1998).

The genetic variability of *H. glycines* populations can offer challenges to both researchers and producers. The natural variability distinctive of *H. glycines* can be difficult to evaluate as it must be measured in populations rather than individuals. In 1969, a group of scientists (nematologists and soybean breeders) met and proposed a race test for *H. glycines* populations based on the comparative development of females on four differential soybean lines (Golden et al., 1970). Characterization of populations has been

improved through development and use of the HG Type Test (Niblack et al., 2002). Both the SCN race test, and the HG Type Tests measure the ability of *H. glycines* populations to reproduce on a standard set of resistant soybean lines relative to a standard susceptible cultivar and provide a means of assessing population variability. Results of these assays are useful to characterize greenhouse isolates maintained for cultivar evaluations and the identification of field populations in order to monitor and maximize the effectiveness of deployed resistance.

The genetic diversity of *H. glycines* populations increases the difficulty of using resistant cultivars to manage the nematode (Cloud, et al., 1988; Rao-Arelli, et al., 1992; Riggs, et al., 1981; Young, 1998; Young, 1992). Resistance must be carefully matched to the virulence spectrum of the nematode population in question. The objectives of this research were to: 1) characterize the genetic diversity of soybean cyst nematode populations in Kansas, 2) determine the frequency of Kansas SCN populations virulent on PI88788, 3) determine which plant introductions used in the HG Type Test provide the best level resistance to Kansas SCN populations, and 4) compare the performance of commercial soybean cultivars to the plant introduction from which their SCN resistance was derived. Knowledge of the virulence phenotypes of *H. glycines* populations is essential both for the development of effective cultivars by soybean breeders and for the optimal deployment of resistant cultivars in infested fields. This information will help Kansas soybean producers make informed decisions on soybean cultivar selection. Effective use of *H. glycines* soybean cultivars can increase crop yield and financial profits for the producer.

Methods and Materials

Soil Sample Collection

In 2007 and 2008 a total of 59 soil samples were collected from agricultural fields under production in Kansas, primarily in west central, north central, northeast, east central and southeast locations of the state. Soil samples were taken from fields that were believed to be infested with *H. glycines*. State-wide contacts were made through county extension agents, producers, researchers and local print media. The 59 soil samples were collected from 13 counties in Kansas and 1 sample collected from Jasper County, Missouri.

Each soil sample was a composite of approximately 15 to 20 soil cores (25 cm deep x 5.0 cm diameter) collected about 4.0 cm parallel to soybean root systems where suspected *H. glycines* activity was noticed by producer. A few soil samples were collected from fields that had been in rotation with non-host crops such as corn and wheat. After each soil sample was collected it was immediately placed in a five-gallon plastic container for transport to the laboratory for analysis. The soil samples were homogenized over a 6.35 mm metal mesh; 250 cm^3 of soil was archived, and 250 cm^3 of soil was sent to the KSU soil laboratory for analysis. The soil samples were stored in a cold room between 4 and 10°C until they were processed for *H. glycines* eggs by elutriation and mechanical cyst crushing to obtain an egg count.

Soil Count of SCN Populations

Heterodera glycines Egg Count

In the lab 100 ml (by volume) of soil was placed in a plastic 3.8 L jug. The jug was filled with water, and then the water was poured over a 100 mesh sieve with a tea strainer to catch and discard sticks, stems, and rocks. To prepare the *H. glycines* samples for egg counts, 30 ml of water was sprayed on the contents on the 100-mesh sieve. Wash water and soybean cyst nematode cysts were washed into a 50 ml beaker and then into a 400 ml centrifuge tube. Using a large medical syringe and a needle, 15 ml of 65% sucrose solution was injected (while stirring) into the bottom of the tube. The tube was placed into a laboratory centrifuge for 30 seconds at 800 rpm. After the centrifuge, the tube contents were washed with water onto a 100-mesh sieve. The soil pellet was discarded. The soybean nematode cysts were washed from the 100-mesh sieve back into the 50 ml beaker and enough water was added to maintain the volume at about 20 ml. The contents were counted using an Olympus SZX16 stereomicroscope to view cysts. After viewing cysts the sample was washed into a 700 ml centrifuge tube, filling it only about ½ full. The tube containing the sample was held against a large revolving drill bit and ground for 5 minutes until the cysts broke and released eggs. The sample was poured over stacked 200-mesh and 500-mesh sieves. The content of the 500 mesh sieve was washed with water into a 50 ml beaker, keeping the water and eggs at 20 ml volume. The contents on the 200-mesh sieve were discarded. *H. glycines* eggs were counted on an Olympus SZX16 laboratory stereomicroscope. Egg densities were reported per 100 cm^3 of soil.

***Heterodera glycines* Egg Increase**

All soil samples with detectable populations of *H. glycines* were mixed with steamed sand resulting in a 50% field sample/50% steamed sand mixture. The steamed sand was added to the field soil to enhance *H. glycines* reproduction and growth. Each *H. glycines* population increase used a total of 80-100 plastic containers, and each plastic container measured 4.0 cm in diameter and 13.5 cm in length and held 450 to 500 grams of the planting soil mixture. The *H. glycines* increase was placed in a greenhouse with environmental controls and planted to *H. glycines*-susceptible soybean cv. KS4404RR or KS3406RR to increase *H. glycines* egg numbers to a sufficient inoculum level to plant an HG Type Test.

After 56 days the *H. glycines* increases were removed from the greenhouse and moved to the laboratory where soybean shoots and leaves were discarded and the soil was gently removed from each soybean root. Each root was incubated in a water bath at 23°C for 2-5 minutes. Roots were rinsed in a water stream into a common tea strainer (to collect stems, leaves, rocks) over a 100-mesh sieve. If the egg count for the increase was 1,000,000/L eggs then a HG Type Test was planted. If the total egg counts were less than $\leq$1,000,000/L the soil was planted to increase again until sufficient eggs counts were obtained. Two to 4 or more *H. glycines* egg increases were needed to generate the required 1,000,000$\pm$ nematode eggs to perform an HG Type Test. An HG Type Test was planted when a sufficient egg count was determined.

HG Type Test

The HG Type Test inoculation procedure ensured that each experimental unit (tube) received the same amount of inoculum. The target was a minimum of 11,000 eggs

per experimental unit. For each experimental unit 2.0 to 3.0 grams of bulk cotton was placed in the bottom of each tube. The experimental design consisted of seven replications (each replication used 7 PI lines, 1 susceptible check, and 5 commercial lines) and was repeated twice. The HG Type Test was set up in the greenhouse using a completely randomized block design. Each container received 450 to 500 grams of a pasteurized sandy loam soil (50% steamed sand/50% steamed greenhouse soil) that had been first placed in a plastic bag, with 10 ml of inoculum spread onto the soil. The plastic bag was closed and then shaken to allow the soil and inoculum to uniformly combine. Then the plastic bag was opened and the soil was placed into the 0.47 ml plastic container and one seed of a differential genotype was planted under 30 to 40 ml of steamed sand and watered to initiate germination and emergence.

To quantify the *H. glycines* diversity in Kansas the following indicator lines were used: PI 548402 (Peking), PI 88788, PI 90763, PI 437654, PI 209332, PI 89772, PI 548316 (Cloud), and the standard susceptible cultivar Lee 74 (Niblack et al., 2002). Five additional indicator lines (resistance sources indicated in parentheses) were included in the test: KS5004N (PI 548402), COMM 1 (PI 88788), COMM 2 (PI 88788), KS5502N (PI 437654), and KS4602N (PI 209332), and two commercial cultivars developed by private companies which are identified in this study as COMM 1 (PI88788) and COMM 2 (PI88788).

Greenhouse conditions were maintained at an ambient air temperature of 27°C to maintain soil temperature at a constant range of 27 - 28 °C (Alston and Schmitt, 1988; Hamblen et al., 1972; Riggs and Schmitt, 1991) under 14 to 15-hour days. Watering of

the soybean plants was performed once per day using a standard spray wand attached to the end of a garden hose.

Data collection was performed following each conclusion of a HG Type Test. The test was maintained for 35 days and broke down for analysis. The plant shoots and leaves were removed and discarded. Each experimental unit was soaked in a 4.0 L plastic bucket of water to loosen soil and avoid dislodging females. The soybean roots were then placed on a tea strainer placed on top of a 100-mesh sieve. The females were removed from the roots with a combination of water spray and mechanical manipulation. The contents on the 100-mesh sieve were then washed onto 20- over 60-mesh sieves. The contents retained on the 60-mesh sieve were washed into a 50 ml beaker. The females were enumerated under magnification using an Olympus SZX16 stereomicroscope. Following the recorded enumeration of females the test was discarded.

The female index (FI) was used to determine the susceptibility or resistance of a soybean indicator line. The FI was calculated for each soybean indicator line as follows: FI = (mean number of females on test indicator soybean line / mean number of females on the susceptible check cv. Lee 74) x 100. Each HG Type is an average of population phenotype defined by its ability (female index [FI] $\geq$ 10) or lack thereof (female index [FI] $\leq$ 9) to develop on a set of soybean differentials compared with a susceptible check. *H. glycines* types were determined according to the standard HG Type Test as outlined above (Niblack et al., 2002).

Soil Analysis

Soil analysis was performed on each soil sample that was collected for this experiment at the Kansas State University Soil Testing Laboratory. Each 75 g soil sample

submitted was homogenized by mechanical means through a 6.35 metal mesh sieve. The following soil tests were performed: pH [1:1 with H_2O, 10 g soil to 10 ml H_2O] (Wateson and Brown, 1998), phosphorus Mehlich-III [plant available, extraction for P] (Frank, et al., 1998), potassium [ammonium acetate extraction] (Warncke and Brown, 1998), iron and manganese [DTPA extraction] (Whitney, 1998), soil texture (particle size, sand, silt, and clay) (Bouyoucos, 1962), and organic matter [Walkley-Black method] (Combs and Nathan, 1998).

HG Type Tests

Of the 59 samples collected, at least two complete HG Type Tests were processed on 20 samples, six samples had one completed HG Type Test and ten samples had low or no *H. glycines* egg counts and were excluded from the data set; twenty two samples were not planted to HG Type Tests due to time restrictions. Soil analyses were performed on all 59 samples.

Statistical Methods

Correlations of soil characteristics (phosphorous, potassium, iron, manganese, organic matter, and percent sand, silt and clay) and *H. glycines* egg counts were obtained using SAS Proc Corr (SAS Institute, Cary, NC). The variation among *H. glycines* populations in female indices on HG Type differentials was summarized by principal components analysis using SAS Proc Princomp. An analysis of covariance using SAS Proc Mixed was conducted to compare regression models for female indices on each commercial cultivar vs. female indices on its respective resistance source.

Results and Discussion

Heterodera glycines Collection Locations

In this study, soil samples were collected in the state of Kansas and one sample from southwest Missouri (Table A.1). A total of 59 populations from 15 counties and 2 states in 2007 and 2008 were analyzed. A majority of the Kansas soil samples were collected from the northeastern, east central, and southeastern counties, with the remainder of the soil samples from several counties in central Kansas (Figure 1.1).

Soil Analyses

Soil analyses were completed on 59 soil samples (Table A.1). Values for each soil characteristic measured ranged from 5.8 to 7.9 for pH, 7 ppm to 568 ppm for phosphorous, 61 ppm to 568 ppm for potassium, 11.1 ppm to 158.3 ppm for iron, 2.2 ppm to 189.1 ppm for manganese, 0.8% to 3.3% organic matter, 0% to 86% sand, 10% to 92% silt, and 4% to 36% clay.

Relationships between *H. glycines* Populations and Soil Characteristics

SCN populations in the soil samples collected ranged from 0 to 6800 eggs per 100 cc^3 of soil (Figure 1.2 and Table B.1.5). *Heterodera glycines* infested 81 % of soybean fields sampled. Fields sampled ranged widely in *H. glycines* egg counts across the state. Eleven samples had zero *H. glycines* eggs and four samples had 2001-6800 *H. glycines* eggs per 100 cc^3.

Correlations were calculated between the *H. glycines* egg count and the soil characteristics. No significant correlations were observed between *H. glycines* egg count and soil pH, phosphorous, potassium, and iron contents; and percent organic matter, sand,

clay, and silt. The SCN population (egg count) and manganese contents were inversely related (Figure 1.3).

Nematode reproduction and the seed yield losses caused by this nematode are influenced by soil texture (Koenning et al. 1988; Todd and Pearson, 1988; Young and Heatherly, 1988). Todd and Pearson (1988) recovered higher numbers of SCN females and cysts from sandy loam than from silty loam soil. In this study, the correlation coefficient between percent clay and egg count was -0.26 ($p \leq 0.1$). Higher total *H. glycines* populations were observed in the near sandy loams, and silt loams, than in clay loam soils. These differences may have resulted from coarse-textured soil, which can enhance migration or root penetration by *H. glycines*, an occurrence documented in the nematode genus *Pratylenchus penetrans* (Townshend, 1972). Soil type may also affect the survival and hatch of *H. glycines*, (Slack et al., 1972). Clay soils have more surface area than other types of soil; this surface area can retain moisture and impair the respiratory system, survival and reproduction of *H. glycines*. Also, sandy loam and silty loams have different *H. glycines* population establishment levels. Establishment of SCN is necessary for reproduction to occur and affect soybean cultivars. For example, a sandy loam at P_i (initial population) = 2.0 (100 eggs and [juveniles] J2), P_t (population total) = 0.7 (five females and cysts) in sandy loam, whereas in the silty loams, the same level of Pt required a Pi of 2.6 (400 eggs and J2). This difference indicates that the population establishment threshold was lower in sandy loam, suggesting that a higher frequency of establishment may occur in coarser soil types (Todd and Pearson, 1988).

The correlation coefficient between manganese content and egg count was -0.36 ($p \leq 0.1$). Manganese is one of the 13 mineral nutrients essential for soybean growth

(Franzen, 1999). Manganese works with plant enzymes to reduce nitrates and aids in protein production. Townsend and Wedgeworth 1936 observed the adverse effects of low Mn concentrations on soybean growth and development. It could be concluded that if the soybean plant had adequate levels of manganese to support plant growth, the enhanced plant development would provide an environment conducive to supporting higher *H. glycines* populations. However, in this study a negative correlation ($r = -0.56$, $p \leq .01$) was observed between percent clay and Mn content. Although the soil fertility improved with increases in clay content, the increase in soil moisture adversely effected SCN population.

The amount of yield loss in a soybean crop is usually related to the *H. glycines* egg density at planting (Todd et al., 2003). A damage relationship for Kansas of approximately 9% loss in seed yield for each 1,000 eggs per 100 cm^3 soil has been suggested (Todd et al., 1995). If a threshold level is set at 5% yield loss, then the SCN threshold estimate would be approximately 500-600 eggs per 100 cm^3 soil. Twenty-five percent of the fields infested with *H. glycines* had population densities that exceeded the damage threshold of approximately 500 eggs per 100 cc^3 in soils.

***Heterodera glycines* Types**

The Plant Introductions

Knowledge about the virulence phenotypes and the frequencies of *H. glycines* populations is necessary for the effective use of the resistant cultivars. The knowledge about virulence of H. glycines populations also is essential for breeding appropriate cultivars for a region and for using the cultivars effectively in fields. Among all 27 soil

samples evaluated, ten HG Types were identified (Tables 1.1, D1). The HG Type 7 represented 29.6% of the populations. HG Type 2.7 represented 14.8% and all other HG Types were represented in low frequencies (≤11%).

Reproduction of Kansas *H. glycines* populations varied among soybean PI (differential) lines (Table 1.2). PI 88788, the most utilized source of resistance in the Midwest (Diers and Arelli, 1999) exhibited less resistance to the populations than all the differentials, except PI 548316. The FI exceed 10% on PI 88788 (Niblack et al.,2003; Mitchum, et al., 2005; Zheng et al., 2006) in 64% of the populations. Peking (PI 548402), also a resistance source for some cultivars in the region, yielded FI<10% in 67% of Kansas *H. glycines* populations. PI 437654 (Niblack et al., 2003) and PI 89722 (Mitchum, et al., 2005) had the highest resistance to *H. glycines* with FI's < 10% in 100% and 76 % of the *H. glycines* populations, respectively.

The variation among in female indices on HG Type differentials was summarizing using principal components analysis. The first and second principal components from the principal components analysis explained 70% of the total variance in female indices among *H. glycines* populations. The first principal component (PC 1) can be interpreted as an average female index across differential lines, with greater weighting associated with indices on PI548402, PI88788, PI90763, and PI89772 (Table 1.3). The second principal component (PC 2) represented a contrast of indices on PI548402, PI437654, and PI89772 with those on PI88788, PI209332, and PI548316. Nematode populations displayed a strong separation on the PC 1 axis that was related to collection site, with populations from SN and RL counties displaying higher ($P \leq 0.05$) average indices compared to populations from CK, DP, and ED counties (Figure 1.5).

No patterns were clearly discernible in the distribution of *H. glycines* populations on the PC 2 axis.

Commercial Lines

The commercial lines were derived from four different sources of resistance (Tables 1.2, E.1). In general, the derived commercial lines did not perform as well as the PI lines, but the relative level of resistance between the resistant source and the commercial line varied. The relative level of resistance exhibited between the resistant source and the commercial line was largest for the two entries, COMM 1 and COMM 2, that derived their resistance to PI 88788 (Table 1.2). The results of regression analyses of the relationship between female indices on commercial lines and their resistance sources are depicted in Fig. 1.5. Regression models included significant linear and quadratic trends ($P \leq 0.05$) that were consistent across genotype pairings. Indices on all commercial lines increased at a rate greater than 1 ($P = 0.04$) compared to indices on resistance sources, and intercepts were greater than 0 ($P \leq 0.05$) for PI88788 and PI209332. The regression models explained 70% of the total variance in female indices across cultivar pairings ($R^2 = 0.70$). FI's on the commercial line were about 25% greater than the FI's on PI 88788 for each HG population. FI's on the commercial line were about 12% greater than the FI's on PI 209332 for each HG population. FI's on the commercial line were about 7% greater than the FI's on PI 548402 for each HG population. KS5502N (PI 437654) exhibited the highest level of resistance compared to the other commercial lines (Table 1.2), with FI's ranging from 0 to 4% greater than the FI's on PI 437654 for each HG population.

H. glycines field populations were highly variable, not only in population densities, but also in their abilities to develop on soybean genotypes. Collected from a diverse range of environments, ten HG types were identified. About 50% of the *H. glycines* populations were virulent on PI 88788, and most of the populations were virulent on commercial SCN resistant lines which derived their resistance from PI 88788. The commercial lines tended to be more susceptible to SCN than the lines from which they derived their resistance, but few HG populations were virulent on PI 437654 or the commercial line that derived its resistance from PI 437654. These results suggest that sources other than PI 88788 should be used in the development of *H. glycines* resistant cultivars in Kansas. On possible source of resistance is PI 437654.

Figure 1.1 Map of Kansas *H. glycines* collection locations.

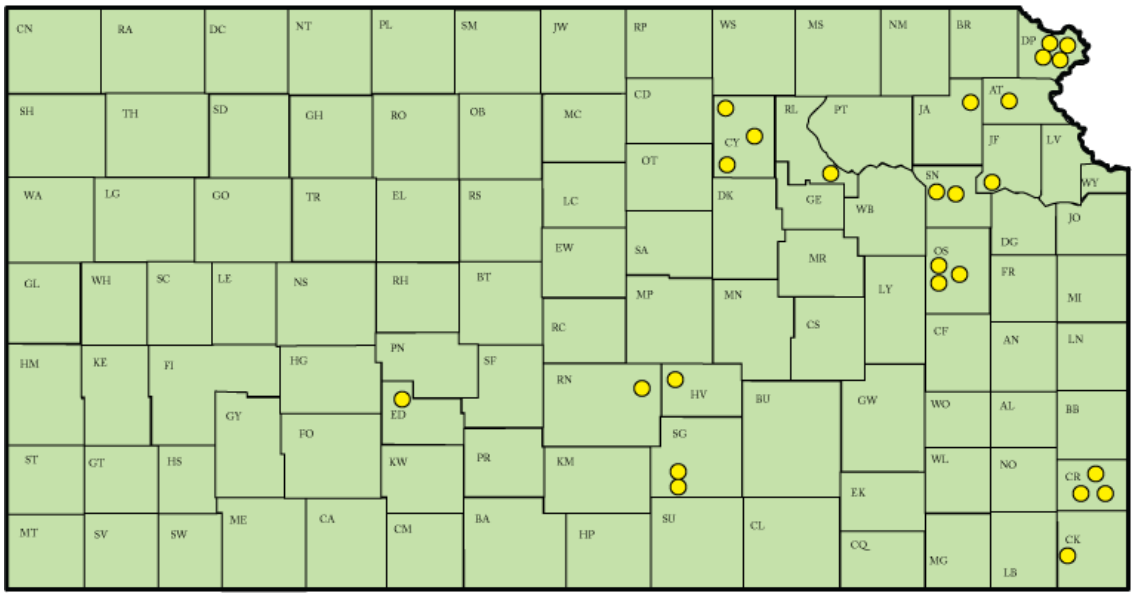

Figure 1.2 Initial *Heterodera glycines* egg counts per 100cm^3 of soil from locations infested with SCN in Kansas.

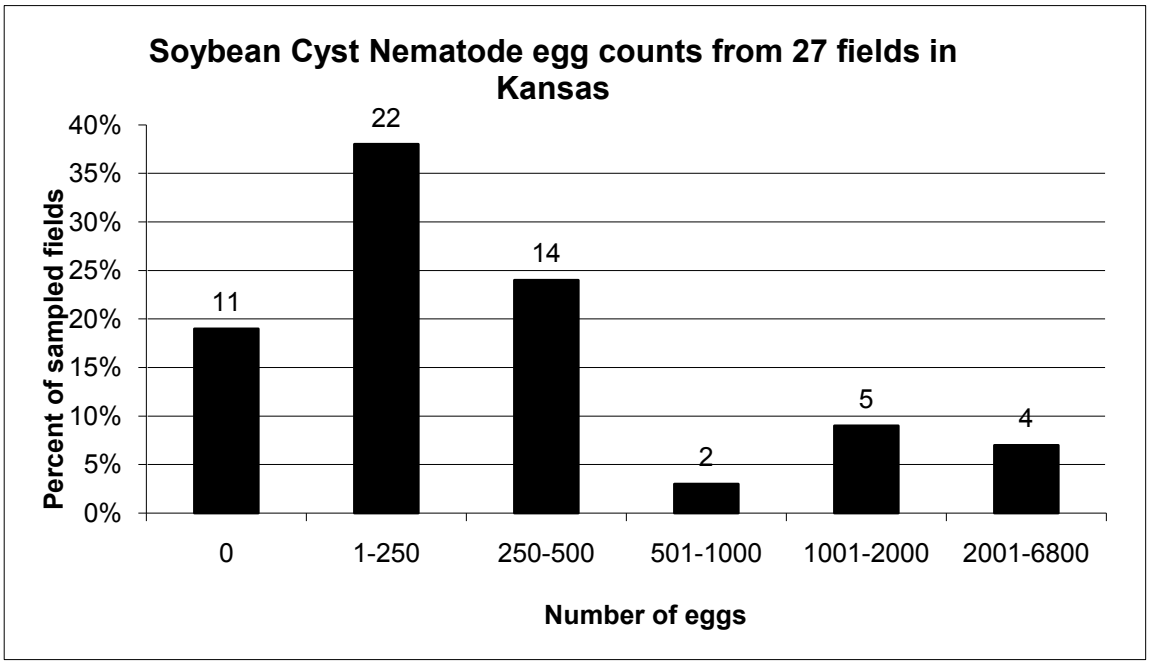

Figure 1.3 Soybean cyst nematode egg count versus. manganese concentration in Kansas soils.

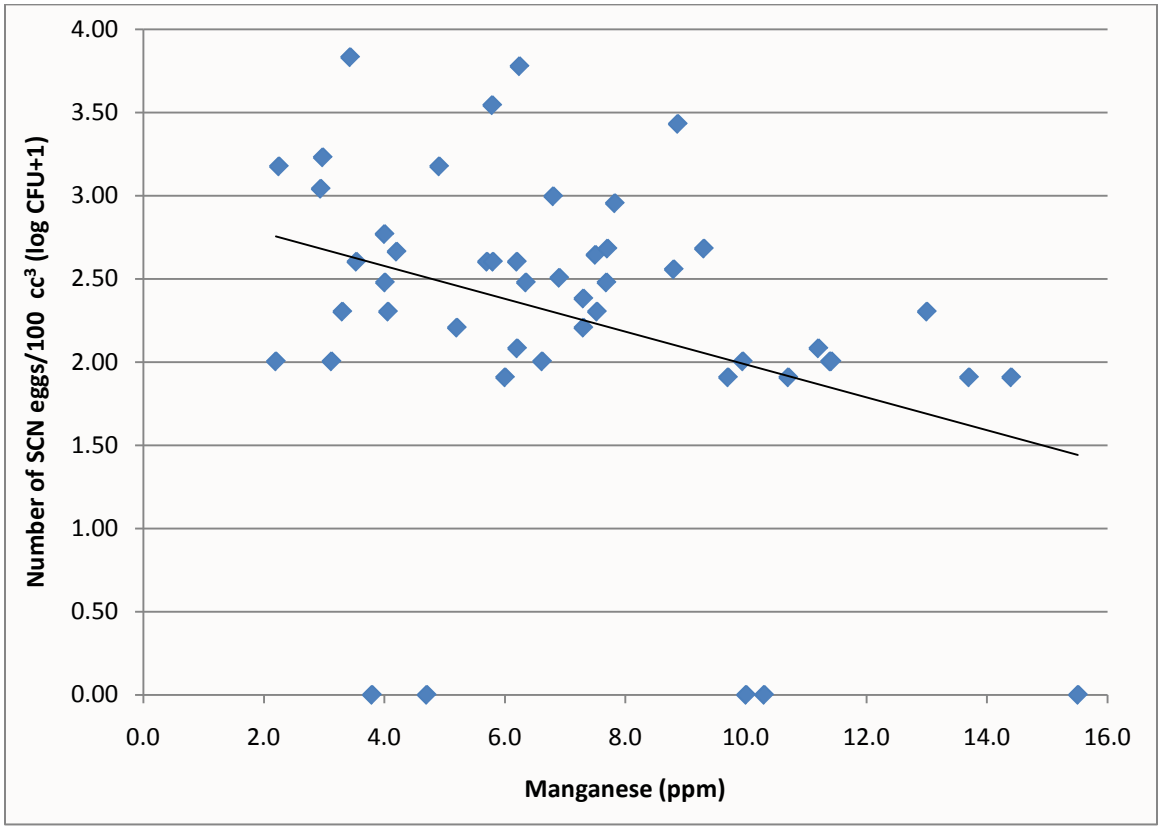

Figure 1.4 Characterization of the virulence diversity in Kansas populations of SCN using four different sources of resistance.

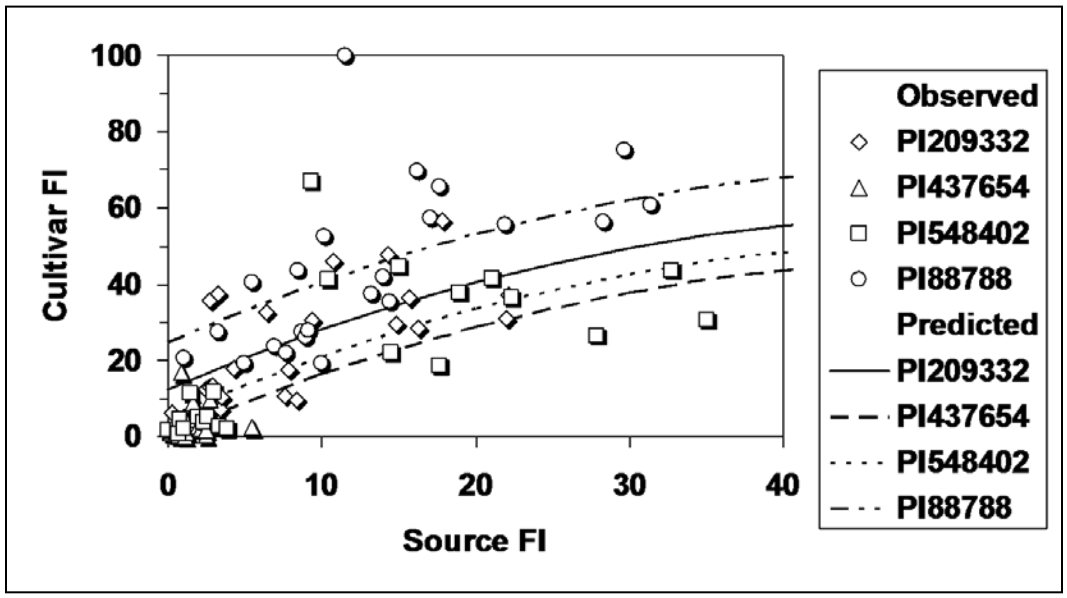

Figure 1.5 Results of the principal components analysis of the variation among in female indices on HG Type differentials.

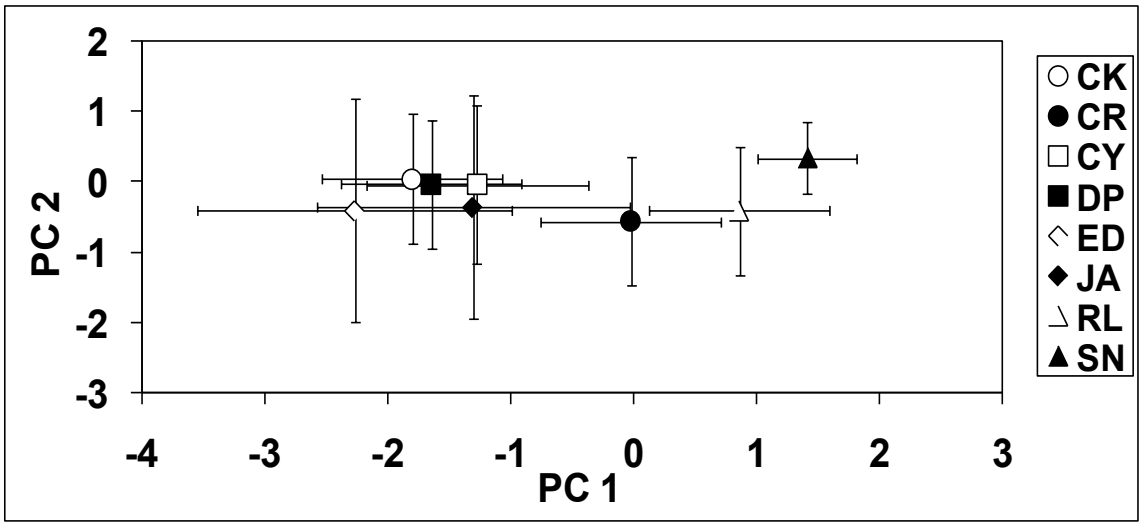

Table 1.1 Frequencies of *Heterodera glycines* HG Types in soil samples collected in 2007-2008 in Kansas.

HG Type	Number of Populations	% of Total Populations	Mean cysts/plant on Lee (range=459)
1.2.3.5.6.7	2	7.4	149 (120-172)
1.2.5.6.7	2	7.4	222 (46-477)
1.2.5.7	3	11.0	206 (98-320)
1.2.7	1	3.7	186 (170-201)
1.3.6.7	2	7.4	140 (118-150)
2.3.5.7	1	3.7	94
2.5.7	3	11.0	220 (40-319)
2.6.7	1	3.7	266
2.7	4	14.8	105 (42-186)
7	8	29.6	203 (51-364)

Table 1.2 Reproduction of *Heterodera glycines* from Kansas soils on soybean resistant sources.

	Female Index			
	Total Soil Sample (%)			
Plant Introductions	1-9	10-20	21-30	>31
1 (PI 548402)	67	15	11	7
2 (PI 88788)	48	33	7	11
3 (PI 90763)	81	15	0	4
4 (PI 437654)	100	0	0	0
5 (PI 209332)	63	22	11	4
6 (PI 89772)	78	15	7	0
7 (PI 548316)	0	30	26	44
Commercial Lines				
KS5004N (PI 548402)	44	15	11	30
COMM 1 (PI 88788)	0	11	26	63
COMM 2 (PI 88788)	4	11	19	67
KS5502N (PI 437654)	96	4	0	0
KS4602N (PI 209332)	22	30	11	37

Table1.3 Eigenvectors for the first and second principal components based on PCA of the response of *Heterodera glycines* populations to HG Type differentials.

Differential	PC 1	PC 2
PI548402	0.432	-0.399
PI88788	0.437	0.393
PI90763	0.493	0.058
PI437654	0.258	-0.271
PI209332	0.302	0.368
PI89772	0.427	-0.418
PI548316	0.199	0.548

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Appendix A - Soil analysis of all Kansas soil samples

Table A.1 Soil analysis of all Kansas soil samples collected in 2007-2008.

Sample ID	pH		Mehlich P	K	Fe	Mn	O.M.	Sand	Silt	Clay
			ppm	ppm	ppm	ppm	%	%	%	%
1	7.1		39	122	17.7	4.0	1.3	44	44	12
2	6.4		8	126	23.5	6.6	1.2	42	46	12
3	7.0		18	124	19.9	2.9	1.2	56	38	6
4	6.8		10	69	11.3	3.1	1.2	74	22	4
5	6.9		17	61	12.1	2.2	0.8	86	12	2
6	6.2		47	262	42.8	6.2	1.6	44	48	8
7	6.3		61	210	40.4	7.7	1.7	28	62	10
8	6.4		20	152	43.0	8.9	1.9	36	52	12
9	6.9		39	255	19.1	4.9	1.2	28	66	6
10	6.5		47	287	27.7	6.3	1.2	66	28	6
11	7.1		7	192	26.3	7.8	2.4	6	60	34
12	7.9		11	104	14.3	3.5	2.1	30	48	22
13	6.7		26	78	32.5	8.6	1.9	38	52	10
14	6.3		50	182	130.4	11.4	3.0	44	48	8
15	6.9		29	152	54.4	14.1	2.5	26	58	16
16	6.8		25	80	40.3	6.2	1.6	24	66	10
17	6.5		18	94	57.4	7.5	1.8	54	38	8
18	5.6		63	87	158.3	11.8	1.6	30	60	10
19	6.1		27	230	77.7	19.1	2.1	28	58	14
20	7.4		82	152	35.2	3.4	1.7	36	54	10
21	7.4		35	140	18.0	4.1	1.4	32	60	8
22	7.3		83	293	36.3	9.9	2.3	34	42	24
23	7.3		104	364	32.6	6.2	1.9	28	64	8
24	6.1		38	71	98.8	8.7	1.6	32	58	10
25	7.4		74	378	44.8	5.8	2.4	24	68	8
26	7.5		170	541	31.4	2.2	2.9	56	32	12
27	7.6		8	218	11.1	3.0	2.0	36	56	8
28	7.9		31	143	18.6	1.3	1.5	72	16	12
29	6.6		106	498	72.0	6.0	1.9	34	58	8
30	7.3		84	165	24.4	3.8	2.7	46	32	22
31	7.0		30	163	45.1	11.4	1.7	16	64	20
32	7.0		31	225	35.2	6.3	1.5	54	36	10
33	7.0		100	527	54.5	6.2	2.0	28	40	32
34	6.8		19	312	16.6	6.8	1.7	64	28	8
35	6.0		39.9	295	28.8	8.8	1.1	48	40	12
36	6.0		43.2	252	32.6	4.0	1.4	70	22	8
37	6.1		158.5	440	96.3	14.6	2.3	4	72	24
38	7.6		47.9	222	23.4	9.7	2.1	6	66	28
39	7.4		56.2	310	21.5	6.2	2.1	26	56	18

Continued

Table A.1 Soil analysis of all Kansas soil samples (continued)

Sample ID	pH		Mehlich P	K	Fe	Mn	O.M.	Sand	Silt	Clay
			ppm	ppm	ppm	ppm	%	%	%	%
40	7.5		72.3	480	19.7	5.7	2.5	40	40	20
41	6.9		12.4	322	17.6	10.0	1.8	66	18	16
42	6.9		17.6	485	34.1	13.0	2.5	40	24	36
43	6.9		26.2	242	36.0	14.4	2.6	0	72	28
44	6.7		50.5	307	38.6	13.7	2.8	24	48	28
45	7.7		18.2	218	15.4	3.3	1.7	10	60	30
46	6.8		42	222	22.3	9.3	2.1	28	42	30
47	6.9		16	276	21.2	10.7	2.0	20	54	26
48	6.8		31.4	289	25.5	10.3	2.0	32	50	18
49	7.6		86.8	234	29.4	5.2	1.9	38	48	14
50	5.8		8.73	72	21.9	4.7	0.8	84	12	4
51	7.4		46.8	207	29.0	7.5	2.9	24	48	28
52	7.0		17.1	432	11.6	7.3	2.3	0	88	12
53	7.1		34.1	280	23.3	6.0	1.4	0	92	8
54	7.1		29.8	363	24.3	7.7	2.1	36	54	10
55	6.8		81.4	568	40.2	11.2	3.3	16	64	20
56	7.2		26.6	521	26.0	6.9	2.6	6	70	24
57	7.4		43.6	374	24.4	7.3	2.3	2	82	16
58	6.8		20.4	100	12.0	4.2	0.9	86	10	4
59	7.7		12.2	205	24.4	5.8	1.1	26	68	6

Appendix B - Location of soil samples

Table B.1 Location of soil samples, egg counts and GPS coordinates.

Site	Location (County)	Soil type	Elevation of sample site (meters)	Global Positioning System (GPS) Coordinates	SCN eggs/100 cm^3 (by volume)
1	Shawnee	Eudora-Bismarckgrove silt loams, occasionally flooded	272	N 39º 04.451' (39 04 27) W 095º 46.257' (095 46 15)	300
2	Shawnee	Eudora-Bismarckgrove silt loams, occasionally flooded	266	N 39º 04.533' (39 04 31) W 095º 46.098' (095 46 5)	100
3	Shawnee	Eudora-silt loam, very rarely flooded	276	N 39º 07.151' (39 07 09) W 095º 55.363' (095 55 21)	1100
4	Shawnee	Stonehouse-Eudora complex, rarely flooded	273	N 39º 07.000' (39 07 00) W 095º 55.554' (095 55 33)	100
5	Shawnee	Stonehouse-Eudora complex, rarely flooded	280	N 39º 07.000' (39 07 00) W 095º 55.532' (095 55 31)	1500
6	Shawnee	Belvue-silt loam, excarpment, 2 - 12 percent slopes	336	N 39º 07.199' (39 07 11) W 095º 59.116' (095 59 00)	400
7	Shawnee	Reading silt loam, moderately wet, very rarely flooded	273	N 39º 09.086' (39 09 05) W 095º 58.722' (095 58 43)	300
8	Shawnee	Eudora-Bismarckgrove silt loams, occasionally flooded	271	N 39º 06.976' (39 06 58) W 095º 56.584 (095 56 35)	2700
9	Riley	Eudora-silt loam, rarely flooded	311	N 39º 08.527' (39 08 31) W 096º 37.730' (096 37 43)	1500
10	Riley	Belvue-silt loam, rarely flooded	309	N 39º 08.641' (39 08 38) W 096º 37.747' (096 37 44)	300
11	Doniphan	Monona silt loam, 2 to 5 percent slopes	338	N 39º 45.268' (39 45 16) W 095º 08.434' (095 08 26)	900
12	Crawford	Hepler silt loam, frequently flooded	293	N 37º 29.097' (37 29 05) W 094º 52.184' (094 52 11)	400
13	Crawford	Parsons silt loam, 1 to 3 percent slopes	290	N 37º 28.214' (37 28 12) W 094º 53.863' (094 53 51)	0
14	Jasper (MO)	Opolis silt loam, 2 to 4 percent slopes	277	N 37º 21.162' (37 21 09) W 094º 35.822' (094 35 49)	100
15	Cherokee	Parsons silt loam, 0 to 1 percent slopes	265	N 37º 11.841' (37 11 50) W 094º 49.912' (094 49 54)	0
16	Cherokee	Parsons silt loam, 0 to 1 percent slopes	270	N 37º 11.575' (37 11 34) W 094º 50.730' (094 50 43)	0

Continued

Table B.1 Location of soil samples, egg counts and GPS coordinates (continued)

Site	Location (County)	Soil type	Elevation of sample site (meters)	Global Positioning System (GPS) Coordinates	SCN eggs/100 cm^3 (by volume)
17	Cherokee	Parsons silt loam, 0 to 1 percent slopes	268	N 37º 11.607' (37 11 36) W 094º 55.420' (094 55 25)	200
18	Cherokee	Hepler silt loam, occasionally flooded	252	N 37º 12.605' (37 12 36) W 094º 57.002' (094 57 00)	0
19	Cherokee	Parsons silt loam, 0 to 1 percent slopes	260	N 37º 12.705' (37 12 42) W 094º 52.132' (094 52 07)	0
20	Cherokee	Parsons silt loam, 0 to 1 percent slopes	*	N 37º 12.700' (37 12 41) W 94º 52.124' (094 52 07)	6800
21	Cherokee	Parsons silt loam, 0 to 1 percent slopes	*	N 37º 10.895' (37 10 53) W 094º 52.073' (094 52 04)	2000
22	Doniphan	Kennebec silt loam, occasionally flooded	270	N 39º 48.774' (39 48 46) W 095º 12.341' (095 12 20)	100
23	Crawford	Dennis silt loam, 1 to 3 percent slopes	273	N 37º 16.854' (37 16 51) W 094º 38.301' (094 38 18)	6000
24	Crawford	Cherokee silt loam, 0 to 1 percent slopes	272	N 37º 27.190' (37 27 11) W 095º 03.110' (095 03 06)	200
25	Crawford	Parsons silt loam, 0 to 1 percent slopes	278	N 37º 19.778' (37 19 46) W 094º 38.969' (094 38 58)	3500
26	Clay	Muir silt loam, rarely flooded	360	N 39º 20.772' (39 20 46) W 097º 07.354' (097 07 21)	100
27	Clay	Muir silt loam, rarely flooded	354	N 39º 21.690' (39 21 41) W 097º 06.488' (097 06 29)	1700
28	Clay	Muir silt loam, rarely flooded	358	N 39º 20.267' (39 20 16) W 097º 04.521' (097 04 31)	300
29	Clay	Eudora loam, occasionally flooded	370	N 39º 24.962' (39 24 57) W 097º 13.163' (097 13 9) Elevation: 1214	200
30	Jackson	Pawnee clay loam, 3 to 6 percent slopes	324	N 39º 24.274' (39 24 16) W 095º 34.277' (095 34 16)	100
31	Doniphan	*	*	*	100
32	Jefferson	Bismarckgrove-Kimo complex, rarely flooded	244	N 39º 03.618' (39 03 37) W 095º 22.149' (095 22 08)	0
33	Clay	Eudora loam, occasionally flooded	362	N 39º 18.293' (39 18 17) W 097º 04.192' (097 04 11)	0
34	Shawnee	*	*	*	991
35	Riley	*	*	*	360

* = No data for this observation

Continued

Table B.1 Location of soil samples, egg counts and GPS coordinates (continued)

Site	Location (County)	Soil type	Elevation of sample site (meters)	Global Positioning System (GPS) Coordinates	SCN eggs/100 cm^3 (by volume)
36	Shawnee	*	*	*	587
37	Doniphan	Contrary-Monona silt loams, 9-17 percent slopes, eroded	362	N39° 47.070 (39 47 04) W095°03.379 (95 03 22)	0
38	Doniphan	Contrary-Monona silt loams, 9 to 17 percent slopes, eroded	331	N39° 46.853 (39 46 51) W095°04.970 (95 04 58)	80
39	Clay	Muir silt loam, rarely flooded	362	N39° 23.444 (39 23 26) W097°09.895 (97 09 53)	120
40	Clay	Muir silt loam, rarely flooded	377	N39° 23.223 (39 23 13) W097°09.894, (97 09 53)	400
41	Clay	Muir silt loam, rarely flooded	399	N 39º 29.532' (39 29 31) W 097º 12.124' (97 12 07)	0
42	Clay	Sutphen silty clay loam, occasionally flooded	381	N 39º 29.027' (39 29 01) W 097º 12.097' (97 12 05)	200
43	Osage	Verdigris silt loam, occasionally flooded	309	N 38º 36.028' (38 36 01) W 095º 43.758' (95 43 45)	80
44	Osage	Verdigris silt loam, occasionally flooded	309	N 38º 36.028' (38 36 01) W 095º 43.758' (95 43 45)	80
45	Osage	*	*	*	200
46	Sedgwick	Tabler silty clay loam, 0 to 1 percent slopes	404	N 37º 35.564' (N37 35 33) W 097º 26.127' (97 26 07)	480
47	Sedgwick	Tabler silty clay loam, 0 to 1 percent slopes	406	N 37º 35.347' (37 35 20) W 097º 26.193' (97 26 11)	80
48	Harvey	Punkin-Taver complex, 0 to 1 percent slopes	438	N37° 56.735 (37 56 44) W097°38.542 (97 38 32)	0
49	Harvey	Farnum and Funmar loams, 0 to 1 slopes	430	N37° 59.109 (37 59 06) W097°38.019 (97 38 01)	160
50	Reno	Saltcreek and naron fine sandy loams, 0 to 1 percent slopes	438	N37° 56.686 (37 56 41) W097°44.347 (97 44 20)	0
51	Osage	*	*	*	440
52	Clay	Muir silt loam, rarely flooded	376	N39° 29.227 (39 29 13) W097°12.384 (97 12 23)	160
53	Clay	Muir silt loam, rarely flooded	399	N 39º 29.532' (39 29 31) W 097º 12.124' (97 12 07)	80
54	Clay	Sutphen silty clay loam, occasionally flooded	*	N 39º 29.027' (39 29 01) W 097º 12.097' (97 12 05)	480
55	Clay	Muir silt loam, rarely flooded	*	N 39º 24' 398 (39 24 23) W 097º 10' 268 (97 10 16)	120
56	Clay	Muir silt loam, rarely flooded	377	N 39º 23.223' (39 23 13) W 097º 09.894' (97 09 53)	320
57	Clay	Muir silt loam, rarely flooded	362	N 39º 23.444 (39 23 26) W 097º 09.995 (97 09 59)	240
58	Edwards	*	*	*	460
59	Shawnee	*	*	*	400

* = No data for this observation

Appendix C - HG Types and SCN Races

Table C.1 HG Types and SCN Races for each PI Line

Location	Sample Number	Eggs per 100cm3	PI Lines	
			HG Type	SCN Race
Upland	11	900	7	3 or 6
Upland	14	100	1.5.7 2.7	2 or 11
Upland	17	200	0 2.7 7	3 or 6
Upland	20	6800	2.7 7	3 or 6
Upland	21	2000	2.7 7	1 or 5
Upland	23	6000	1.2.6.7 2.5.7	2 or 11
Upland	25	3500	2.6.7	1 or 5
Upland	30	0	6	3 or 6
Upland	58	460	7	3 or 6
Upland	59	400	2.3.5.7	8 or 10
River Bottom	1	300	2.5.7	1 or 5
River Bottom	2	100	2.7	1 or 5
River Bottom	3	1100	1.2.5.6.7	2 or 11
River Bottom	4	100	1.2.3.5.6.7	4 or 16
River Bottom	5	1500	1.2.7 1.2.3.5 1.2.5.6.7	2 or 11
River Bottom	6	400	1.2.5.7 2.7 7	1 or 5

Continued

Table C.1 HG Types and SCN Races for each PI Line (continued)

Location	Sample Number	Eggs per 100cm3	PI Lines	
			HG Type	SCN Race
River Bottom	7	300	1.2.3.5.6.7	4 or 16
River Bottom	8	2700	1.3.6 1.5.6.7	12 or 14
River Bottom	9	1500	2.5.7	1 or 5
River Bottom	10	300	1.2.5.7	2 or 11
River Bottom	12	400	2.3.5.7 2.7 7	3 or 6
River Bottom	22	100	2.3 2.3.4.5	3 or 6
River Bottom	26	100	7	3 or 6
River Bottom	27	1700	0 2.5.7 7	1 or 5
River Bottom	31	100	2.7 7	1 or 5
River Bottom	34	991		
River Bottom	35	360		

Appendix D - Types of *Heterodera glycines*

Table D.1 Types of *Heterodera glycines* on PI lines in Kansas fields in 2007-2008

		Female Index								
Populations	County	PI 548402	PI 88788	PI 90763	PI 437654	PI 209332	PI 89772	PI 548316	Females on Lee 74	HG Type
1a	Shawnee	1.2	13.2	0.76	0.31	13.3	0.37	50.8	319	2.5.7
1b	Shawnee	2.65	30.6	2.65	2.65	31.06	4.98	51.82	86	2.5.7
2a	Shawnee	3.74	12.38	2.38	1.98	8.16	2.77	44.44	42	2.7
3a	Shawnee	13.36	12.72	8.29	3.53	14.2	12.29	28.85	93	1.2.5.6.7
3b	Shawnee	16.67	22.57	5.97	1.38	14.44	11.53	20.64	477	1.2.5.6.7
4a	Shawnee	18.92	17.08	11.3	1.54	17.85	15.27	48.92	120	1.2.3.5.6.7
5a	Shawnee	13.06	19.73	4.44	1.17	10.78	13.29	31.84	257	1.2.5.6.7
5b	Shawnee	23.4	32.4	10.8	0.4	27.0	9.0	9.5	46	1.2.3.5
5c	Shawnee	26.7	37.02	5.57	1.98	9.3	9.5	33.05	239	1.2.7
6a	Shawnee	8.79	18.6	4.21	0.21	4.8	3.2	50.3	78	2.7
6b	Shawnee	12.5	10	8.88	2.38	16.6	6.3	38.8	18	1.2.5.7
6c	Shawnee	1.15	2.15	0.84	0.54	3.0	0.4	11.44	186	7
7a	Shawnee	22.48	34.01	19.04	2.32	17.6	17.9	28.1	172	1.2.3.5.6.7
7b	Shawnee	36.03	17.94	12.73	1.09	15.0	15.5	40.44	157	1.2.3.5.6.7
7c	Shawnee	39.82	42.23	17.81	2.54	16.2	34.7	41.48	146	1.2.3.5.6.7
8a	Shawnee	26.59	8.33	8.41	1.5	12.0	22.0	15.36	146	1.5.6.7
8b	Shawnee	43.52	8.5	21.14	0.666	3.7	26.5	7.86	150	1.3.6
9a	Riley	3.01	13.96	2.72	1.58	14.8	1.6	85.71	105	2.5.7
10a	Riley	17.6	16.2	6.93	0.7	22.0	5.0	13.65	238	1.2.5.7
10b	Riley	17.65	16.24	6.9	0.7	22.0	5.0	13.71	237	1.2.5.7

Continued

Table D.1 Types of *Heterodera glycines* on PI lines in Kansas fields in 2007-2008 (continued)

		Female Index								
Populations	County	PI 548402	PI 88788	PI 90763	PI 437654	PI 209332	PI 89772	PI 548316	Females on Lee 74	HG Type
11b	Doniphan	0.588	5.03	0.732	0.228	9.0	0.4	16.2	364	7
12a	Crawford	1.12	10.58	1.17	5.04	5.4	2.6	26.47	51	2.7
12b	Crawford	0.583	6.037	2.55	1.09	6.3	0.3	36.98	196	7
12c	Crawford	2.78	10.83	17.31	1.34	13.4	0.8	34.96	297	2.3.5.7
14a	Jasper (MO)	12.97	9.77	5.95	2.77	20.4	2.9	40.61	98	1.5.7
14b	Jasper (MO)	7.81	10.56	9.84	0.803	1.1	0.5	35.35	320	2.7
17a	Cherokee	0.42	17.15	1.96	0.49	2.9	2.0	57.05	102	2.7
17b	Cherokee	2.63	9.63	0.55	2.67	5.5	0.5	11.69	218	7
17c	Cherokee	0.0504	0.07	0	0.35	0.4	0.1	1.34	283	0
20a	Cherokee	0	4.1	0.5	1.4	2.5	0.3	24.3	321	7
20b	Cherokee	0	11.2	0.0	0.0	2.9	0.0	32.6	158	2.7
21a	Cherokee	4.2	13.6	0.3	0.8	3.8	0.0	16.6	83	2.7
21b	Cherokee	0.48	6.31	0.103	0.241	1.13	1.0	19.27	138	7
22a	Doniphan	0.61	2.2	2.52	1.47	4.7	1.9	8.52	136	0
22b	Doniphan	0.45	1.92	0.9	0.3	1.75	0.5	14.43	95	7
22c	Doniphan	1.19	5.5	2.38	0.868	4.01	0.6	15.029	96	7
23a	Crawford	38.49	14.41	7.29	5.2	8.6	10.7	60.59	170	1.2.6.7
23b	Crawford	6.18	12.08	5.82	0.331	10.1	2.7	13.1	201	2.5.7
25a	Crawford	9.3	11.5	2.9	2.1	2.7	10.2	24.8	266	2.6.7
26a	Clay	0.68	6.91	0.68	1.15	4.26	0.41	23.25	246	7
27a	Clay	2	8.33	2.1	1.8	7.5	1.0	9.5	40	0
27b	Clay	3.37	4.44	6.5	3.0	4.62	1.8	20.83	72	7
27c	Clay	4.16	31.88	0.0	1.1	19.58	2.5	26.5	40	2.5.7

Continued

Table D.1 Types of *Heterodera glycines* on PI lines in Kansas fields in 2007-2008 (continued)

		Female Index								
Populations	County	PI 548402	PI 88788	PI 90763	PI 437654	PI 209332	PI 89772	PI 548316	Females on Lee 74	HG Type
30b	Jackson	1.4	6.07	1.1	3.6	3.63	0.1	26.92	234	7
31a	Doniphan	4.26	6.09	2.8	1.9	2.68	1.0	35.97	134	7
31b	Doniphan	0.88	22.69	2.9	0.1	3.88	1.8	32.82	163	2.7
34a	Shawnee	11.61	23.36	5.34	0	64.25	4.4	30.0	214	1.2.5.7
34b	Shawnee	17.44	33.26	2.92	.25	47.7	7.37	49.61	131	1.2.5.7
35a	Riley	31.0	5.20	20.0	0	6.5	15.6	6.0	144	1.3.6
35b	Riley	24.81	12.28	7.51	11.01	6.21	21.18	19.49	118	1.2.4.6.7
58a	Edwards	0.287	1.37	0.4	0.5	0.114	0.5	23.9	174	7
58b	Edwards	7.29	0.67	0.3	0.0	0.39	0.1	13.36	297	7
59a	Shawnee	4.89	54.68	34.49	2.48	20.74	3.2	73.75	94	2.3.5.7

Appendix E - *Heterodera glycines* on commercial lines

Table E.1 Types of *Heterodera glycines* on commercial lines in Kansas fields in 2007-2008

		Female Index						
Populations	County	KS5004N PI 548402	COMM 1 PI 88788	COMM 2 PI 88788	KS5502N PI 437654	KS4602N PI 209332	Females on Lee 74	HG Type
1a	Shawnee	4.75	47	46.7	0.22	35.34	319	2.3.5
1b	Shawnee	5.48	53.48	76.16	4.65	38.66	86	2.3.5
2a	Shawnee	3.97	21.43	49.21	1.9	7.14	42	2.3
3a	Shawnee	54.22	78.49	70.43	5.56	58.06	93	1.2.3.5
3b	Shawnee	35.07	65.31	48.36	2.03	37.6	477	1.2.3.5
4a	Shawnee	37.91	59.28	55.83	2.61	56.66	120	1.2.3.5
5a	Shawnee	27.96	70.56	73.07	0.52	35.28	257	1.2.3.5
5b	Shawnee	44.9	73.1	58.6	0	40.5	46	1.2.3.5
5c	Shawnee	51.56	101.31	73.91	2.44	33.47	239	1.2.3.5
6a	Shawnee	15.8	37.5	48	1.06	23.07	78	1.2.3.5
6b	Shawnee	16.66	53.17	97.2	5.55	0	18	1.2.3
6c	Shawnee	1.82	15.1	17	0.36	17.81	186	2.3.5
7a	Shawnee	32.17	80.32	33.13	1.74	29.06	172	1.2.3.5
7b	Shawnee	59.69	65.33	72.61	2.54	.	157	1.2.3
7c	Shawnee	38.84	47.55	65.06	3.62	28.08	146	1.2.3.5
8a	Shawnee	43.72	74	41.91	2.32	24.54	146	1.2.3.5
8b	Shawnee	17.33	36.85	21.73	7.22	10.66	150	1.2.3.5
9a	Riley	11.74	52.78	30.88	8.95	29.5	105	1.2.3.5
10a	Riley	18.65	89	50.3	0.078	31	238	1.2.3.5
10b	Riley	18.73	88.94	50.54	0.78	30.8	237	1.2.3.5

Continued

Table E.1 Types of *Heterodera glycines* on commercial lines in Kansas fields in 2007-2008 (continued)

		Female Index						
Populations	County	KS5004N PI 548402	COMM 1 PI 88788	COMM 2 PI 88788	KS5502N PI 437654	KS4602N PI 209332	Females on Lee 74	HG Type
11b	Doniphan	1.41	40.1	40.65	0.824	7.05	364	2.3
12a	Crawford	6.16	40.52	29.41	3.36	8.82	51	2.3
12b	Crawford	15.56	19.72	9.82	0.76	11.58	196	1.2.5
12c	Crawford	12.34	33.71	34.27	1.34	8.64	297	1.2.3
14a	Jasper (MO)	44.02	72.16	53.49	7.73	54.29	98	1.2.3.5
14b	Jasper (MO)	38.54	64.75	20	1.093	37.67	320	1.2.3.5
17a	Cherokee	0	34.96	50	2.24	.	102	2.3
17b	Cherokee	5.73	22.4	40.09	0.73	25.68	218	2.3.5
17c	Cherokee	0	5.83	3.35	0.058	0.795	283	
20a	Cherokee	1.8	24.3	19	0.31	12.8	321	2.3.5
20b	Cherokee	1.3	23.6	21.3	0.56	13.5	240	2.3.5
21a	Cherokee	5.62	22.38	21.45	1.03	14.94	83	2.3.5
21b	Cherokee	2.05	27.95	5.79	0.724	9.62	138	2
22a	Doniphan	7.7	25.6	24.8	2.3	8.2	136	2.3
22b	Doniphan	3.15	15.18	41.4	0.36	6.66	95	2.3
22c	Doniphan	2.97	18.75	39.43	47.74	16.22	96	2.3.4.5
23a	Crawford	62.35	41.43	50.25	18.33	32.18	170	1.2.3.4.5
23b	Crawford	10.74	39.71	18.57	0.62	29.18	201	1.2.3.5
25a	Crawford	66.92	88.78	111.17	1.99	35.77	266	1.2.3.5
26a	Clay	246	0.8	26.36	21	0.1	17.9	2.3.5
27a	Clay	1.25	57.5	27.14	3	5	40	2.3
27b	Clay	0.55	18.25	10.64	1.78	2.77	72	2.3
27c	Clay	24.5	121.07	2.5	4.16	48.92	40	1.2.5

Continued

Table E.1 Types of *Heterodera glycines* on commercial lines in Kansas fields in 2007-2008 (continued)

		Female Index						
Populations	County	KS5004N PI 548402	COMM 1 PI 88788	COMM 2 PI 88788	KS5502N PI 437654	KS4602N PI 209332	Females on Lee 74	HG Type
30b	Jackson	2.65	13.03	24.68	0.43	5.77	234	2.3
31a	Doniphan	7.27	28.54	31.79	4.92	25.62	134	2.3.5
31b	Doniphan	2.8	31.81	49.4	1.7	49.16	163	2.3.5
34a	Shawnee	24.8	55.74	50.6	0	.	214	1.2.3
34b	Shawnee	19.1	54.96	63.9	1.9	61.06	131	1.2.3.5
35a	Riley	24.3	23.8	22.2	4.8	.	144	1.2.3
35b	Riley	28.8	32.08	32.2	0.3	32.48	118	1.2.3.5
58a	Edwards	1.58	14.46	26.43	0	10.34	174	2.3
58b	Edwards	2.46	25.25	16.9	3.09	2.42	297	2.3
59a	Shawnee	25.53	102.12	127.6	1.95	0	94	1.2.3