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IPM OF SOYBEAN CYST NEMATODE IN THE USA

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Abstract. The cropping system in the USA that produces soybean every other year exerts severe pressure on the production system. Unless the system changes dramatically to produce soybean every third or fourth year, severe pressure will be continue and will reduce the likelihood of sustainable soybean production. In the foreseeable future, genetic resistance of soybean coupled with crop rotation will be the foundation of any management system for *Heterodera glycines*. Marker assisted selection will aid in selection and incorporation of specific genes and will increase the efficiency of developing resistant cultivars. However, any source of resistance may not be durable even with sound nematode management practices. Rotation of resistance genes (sources of resistance) has met with some success and may increase durability of sources of resistance. Integrating biological control in the production system with promising organisms such as *Hirsutella rhossiliensis* and *Pasteuria nishizawae* may lead to a truly sustainable system of soybean production in which *H. glycines* is no longer a yield limiting production factor.

1. INTRODUCTION

Although more than 100 species of nematodes have been associated with soybean in North America, only a few species are of economic importance (Donald et al., 1984; Noel, 1999). The soybean cyst nematode (*Heterodera glycines*) and root-knot nematodes (*Meloidogyne arenaria, M. javanica,* and *M. incognita*) are the nematodes responsible for most of the crop loss in soybean (*Glycine max* (L.) Merr.) in the USA., with *M. hapla* rarely causing economic loss. Crop loss caused by *H. glycines* was 2.91 million tonnes (t) in 2003, 3.48 million t in 2004, and 1.94 million t in 2005 (Wrather & Koenning, 2006). These losses were 31%, 28% and 28% respectively of the total crop loss due to diseases and nematodes and exceed any other disease. Crop loss due to individual species of *Meloidogyne* and other nematodes is not readily available. During the years of 2003–2005, the combined crop loss due to *Meloidogyne* spp. and all other species ranged from 106,000 to 139,000 t. Crop loss data is not readily available for the other major soybean producing nations Argentina, Brazil, and China.

In recent years the incidence and distribution of the reniform nematode (*Rotylenchulus reniformis*) have increased in the southern USA. Nearly 100 species of nematodes have been associated with soybean (Schmitt & Noel, 1984; Noel, 1999). The Columbia lance nematode (*Hoplolaimus columbus*) is important in the states of Georgia, North Carolina and South Carolina, but also has been reported from Alabama and Louisiana. *Hoplolaimus galeatus* is found frequently in

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association with soybean in the northern USA, but crop loss has not been demonstrated. *Hoplolaimus magnistylus* occurs in Arkansas, Mississippi, and Tennessee, but is considered of minor economic importance. Although several species of lesion nematodes (*Pratylenchus alleni, P. brachyurus, P. coffeae, P. hexincisus, P. neglectus, P. penetrans,* and *P. scribneri*) are associated with soybean, crop loss has rarely been demonstrated with lesion nematodes (Lawn & Noel, 1986). The sting nematodes *Belonolaimus gracilus* and *B. longicaudatus* have been associated with soybean primarily in the southern Atlantic states, but infestations have been reported from Alabama, Arkansas, Kansas, New Jersey, Oklahoma, and Texas. In 2003–2005 crop loss was reported for *Paratrichodorus minor* in Virginia, *Rotylenchulus reniformis* in Alabama, Arkansas and North Carolina, *H. magnistylus* in Louisiana and *H. columbus* in Georgia and North Carolina (Wrather & Koenning, 2006). *Hoplolaimus columbus* also caused crop loss in South Carolina (J. Mueller, pers. comm.). Nematodes other than *H. glycines* are important on a local or regional basis. Since *H. glycines* is of paramount importance in soybean production in the USA and other countries, certain aspects of management and IPM will be discussed herein.

Perhaps the most difficult aspect of nematode control for the soybean farmer is the determination of damage thresholds and action thresholds. In soils typical of much of the midwestern USA, a damage threshold based on experiments in commercial production fields was determined (Noel, 1984). The soil in both fields was a silt loam with 2% organic matter. Damage functions generated under field conditions are illustrated in Fig. 1A and 1B. In order to develop those damage functions, 20 soil cores were taken in each of 24 sites in a grid within fields and the number of cysts and eggs were determined at planting. Additionally, aldicarb was applied in paired comparisons of treated and nontreated soil. Yield and numbers of eggs and cysts were determined at the end of the growing season. The damage functions demonstrate that increasing numbers of eggs at planting resulted in greater crop loss and aldicarb was effective in increasing yield.

Application of aldicarb also illustrated other considerations in management of nematodes in soybean. First, most of the sites in the field where no cysts were recovered at planting had detectable cysts at harvest. Thus, absence of cysts in a soil sample does not mean that *H. glycines* is absent, and even when the nematode is believed to be absent it may in fact cause crop loss, as illustrated by the increase in yield associated with aldicarb when no nematodes or low numbers of nematodes were present at planting. In addition, these fields were infested with *P. scribneri*, but it is not known if the numbers and environmental conditions were conducive to the nematode. Research conducted in microplots established that damage to soybean caused by *H. glycines* is greater in sandy soils as compared to soils with more silt and clay (Koenning & Barker, 1995). Effects of the nematode on yield were ameliorated by irrigation in the sandy clay loam at all population levels, but not in the loamy sand and higher population levels.

Developing a practical and affordable sampling recommendations for *H. glycines* is complicated. Farmers simply cannot afford to pay for sufficient samples to blanket an entire field or spend the number of man hours necessary to develop reliable data as to the distribution and numbers of *H. glycines* (Schmitt, Barker, Noe,

& Koenning, 1990). Also, predictive sampling for *H. glycines* has not been investigated sufficiently. Thus, farmers need to adopt an action threshold of one cyst (i.e. detection of *H. glycines*). The adoption of this action threshold is supported by the damage functions (Fig. 1), which illustrate (as supported by subsequent studies) that yield loss of 15–20% can occur in the absence of visible symptoms (Donald et al., 2006; Wang et al., 2000; Noel & Edwards, 1996). Another practical aspect of predictive sampling is that the vast majority of farmers will take samples after harvest. Samples can be processed during the next one or two months prior to purchase of seed for the next growing season. The number of eggs, especially viable eggs, will be higher in the fall sample.

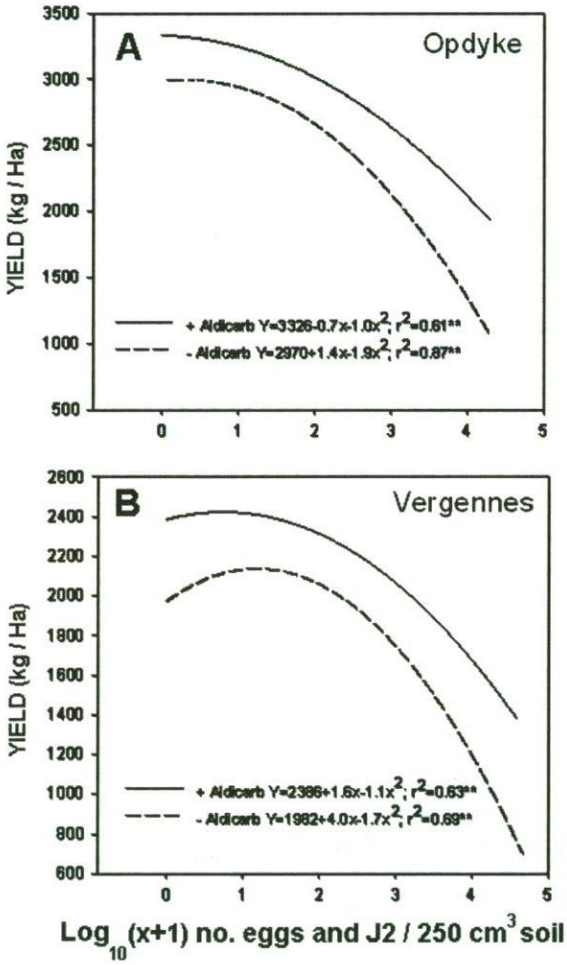

Figure 1. Damage functions for Heterodera glycines *on soybean treated and not treated with aldicarb (11.0 g a.i./100 m of row) at (A) Opdyke and (B) Vergennes, Illinois, USA.*

The recommendation to alternate crop rotation with planting resistant and then susceptible cultivars, to stabilize selection pressure, was never investigated in the field. The recommendation was based on expected reestablishment of the Hardy-Weinberg equilibrium when selection pressure would be removed by planting the susceptible cultivar. Thus, effects on selection for nematode aggressiveness on resistant cultivars would be ameliorated. I know a farmer who has faithfully practiced the maize/resistant soybean/maize/susceptible soybean rotation for 20 years and has averaged a soybean yield of 3,700 kg/ha during that time. Soil samples taken during this time have not indicated any increase in numbers of *H. glycines* on his farm and the yields indicated no increase in nematode virulence has occurred. He has always planted resistant cultivars that carry the PI88.788 source of resistance. In his situation, good nematode management has maintained a high yield and also protected the durability of resistance on his farm. In a long-term study, rotation of cultivars with different sources of resistance was effective in reducing numbers of *H. glycines* below the detection level (Noel & Edwards, 1996).

Management of nematodes in soybean primarily consists of planting resistant cultivars and crop rotation. Application of nematicides is almost nonexistent. Approximately 700 cultivars resistant to *H. glycines* are available (Shier, 2006). Differences in the levels of resistance in these cultivars to *H. glycines* may compromise their effectiveness. Figure 2 illustrates the level of resistance of 300 commercial cultivars stated as being resistant to *H. glycines* Hg Type 0 (race 3). It is obvious that the full level of resistance of PI88.788 has been lost in many cultivars. At present there are about 700 cultivars listed as having resistance to *H. glycines* (Bond, Niblack, & Noel, 2006; Shier, 2006). About 99% of these derive their resistance from PI88.788 and have cv. Fayette in their pedigree (Bernard, Noel, Anand, & Shannon, 1988).

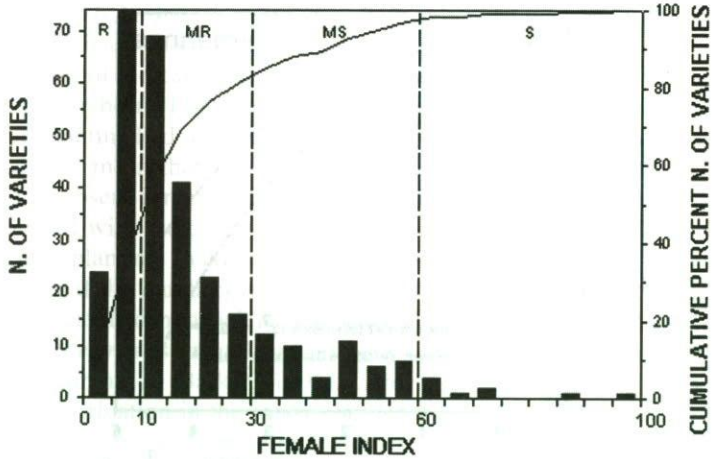

Figure 2. Level of resistance of 300 proprietary varieties to Heterodera glycines *Race 3 (HgType 0), where R is resistant, MR is moderately resistant, MS is moderately susceptible, and S is susceptible (from Noel, 2004).*

Unfortunately, "yield drag", that is the lower yield potential of resistant cultivars in the absence of *H. glycines* or numbers below the damage threshold, has caused many farmers at some point to abandon the planting of a resistant cultivar. This has had disastrous results for many soybean farmers. In order to ameliorate the lower yield potential of resistant cultivars, some companies have marketed multilines or blends. This management practice is of no value. Yield of the multilines often is less than the resistant cultivar (Table 1). Planting a high yielding resistant variety is an economically more viable option for the farmer.

Application of nematicides is used rarely to control *H. glycines* because planting resistant cultivars is more economically viable (Table 1; Koenning, Coble, Bradley, Barker, & Schmitt, 1998; Noel, 1987). Very few soybean producers know what Hg Type is present in their fields, but tests to determine Hg Types are expensive. Therefore, most farmers plant resistant cultivars without knowledge of the parasitic ability of *H. glycines* in their fields. Rotation of resistance genes by planting cultivars derived from different sources of resistance is promising (Noel & Edwards, 1996).

Table 1. Yield (kg/ha) of soybean cultivars and blends in Heterodera glycines *infested soil either treated (+) or not treated (–) with aldicarb applied in furrow at the rate of 11.0 g a.i./100 m of row, on four farms in Illinois, USA.*

	Bogota		*Opdyke*		*Sidney*	
Cultivar or blend	–	+	–	+	–	+
Union[a] (U)	2,157	2,265	1,183	1,048	2,748	2,816[b]
Fayette[c]	3,152	3,300	1,976	1,908	2,997	3,057
Franklin[d] (FR)	2,661	2,654	1,808	1,552	2,695	2,742
U/FR 3:1	2,661	2,829	1,740	1,693	2,782	2,715
U/FR 1:1	2,695	2,728	1,788	1,680	2,796	2,816
U/FR 1:3	2,480	2,621	1,478	1,572	2,641	2,829
$FLSD_{0.05}$	255		319		160	

[a]Susceptible to *H. glycines*.
[2/3]Century (susceptible) and CN290 (Peking source of resistance) planted at Sidney.
[1/3]PI88.788 source of resistance.
[3/3]Peking sources of resistance.

With the increase in no-till crop production in the USA during the last 10 years, there are unanswered questions regarding soil health, soil suppressiveness, and control of nematodes and plant pathogens. There are conflicting reports concerning the effect of no-till production on *H. glycines*, which may be due to site specific parameters. Chen, Stienstra, Lueschen, and Hoverstad, (2001) reported no effect of tillage, whereas Noel and Wax (2003), showed that numbers of *H. glycines* eggs increased more in no-till, but following rotation with maize there was no long-term

effect. In the first few years of adapting no-till production, numbers of *H. glycines* eggs may increase. However, a survey in the midwest USA found that tilled fields with a high clay content supported higher numbers of *H. glycines*. No-till fields with a lower clay content supported larger nematode numbers. In the southern USA several researchers reported lower numbers of *H. glycines* associated with soybean grown no-till (Edwards, Thurlow, & Eason, 1988; Hershman & Bachi, 1995; Koenning, Schmitt, Barker, & Gumpertz, 1995; Tyler, Chambers, & Young, 1987).

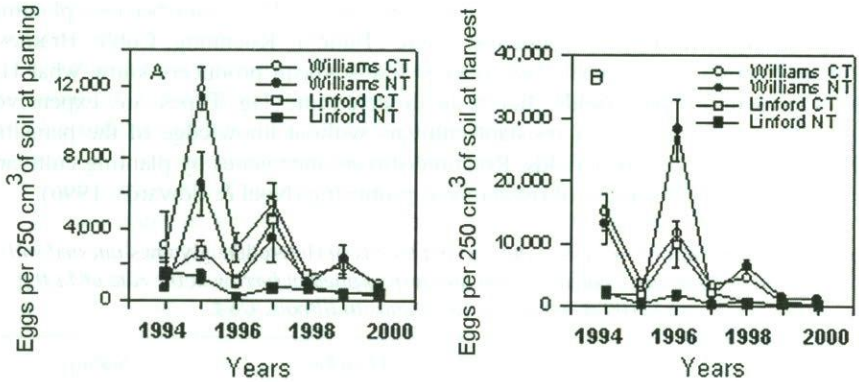

Figure 3. Population dynamics of Heterodera glycines *in a soybean-corn rotation planted either with conventional tillage (CT) or no-tillage (NT). (A) Numbers of eggs at planting, and B) numbers of eggs at harvest. Soybean cvs. Williams 82, susceptible to* H. glycines, *and Fayette or Linford, resistant to* H. glycines, *were planted in 1994 (Fayette) 1996, 1998, 1999, and 2000. Corn was planted in 1995 and 1997. Each datum is the treatment mean, and bars represent the standard error of the mean (from Noel & Wax, 2003).*

Many times, via anecdotal accounts and via personal experience, fields in which soybean yield was severely reduced become profitable. The soils have become suppressive, but capitalizing on this suppressiveness has proven difficult. Chen (2004) published a thorough review of SCN management with biological methods, including soil amendments and various organisms.

Many species of fungi have been isolated from cysts. Various fungal and bacterial species have been evaluated for their potential as biological control agents, but success in the field has been elusive. Chen and Reese (1999) reported the parasitism of *H. glycines* by *Hirsutella rhossiliensis* and population dynamics during a long-term corn/soybean rotation study. Although numbers of *H. glycines* were not reduced below the damage threshold, parasitism by *H. rhossiliensis* could play an integral role in IPM of *H. glycines*. In a microplot study, *Pasteuria nishizawae* was effective in reducing the number of cysts and eggs/cyst of *H. glycines* (Atibalentja, Noel, Liao, & Gertner, 1998; Noel et al., 2005; Fig. 4.). Infested soil from the microplots was used to infest a long-term study on tillage. *Pasteuria nishizawae* was transferred successfully and in years 1, 2 and 3 was associated with management of *H. glycines* and increases in yield of soybean (Noel et al., 2005).

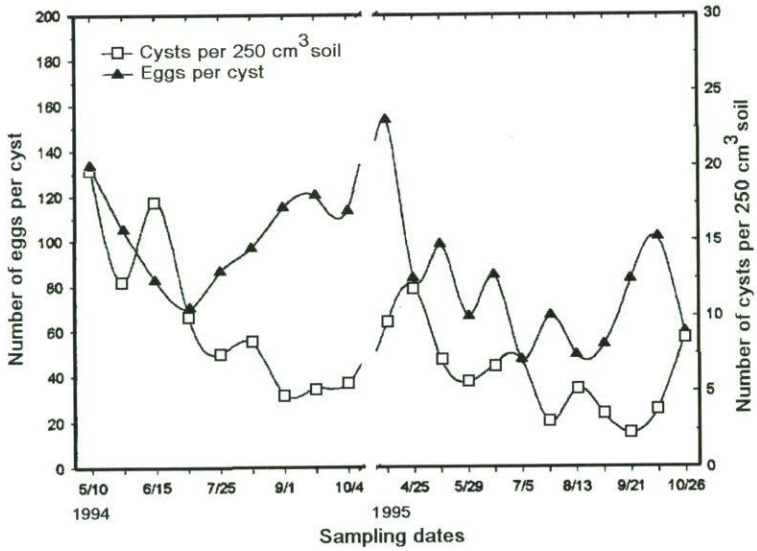

Figure 4. Population dynamics of Heterodera glycines *in a microplot study using soil naturally infested with* Pasteuria nishizawae *(from Atibalentja* et al., *1998).*

2. CONCLUSIONS

In the last decades, much progress has been made in the management of *H. glycines* for several aspects, including the application of resistant/tolerant germplasm and deployment of biological and/or agronomic management procedures. However, the intensive cropping system practiced in North and South America presents many challenges, and further research efforts are required for incorporation of IPM in a more sustainable and environment friendly production system.

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