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THE SOYBEAN CYST NEMATODE *HETERODERA GLYCINES* ICHINOHE, 1952 IN ARGENTINA

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Abstract. The damage caused by the soybean cyst nematode *Heterodera glycines* in Argentina is revised, together with possible management strategies. This nematode emerged in the last decade as one of the most important parasites of soybean in the region. The histopathology, population dynamics and dispersal of *H. glycines* and the effects of selected resistant lines and varieties are discussed. Among management tools, observations on the effects of soil fungi on *H. glycines* densities suggest a possible role of natural suppressiveness and biological control. Recommended actions include development of detailed knowledge about the occurrence of the nematode, trainings of experts, development of sound outreach programs and extension activities, evaluation of the nematode incidence on yields and research related to soybean resistance and possible exploitation of natural antagonists.

1. INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is the crop of greatest production in Argentina. It is the main commodity export, both unprocessed and processed (Weskamp, 2006), generating the greatest foreign currency income in the country (Giorda, 1997). Soybean expansion in the country started in the 1970s, and since then cultivated areas continued to expand up to 15.2 M ha in the 2005/2006 cropping season, with a production estimated in 40.5 M TM and an average yield of 2660 kg/ha. A 127% increase in the cultivated area has been estimated for the last 10 year-period, whereas production increased by 237% (Rossi, 2006). Transgenic cultivars comprise 98% of cultivars planted (Secretaría de Agricultura, Ganadería, Pesca y Alimentos). The Pampas region concentrates 83.68% of the soybean-producing area, the remaining 16.32% being distributed in other provinces (Fig. 1). Among pests affecting soybean yield, several soil nematode species have a particular incidence. To date, 32 genera and 25 phytophagous species (according to the classification criteria of Yeates, Bongers, Goede, Freckman, & Georgieva, 1993) have been detected in soybean-producing areas in Argentina (Table 1), among which *Meloidogyne* spp. and *Heterodera glycines* stand out.

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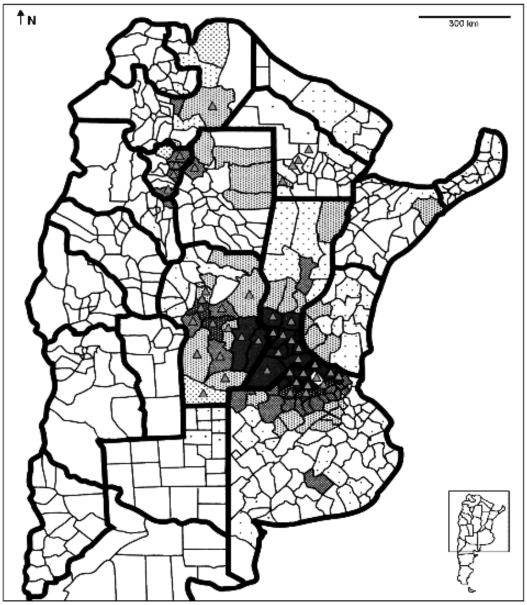

Figure 1. Distribution of the soybean-producing area in Argentina and of the nematode Heterodera glycines. *Each point corresponds to a 500-ha area or fraction larger than 100 ha; triangles indicate the departments (in provinces) where the nematode has been detected. (Adapted from Giorda, 1997).*

2. *HETERODERA GLYCINES*

The soybean cyst nematode (SCN), *Heterodera glycines*, poses the greatest problem to the normal soybean crop development and yield in the principal producing countries worldwide (Ichinohe, 1988; Noel, 1992, 1993; Noel, Mendes, & Machado, 1994; Young, 1996; Kim, Riggs, Robbins, & Rakes, 1997).

This species has a high reproductive potential, an efficient dispersal mechanism, populations with marked variability, and the capacity to survive in the soil for several years in the absence of a suitable host (Riggs & Wrather, 1992).

Up to the end of the 1990s, the greatest problems in soybean crops caused by nematodes in Argentina were attributed only to species of the genus *Meloidogyne* (March, Ornaghi, Beviacqua, Astorga, & Marcellino, 1985; Doucet & Racca, 1986; Doucet, 1993). However, during the 1997/98 cropping season fields strongly attacked (Fig. 2) by representatives of the genus *Heterodera* were detected in different localities of the provinces of Córdoba and Santa Fe (Doucet et al., 1997; Baigorri, Vallone, Giorda, Chaves & Doucet, 1998). Subsequent studies showed that the species attacking soybean was *H. glycines* (Doucet & Lax, 1999).

Table 1. Genera and species of nematodes detected in soils cultivated with soybean in Argentina.

Nematode	References
Aorolaimus sp.	Doucet and Racca, 1986
Aphelenchoides sp.	Doucet and Racca, 1986; Niquén Bardales and Venialgo Chamorro, 2004
Aphelenchus sp.	Niquén Bardales and Venialgo Chamorro, 2004
Boleodorus sp.	Doucet and Racca, 1986
Belonolaimus longicaudatus	Doucet, 1998
Cactodera sp.	Doucet and Racca, 1986; Costilla and Coronel, 1998a, 1999a
C. cacti	Costilla and Coronel, 1998a, 1999a
Coslenchus sp.	Doucet and Racca, 1986
Criconema sp.	Doucet and Racca, 1986
Criconemella ornata	Doucet, 1998
Ditylenchus sp.	Niquén Bardales and Venialgo Chamorro, 2004
Filenchus sp.	Niquén Bardales and Venialgo Chamorro, 2004
Globodera sp.	Niquén Bardales and Venialgo Chamorro, 2004
Helicotylenchus sp.	Doucet and Racca, 1986; Costilla and Coronel, 1999a; Vega and Galmarini, 1970; Coronel, Ploper, Jaldo, and Gálvez, 2004a; Niquén Bardales and Venialgo Chamorro, 2004; Fuentes, Salines, Distéfano, Gilli, and Mazzini, 2006
H. dihystera	Doucet, 1998
H. multicinctus	Costilla and Coronel, 1998a
Hemicycliophora sp.	Niquén Bardales and Venialgo Chamorro, 2004
Heterodera sp.	Baigorri et al., 1998
H. glycines	Costilla and Coronel, 1998a, 1999a, 1999b; Doucet and Lax, 1999
Ibipora sp.	Niquén Bardales and Venialgo Chamorro, 2004
Lelenchus sp.	Doucet and Racca, 1986
Macroposthonia sp.	Coronel et al., 2004a
Meloidogyne sp.	Astorga, Ornaghi, March, Beviacqua, and Marcellino, 1984; Ornaghi, Boito, and López, 1984; Coronel et al., 2004a; Niquén Bardales and Venialgo Chamorro, 2004
M. arenaria	Baigorri et al., 2004
M. incognita	Ornaghi, Beviacqua, March, and Astorga, 1981; March et al., 1985; Doucet and Racca, 1986; Doucet and Pinochet, 1992; González, Cap, and Andreozzi, 1983; Costilla and Coronel, 1998a; 1999a; Fuentes et al., 2006
M. incognita (race 2)	Ornaghi et al., 1984
M. javanica	Doucet and Racca, 1986; Doucet and Pinochet, 1992; Costilla, 1994; Costilla and Coronel, 1998a, 1999a; Fuentes et al., 2006
Neopsilenchus sp.	Niquén Bardales and Venialgo Chamorro, 2004
Nothocriconema sp.	Fuentes et al., 2006
Paratrichodorus sp.	Doucet and Racca, 1986
P. minor	Doucet, 1998
Paratylenchus sp.	Doucet and Racca, 1986; Niquén Bardales and Venialgo Chamorro, 2004
Pratylenchus sp.	Doucet and Racca, 1986; Costilla and Coronel, 1999a; Coronel et al., 2004a; Niquén Bardales and Venialgo Chamorro, 2004

(continued)

Table 1 (continued)

Nematode	References
P. agilis	Doucet and Racca, 1986
P. brachyurus	Doucet and Racca, 1986; Costilla and Coronel, 1998a
P. delattrei	Doucet and Racca, 1986
P. goodeyi	Costilla, 1994
P. hexincisus	Doucet and Racca, 1986; Doucet, 1988
P. neglectus	Doucet and Racca, 1986
P. penetrans	Doucet and Racca, 1986
P. pratensis	Costilla, 1994
P. scribneri	Doucet and Racca, 1986
P. vulnus	Doucet and Racca, 1986
P. zeae	Doucet and Racca, 1986; Costilla, 1994; Costilla and Coronel, 1998a
Psilenchus sp.	Niquén Bardales and Venialgo Chamorro, 2004
Rotylenchus sp.	Doucet and Racca, 1986
Scutellonema sp.	Doucet, 1998; Coronel et al., 2004a; Niquén Bardales and Venialgo Chamorro, 2004
Trichodorus sp.	Coronel et al., 2004a
Tylenchorhynchus sp.	Doucet and Racca, 1986; Coronel et al., 2004a
Tylenchus sp.	Coronel et al., 2004a; Niquén Bardales and Venialgo Chamorro, 2004
Xiphidorus sp.	Doucet and Racca, 1986
X. saladillensis	Luc and Doucet, 1990
Xiphinema sp.	Doucet and Racca, 1986; Coronel et al., 2004a; Niquén Bardales and Venialgo Chamorro, 2004
X. "americanum" (*sensu lato)*	Luc and Doucet, 1990
X. index	Doucet, 1998
X. krugi	Luc and Doucet, 1990

The knowledge that species had appeared in Brazil in the 1991/92 cropping season should have been a well-founded reason to organize a systematic exploratory search in the main soybean-producing areas in the country, especially in those areas where seeds from Brazil were used. However, because of the lack of preventive policies, it was only in the 1997/98 cropping season that authorities and producers became aware of the occurrence of this nematode in the country. At that time, damage became evident, possibly because of the high population densities.

Since that moment, surveys in different fields devoted to this crop were performed, with the aim of defining infested and pathogen-free areas. At present, the nematode can be considered to have a wide distribution (Fig. 1), occurring in several localities in the provinces of Buenos Aires, Córdoba, Chaco, Salta, Santa Fe, Santiago del Estero and Tucumán (Lax, Doucet, & Lorenzo, 2001). It has been mentioned that between 500,000 ha (Wrather et al., 2001) and 1,500,000 ha would be infested by this pest within the core soybean-producing area of the country (Gamundi, Borrero, & Lago, 2002).

Figure 2. Infested field with Heterodera glycines *in the province of Córdoba, Argentina.*

Several highly infested plots have been detected in some localities, very often exceeding the damage threshold levels accepted by other countries (Table 2).

Table 2. Density of Heterodera glycines *(cysts) in soils, for different provinces of Argentina.*

Province	*Cysts/100 g soil*	*Reference*
Buenos Aires	1–134	Gamundi et al., 1999a
Chaco	2–6	Gamundi et al., 1999a
Córdoba	1–352	Serrano et al., 1999
	17–362	Doucet, Lax, Giayetto, and Di Rienzo, 2001a
	1–403	Gilli et al., 2000
Salta	2	Gamundi et al., 1999a
Santa Fe	0–197	Gamundi, Lago, Bacigalupo, Borrero, and Riart, 1999b
	1–299	Gamundi et al., 1999a
Tucumán	15–300	Costilla and Coronel, 1998a
	1–400	Coronel and Costilla, 1999
	1–498	Coronel, Costilla, Ploper, and Devani, 2001
	3-67	Gamundi et al., 1999a

3. LIFE CYCLE

While the information available indicates that the different stages of the nematode's cycle in Argentina fit with those reported for the species, there are no accurate data on the duration of each stage, for the different soybean-producing areas. The areas are distributed in phytogeograhical regions with very different climatic, pedological and plant cover characteristics. It is possible therefore that, depending on the sites and the maturity groups for the soybean cultivars that can be cultivated, the species' life cycle length may vary considerably. It has been mentioned that the cycle length mainly depends on soil temperature (Lawn & Noel, 1990; Noel, 1993), and, in some places, three to seven generations may occur in a single cropping season (Burrows & Stone, 1985).

Research conducted in an infested plot in the province of Córdoba revealed that by the end of the cropping season, a great number of seeds fell to the ground during harvest. Driven by favourable climate conditions, new soybean plants grew some time later and continued to develop until early winter. Although the development of the aerial part of these plants is limited, analyses performed in the roots demonstrated the presence of white females with egg masses and cysts, indicating that the nematode development continues, even at very low soil temperatures in July (6.2–10ºC). Thus, although environmental conditions are not optimal, a population in these conditions would complete at least one new generation between autumn and early winter (Lax, 2003). It would therefore be very important to gather accurate information, in the country, about the situation in other soybean cultivated areas where the SCN is present.

4. POPULATIONS AND RACES

As in other phytophagous nematode populations, several aspects of *H. glycines* show a considerable variability. The evaluation and comparison of certain morphometrical characters corresponding to second-stage juveniles, males, females, and cysts showed significant differences among populations corresponding to different races (Lax & Doucet, 2001a, 2001b, 2001c, 2002; Lax, 2003).

Some level of intra and inter-population variability were recorded in morphological characters at these stages, not being possible to detect characters that clearly differentiated the populations examined (Lax & Doucet, 2001a, 2001b, 2001c, 2002). Although SCN was detected in numerous localities of different provinces, only a few populations have been properly characterized with respect to both the parameters used to identify the species, and different aspects of its biology.

The species has several races, each one showing a particular preference for certain soybean cultivars. To date, races 1, 3, 5 (HG type 2, 5, 7), 6, 9, and 14 (Table 3) have been recognized by the differential host test (Riggs & Schmitt, 1988; Niblack et al., 2002) in the country, race 3 appearing as the most frequent.

Moreover, the levels of variability were analysed in two populations of the nematode from different provinces, using Random Amplified Polymorphic DNA markers, with the aim of evaluating the genetic population structure of this species. This study revealed an important degree of genetic differentiation between both populations, probably as a consequence of limited gene flow between them or because each population was under different management practices at its site of origin (Lax, Rondan Dueñas, Gardenal, & Doucet, 2004).

Table 3. Races of Heterodera glycines *in different localities of Argentine provinces where soybean is cultivated.*

Province	Locality	Race	References
Córdoba	Córdoba	3	Gilli et al., 2000
	Corral de Bustos	3	Gilli et al., 2000
	Laguna Larga	1, 3	Silva et al., 1999
	Marcos Juárez	3	Dias, Silva, and Baigorri, 1998; Silva et al., 1999
Santa Fe	Armstrong	3	Silva et al., 1999
	Las Parejas	3	Dias et al., 1998; Rossi, Nari, and Cap, 1999
	Maciel	3	Zelarrayán, 1999
	Santa Fe	3	Gilli et al., 2000
	Tortugas	3, 14	Dias et al., 1998
	Totoras	1	Silva et al., 1999
	Totoras	3	Rossi et al., 1999; Zelarrayán, 1999
Tucumán	Burruyacú	3	Coronel and Costilla, 1999
	Cruz Alta	5 (HG type 2, 5, 7)	Coronel and Costilla, 1999; Coronel, Ploper, Devani, and Galvez, 2005
	Garmendia	3	Coronel et al., 2001
	La Virginia	3	Zelarrayán, 1999
	Los Hardoy	3	Zelarrayán, 1999
	Los Pereyra	5	Coronel et al., 2001
	San Agustín	5	Coronel et al., 2001
	San Luis de las Casas Viejas	6	Coronel et al., 2001
	Taruca Pampa	6	Coronel et al., 2001
Unknown	Unknown	9	Gamundi et al.,2002

5. HOST-NEMATODE RELATIONSHIPS

5.1. Histological Alterations

Histological changes induced by this nematode species in roots of cultivars usually used in the soybean-producing areas in Argentina were analyzed. Depending on the cultivar, such alterations may be of major or minor intensity. In susceptible plants, both in the primary and lateral roots, cell necrosis in the cortex can be observed, which is produced by the lesion generated by juveniles penetrating and migrating and by females subsequently establishing inside tissues. Females are located near the central cylinder, which is the most affected region because of the parasite feeding site (syncytium) formed here. Syncytia can occasionally project to the cortex or form in that region. When two or more syncytia develop in neighbouring areas, they can occupy almost the entire central cylinder, which can be reduced to a small group of cells. Functional syncytia (Fig. 3), associated with females with egg masses, are composed of cells of variable shape and show different degrees of hypertrophy. Cell walls are slightly thickened and show interruptions in some sectors, allowing cytoplasm movement in neighbouring cells.

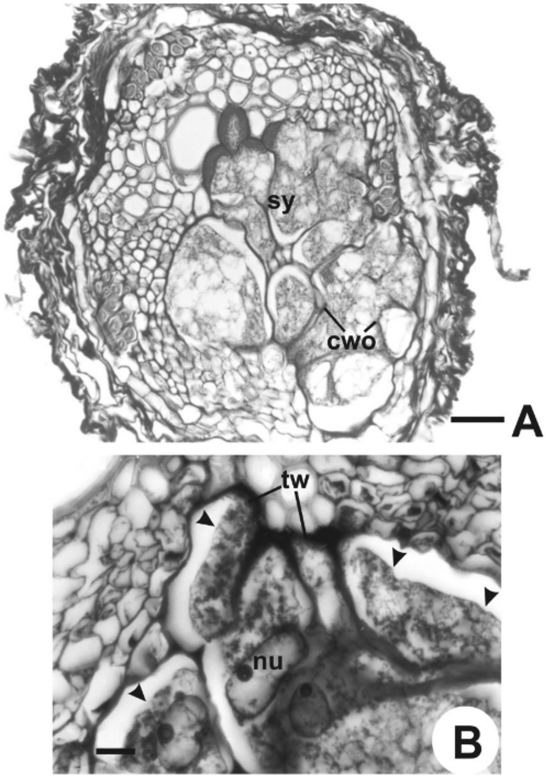

Figure 3. Histological section of root of soybean parasited by a Heterodera glycines *population, race 1. (A) Cultivar Pioneer 9501, functional syncytium in the central cylinder. (B) Cultivar Asgrow 5401, details of the syncytium showing cell plasmolysis (arrows). Abbreviations: cwo: cell wall opening; nu: nucleus; tw: thickened wall; sy: syncytium. Scale bars: A = 25 μm; B = 10 μm. (Adapted from Tordable, 2004).*

The syncitia cytoplasm is dense, of granular aspect, with different degrees of vacuolization and with large-sized nuclei of spherical, ovoid, or lobulated shape and prominent nucleoli. Walls adjacent to xylem vessels usually show a good development of irregular wall thickenings and of rugose texture. Non-functional syncytia can also be distinguished (Fig. 4), frequently associated with cysts. Dead cells show different levels of disorganization and are non-functional (Tordable, 2004).

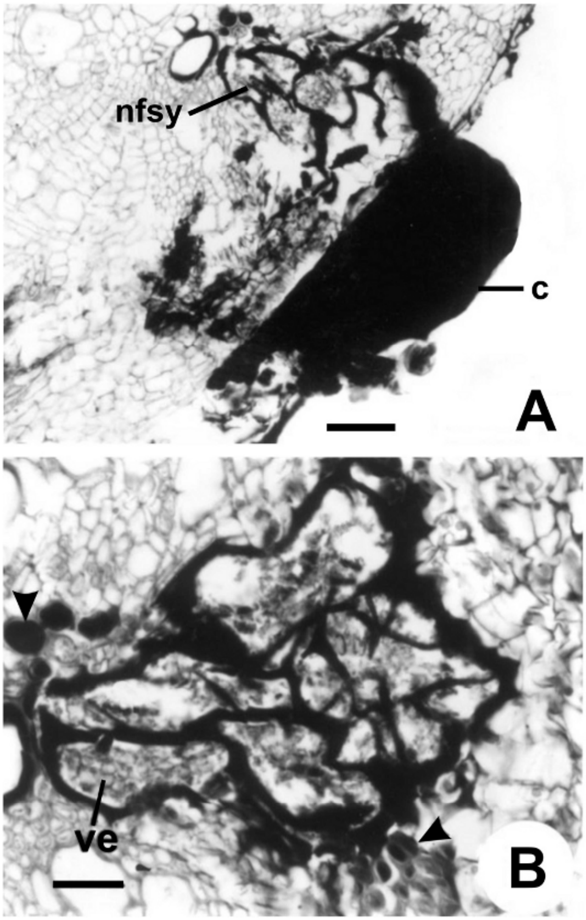

Figure 4. Histological section of root of the soyben cultivar Pioneer 9501, parasitised by a Heterodera glycines *population, race 1. (A) Non-functional syncytium related to a nematode cyst. (B) Detail of non-functional syncytium showing occluded cells of xylem and modified fibres (arrows). Abbreviations: c; cyst; nfsy: non-funcional syncytium; ve: vesicle. Scale bars: A = 50 μm; B = 25 μm. (Adapted from Tordable, 2004).*

Nodules of *Bradyrhizobium japonicum* with functional syncytia were occasionally detected at an early differentiation stage. The nematode-induced syncytium was located in the cortical area of the nodule, close to the conductive tissue (Fig. 5). It was composed of slightly hypertrophied cells of thin, partially fragmented walls.

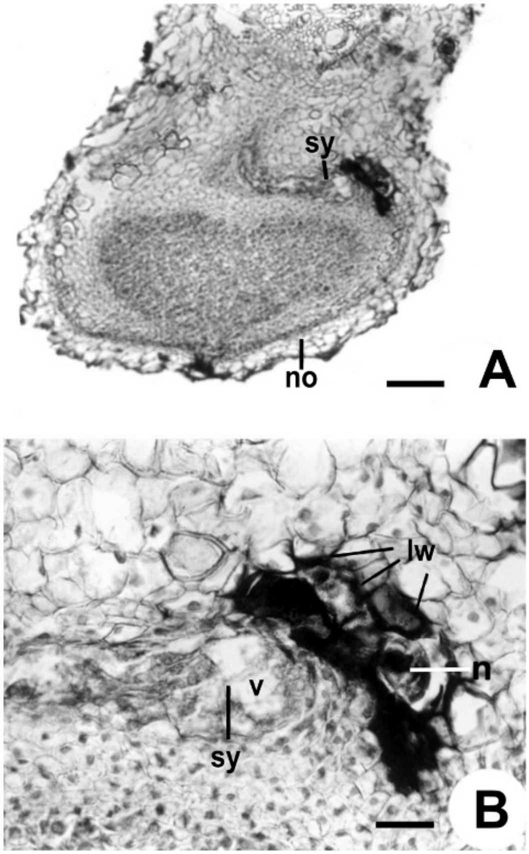

Figure 5. Histological section of a nodule of Bradyrhizobium japonicum *in the soybean cultivar Pioneer 9501, associated to a* Heterodera glycines *population, race 1. (A) Functional syncytium in the nodule cortical zone. (B) Detail of syncytium. Abbreviations: lw: lignified wall; n; nematode; no: nodule; sy: syncytium; v: vacuole. Scale bars: A = 50 μm; B = 25 μm. (Adapted from Tordable, 2004).*

The cytoplasm was granulose, slightly dense, and with a large vacuole in some cells, and nuclei were spherical, somewhat hypertrophied, with prominent nucleoli (Tordable, Lorenzo, & Doucet, 2003). Infested nodules degenerate rapidly and represent one of the reasons for plants losing their efficiency in atmospheric nitrogen fixation (Khan, 1993).

Specific studies showed that, under local crop conditions, both transgenic cultivars – Asgrow 5435 RG (Tordable et al., 2003), Pioneer 94B01, Asgrow 5901 (Tordable, 2004) – and non-transgenic cultivars – Pioneer 9501 (Doucet, Tordable, & Lorenzo, 2003), Asgrow 5401 (Lorenzo, Doucet, & Tordable, 1999), Asgrow 5402, Asgrow 5409, NK 641, Torcacita (Tordable, 2004) – were susceptible to a *H. glycines* population of race 1, in the province of Córdoba. It should be noted that Asgrow 5435 RG, indicated as resistant to SCN in soybean seed catalogues (Nidera Semillas, 1998/1999), behaved as a susceptible cultivar (Tordable et al., 2003). Only one of the cultivars evaluated, Asgrow 5153 (non-transgenic) showed to be resistant to this population.

The histopathological analysis conducted in this cultivar did not reveal the presence of syncytia in the roots. Some modifications were observed (cell necrosis, wall thickenings, hypertrophied nuclei being among the main ones), not directly related, however, to the presence of juveniles or another stage of *H. glycines* (Tordable, 2004).

5.2. Response of Cultivars to the Attack of SCN

In Argentina, works on genetic improvement of soybean are carried out with the aim of gathering more informations on yield, tolerance to herbicides, behaviour in the presence of different pathogens, among the main aspects (Baigorri et al., 2004). Since 1980, the Instituto Nacional de Tecnología Agropecuaria (INTA) has been leading the National Network for the Evaluation of Soybean Cultivars (Red Nacional de Evaluación de Cultivares de Soja).

Annual studies are conducted to evaluate yield, agronomic characteristics, and response of new cultivars of different maturity groups to certain pests, as well as new cultivars' development in different soybean-producing regions in the country (north, northern pampas, and southern pampas) (Baigorri et al., 2000, 2004; Fuentes et al., 2005). To date, the degree of susceptibility to SCN has been evaluated only for some cultivars in nursery, and the response of some of them has been evaluated in the field only exceptionally. The races to which the cultivars considered are susceptible/resistant were not considered either.

The response of a group of soybean cultivars usually cultivated in the northwestern region of the country to the action of SCN populations belonging to races 5 and 6 was evaluated in greenhouse conditions. Most of these cultivars behaved as susceptible and moderately susceptible to these races, whereas few of them showed to be moderately resistant (Coronel et al., 2001; Coronel, Ploper, Devani, Galvez, & Jaldo, 2003a; Coronel & Devani, 2006). Table 4 summarizes the cultivars that were found to be moderately resistant (MR) and resistant (R) to populations of different races of SCN in Argentina.

Table 4. Soybean cultivars indicated as moderately resistant (MR) and resistant (R) to Heterodera glycines *populations in Argentina. Nematode race is indicated in parenthesis.* **Names of cultivars correspond to those given by authors in the references.*

Cultivar*	Response to SCN	References
A 4602 RG	R (3, 14)	Vallone, 2002
A 5428 RG	R (3)	Vallone, 2002
A 6401 RG	MR (6)	Coronel et al., 2003a

(continued)

Table 4. (continued)

Cultivar*	Response to SCN	References
A 6040 RG	MR (6); R (3)	Vallone, 2002; Coronel et al., 2003a
A 6411 RG	MR (5)	Coronel and Devani, 2006
AW 4902 RR	R (3, 14)	Vallone, 2002
AW 5581 RR	R (3, 14)	Vallone, 2002
Asgrow 4004	R (3)	Gamundi, Bodrero, Mendez, Lago, and Lorenzatti, 1998
Asgrow 4501 RG	MR (3)	Gamundi et al., 1998
Asgrow 5153	R (3)	Gamundi et al., 1998
Asgrow 5435 RG	R (3)	Gamundi et al., 1998
Asgrow 5634 RG	R (3)	Gamundi et al., 1998
Asgrow 6001	MR (3)	Lago, Riart, Gamundi, Bodrero, and Midula, 1999
Asgrow 6444 RG	R (3)	Gamundi et al., 1998
Asgrow 6445 RG	MR (3, 14)	Gamundi et al., 1998
Anta 82 RR	MR (6)	Coronel et al., 2003a
Campeona 6.4	MR (5, 6); R (3, 14)	Coronel et al., 2001, 2003a; Vallone, 2002
NK Coker 6738 SC	MR (6); R (1, 3)	Gamundi et al., 1998
NK Coker 8.1	MR (5, 6); R (1, 3)	Gamundi et al., 1998; Coronel et al., 2001, 2003a
Forrest	MR (5)	Coronel et al., 2001
GR 80	MR (6)	Coronel et al., 2003a
Hartwig	R (5)	Coronel et al., 2001; Coronel, Ploper, Jaldo, and Gálvez, 2004b
Leo 56 RR	MR (3)	Ferrarotti and Roldán, 1999
Leo 81 RR	MR (3)	Ferrarotti and Roldán, 1999
Leo 240 RR	R (3)	Ferrarotti and Roldán, 1999
Leo 558 RR	R (3)	Ferrarotti and Roldán, 1999
Leo 10074	MR (3)	Ferrarotti and Roldán, 1999
Leo 10364	R (3)	Ferrarotti and Roldán, 1999
Leo 10448	R (3)	Ferrarotti and Roldán, 1999
Leo 10560	MR (3)	Ferrarotti and Roldán, 1999
Leo 10888	MR (3)	Ferrarotti and Roldán, 1999
Mágica 7.3 RR	MR (6); R (3)	Vallone, 2002; Coronel et al., 2003a
Maleva 42 RR	R (3; 14)	Vallone, 2002
Maravilla 45 RR	MR (6)	Coronel et al., 2003a
Nativa 46 RR	R (3)	Vallone, 2002
Nueva Maria 55 RR	MR (5)	Coronel and Devani, 2006
PI 437654	R (5)	Coronel et al., 2001, 2004b
Pioneer 94B01	R (3, 14)	Gamundi et al., 1998
Pioneer 94B41	R (3, 14)	Gamundi et al., 1998
Pioneer 9492	R (3, 14)	Gamundi et al., 1998
Qaylla RR	MR (5, 6)	Coronel et al., 2003a; Coronel and Devani, 2006
TJ 2046	R (1)	Vallone, 2002
TJ 2055 RR	MR (5)	Coronel and Devani, 2006
TJ 2070 RR	MR (5)	Coronel and Devani, 2006

5.3. Relationship of SCN with the Environment

It is well known that population density of *H. glycines* fluctuates throughout the development of the soybean crop in response to different environmental factors, temperature and humidity having the greatest influence (Schmitt, 1992). A single three-year study has been conducted on the basis on this information, which evaluated the possible correlations between the factors mentioned, a given sequence of susceptible cultivars, and the density of the nematode population in an infested field in Córdoba province (Lax & Doucet, 2004).

Only a small proportion of the variation detected in the number of individuals (second-stage juveniles and cysts) in soil was explained by temperature and humidity. With respect to the relationship with the cultivars used, density of individuals gradually decreased over time, although cultivars were susceptible plants. Observations in cysts revealed that many of them had eggs attacked by fungi (Fig. 6) which behaved as biological control agents of this SCN population. Eggs of the nematode attacked by pathogenic fungi were also observed in fields of the province of Tucumán (Costilla & Coronel, 1998a, 1998b). Another situation of a decrease in a *H. glycines* population was also observed during 1998/2004 in some plots of the province of Santa Fe, but the apparent causes were not mentioned (Lago, Borrero, & Gamundi, 2006).

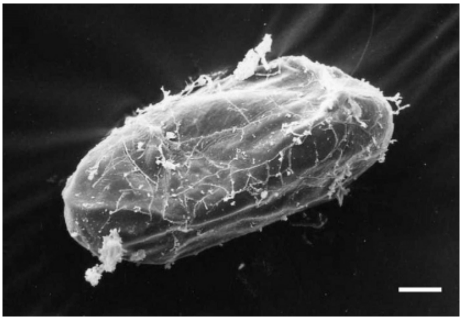

Figure 6. Scanning electron microscopy. Egg of Heterodera glycines *attacked by fungi. Scale bar: 10 µm.*

6. LOSSES

Losses produced in Argentina by *H. glycines* have been estimated only in some areas. In the localities of Marcos Juárez (province of Córdoba) and Totoras (province of Santa Fe) losses of 1400 and 2300 kg/ha, respectively, were recorded for the 1997/1998 cropping season (Gamundi et al., 2002). Losses of 30% were estimaded in plots located in central Córdoba (Doucet & Lax, 1999). For localities of southern Córdoba, yield reductions up to 64% were recorded (Gamundi, 1999). For the same cropping season and in the same provinces, a yield reduction of more than 58% was recorded, and production losses of about 55,000 tons were estimated in the country (Wrather et al., 2001). However, the values indicated were taken from publications that did not provide the methods used for losses evaluation.

The yield of different soybean commercial cultivars was evaluated in microplots infested with SCN in the northwestern region of the country (Coronel et al., 2003b). In all cases yields were significantly higher in non-infested than in infested plots. Losses ranged from 24.4 to 36.0%, and tended to be greater in the highest yielding cultivars (Table 5).

Table 5. Evaluation of yields of commercial soybean cultivars in non-infested and infested plots of the province of Tucumán, Argentina (From Coronel, Ploper, Jaldo, Galvez, & Devani, 2003b).

Cultivar	*Yield (kg/ha)*			
	Non-infested plots	*Infested plots*	*Yield losses (kg/ha)*	*% Yield losses*
A 8000 RG	2958	1991	967**	32.1
A 6040 RG	2806	1809	997*	35.5
Munasqa RR	2767	1771	996**	36.0
A 5409 RG	2722	1827	895*	32.9
Anta 82 RR	2208	1556	652*	29.5
Qaylla RR	2133	1533	600**	28.1
Mágica 7.3 RR	1974	1493	481*	24.4

*, ** Means significantly different between non-infested and infested plots at $P \leq 0.05$ and $P \leq 0.01$, respectively.

7. MANAGEMENT

Heterodera glycines has some characteristics that make its management complex: a short life cycle, high reproductive potential, populations with remarkable physiological variability, resistance stage (cyst) and very efficient dispersal mechanisms (wind, water, animals, contaminated seed bags). In Argentina, management of the species should be based on an integrated control approach. This involves having a thorough knowledge of all those aspects related to the biology and ecology of both the parasite and the host. It is surprising to note that in some works addressing integrated control of soybean pests, nematodes are not included (Satorre et al., 2003; Aragón & Flores, 2006).

7.1. Early Nematode Detection

Knowing if SCN is present or absent in a soil prior sowing is the most important step in the management of possible problems. If the species is absent, it will be possible to cultivate any crop suitable for the region. If it is present, depending on the race and nematode population density, it will be necessary to take measures in order to protect the plants. Thus, early detection of the pathogen is crucial. Given the particular life cycle of this species, infective juveniles, cysts, and possibly males may be found in the soil. While the first two stages appear more frequently, cysts will always be detected. The soil analysis prior to seeding will determine what steps must be followed.

Different soil extraction techniques are used for nematodes, depending on the stages to be detected. Vermiform specimens (second-stage juveniles and males) are obtained by centrifugal-flotation technique (Jenkins, 1964), whereas cysts are extracted by the traditional flotation technique (Fenwick, 1940). While detecting cysts is of greatest concern, studies on population dynamics require observation and counting of the three stages mentioned. This requires having soil samples to extract the different stages separately, which in turn involves investing a considerable amount of time and effort. Combining both methods mentioned offers the possibility of extracting the three stages from the same soil sample, with the advantage of ensuring a more efficient cyst recovery (Doucet, Lax, Di Rienzo, & Suarez, 2001b).

7.2. Identification of Races

Once the presence of *H. glycines* in a field is confirmed, the race must be defined with the aim of selecting resistant/tolerant cultivars that may be cultivated in that field. Although 6 races have been identified so far, given the extensive area devoted to soybean in Argentina the information available is probably very limited. Since studies on this particular topic were carried out at specific sites and at a given moment, they do not necessarily show the real situation in the area. Besides, it is important to evaluate the race identity regularly at a given place, since the continuous use of the same resistant cultivar may, through the insurgence of a selection pressure, bring about the appearance of a different race that may cause severe damage to such plant.

7.3. Chemical Control

Given the vast areas devoted to soybean crops in Argentina, the use of nematicides is economically unfeasible (besides producing environmental pollution and other problems). However, an assay was carried out in the province of Santa Fe to evaluate the action of carbofuran and aldicarb, in a plot attacked by the nematode and cultivated with susceptible cultivars. The results showed that applying the product did not provide increased yields (Gamundi et al., 1998).

7.4. Crop Rotation

When the presence of one or several nematode races is detected, measures must be taken so that crop production is not reduced significantly. This means that soybean will coexist with the SCN. Hence the SCN population density will have to be reduced to levels that do not produce severe damage to the crop, which is accomplised by using different medium/long term crop rotation schemes in the cultivated plots (non-host plants, resistant or susceptible cultivars).

Among the crops most commonly grown in the Pampas, the following have been mentioned as non-hosts: maize, sorghum, sunflower, peanut, cotton, sugarcane, alfalfa and safflower (Gamundi et al., 1998). Observations in three infested plots showed that density of viable cysts decreased by 75% with maize, 90% with sorghum, and 80% with sunflower followed by pasture seeding in autumn (Gamundi et al., 1998).

The incidence of different crop sequences on the cyst population was evaluated in different fields of Santa Fe (Lago et al., 1999; Méndez, Bodrero, Gamundi, & Lago, 1999; Gamundi et al., 2002, 2004). The sequences of susceptible soybean-sunflower, maize-susceptible soybean, susceptible soybean-moderately resistant soybean reduced the amount of cysts in soil (Lago et al., 1999). When SCN density exceeds 10 viable cysts/100 gr of soil it is considered necessary to plant a non-host crop (corn or resistant soybean) for a period longer than a cropping season, in order to reduce the SCN population to levels below the damage treshold. When populations are lower, alternating a non-host crop or resistant soybean with susceptible soybean or with the wheat-susceptible soybean sequence contributes to a decrease of cysts in soil, and therefore yields are not so much affected. Wheat/susceptible soybean double crop was the most effective way to place the susceptible materials in the rotations to avoid the appearance of new races and the growth of the population. The lowest cyst infestation levels were achieved with maize as a monoculture (Gamundi et al., 2002; Gamundi, Bodrero, Lago, Mendez, & Capurro, 2004). However, it is very important to remember that once the nematode was established in a field, its eradication has not been possible, so far.

7.5. Preventive Measures Against Cyst Dispersal

Preventing this species' spread represents, as in many other cases, one of the most efficient strategies to tackle the problems it causes. Among the measures that are advocated, no-till is usually considered. Through this system much less soil is removed than through conventional tillage, reducing wind-borne cyst dispersal (Andrade & Asmus, 1997).

Using nematode-free seeds is another preventive measure of great importance. This system contributes to the preservation of crop development and to prevent the pathogen from establishing in the plots to be cultivated. If the SCN is already present, its population may be increased with the presence of new cysts (of the same or another race) together with seeds contaminated with soil particles.

In Argentina, soybean is frequently cultivated on roadsides along roads heavily used even by soybean seed transporting trucks. This practice is strongly discouraged, since it may contribute to the appearance of new infestation sources as seeds and nematode-contaminated soil fall on the ground. To avoid transport of infested soil, agricultural machinery used in a given plot should be carefully washed before being used in another plot. Using hired machinery without taking into account this recommendation is one of the many causes of nematode dispersal and colonization of new soils.

Preventing *H. glycines* dispersal requires not only practices like the ones mentioned above, but also implies the implementation of efficient phytosanitary control programs by responsible institutions, both at the national and provincial levels, as well as strong awareness of the problem by technicians and producers.

8. CONCLUSIONS

H. glycines is widely dispersed in Argentina. However, little attention has been given to basic aspects of the species biology, mode of recognition, races, behaviour, natural antagonists, ecology, interactions with other nematode species, such as *Meloidogyne* spp., among other aspects that are essential for selecting more efficient management strategies. Enhancing the knowledge of these aspects is of great importance, since this crop has been expanded enormously in the country in the last years. Different soybean cultivars show a notable adaptation capacity to diverse climate and pedological conditions; therefore, colonization of new soils by the crop is very likely to be coupled with dispersal of this nematode species.

Therefore, the following actions are highly recommended:

(1) *Knowledge of the areas free of and infested by SCN.* Thus, cultivating new cultivars of high yield in non-infested soils and defining necessary rotation schemes in infested soils will be feasible. This implies developing specific prospective programs in all those localities where the crop is cultivated in the country. Furthermore, this previous knowledge will prevent soils attacked by the nematode from being cultivated with cultivars that contribute to increase the pathogen population.

(2) *Training of experts in the subject.* It is very important that experts are very well trained in this issue. The occurrence of morphologically similar species like *H. trifolii* in the country highlights the need for training people who are provided with all the necessary information in the subject, to perform sound and reliable diagnosis.

(3) *Development of sound outreach programs.* Despite the time elapsed since this nematode was first detected and the damage it produces to the soybean crop, some technical experts and producers still do not have basic robust information on the topic. The institutions responsible for this problem must ensure efficient outreach mechanisms to reverse this situation.

(4) *Evaluating the magnitude of the impact of SCN on the crop production.* Determining the nematode incidence on yields, both at the local and national levels, is very important. Up to the present, results published on this issue would correspond to specific trials lacking a rigorous experimental design; hence, the information obtained would have a relative significance. The estimation of losses caused by the nematode in numerous regions of the country requires adapting different methods according to the places, the most widely used cultivars, the race, and the pathogen population density.

(5) *Conducting research related to possible natural antagonists.* As it has been already indicated, some natural antagonists naturally occurring in the soil (e.g., fungi) would contribute to the reduction of the nematode population density. The diversity that characterizes the different environments where the crop is cultivated suggests that there may be other natural antagonists that could be employed with the same purpose.

Contrarily to what was assumed, population densities of the SCN seem to have decreased in different soybean-producing areas since it was detected. Up to the present, the action of antagonists is considered to be the reason of such reduction. However, whether this trend will continue or not is uncertain. For this reason, the nematode occurrence in the principal soybean-producing areas in the country is a serious threat, which implies the urgent need for further basic and applied research aimed at gathering useful information to manage the problem.

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