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Current nematode threats to Brazilian agriculture

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ABSTRACT

Since the description of the first species of a root-knot nematode, *Meloidogyne exigua*, causing extensive losses on coffee crops at Rio de Janeiro State,19th century ending, nematological problems have been emerged on different crops in Brazil, causing high losses for economic important commodities, as coffee, sugarcane and soybean. The current intensified use of agricultural lands in Brazil is only one of the causes of this constant problem. Therefore, it will be discussedin this review the current nematological problems to Brazilian agriculture, the losses and damages associated, as well as a brief historic and future prospect of emergent nematode species.

Keywords: root-knot nematodes, lesion nematodes, ectoparasitic nematodes, soybean cyst nematode

INTRODUCTION

In the year of 40th birthday of the Brazilian Nematological Society, nematodes continue to cause serious damage to Brazilian agriculture and challenges are renewed continuously. Since the description of the first species of a root-knot nematode, *Meloidogyne exigua*, causing extensive losses on coffee crops at Rio de Janeiro State (Goeldi, 1892), periodically we are faced with an emergent species which becomes a serious pathogen in some economically important crop in Brazil.

Indeed, about one century after this first catastrophic disease caused by a nematode, the soybean cyst nematode (SCN) (*Heterodera glycines* Ichinoe) was found in Brazil. This pathogen spread very fast and, from an infested area of about 5,000 ha at 1991/92, it expanded to more than 200,000 ha in the following years, with losses estimated at 20,000 million dollars (Silva et al., 1999). Nowadays, the SCN continues to cause extensive damages on soybean fields in Brazil, despite the wide use of resistant cultivars.

Besides, in despite of the well-known and constant importance of the root-knot nematodes (RKNs) for Brazilian agriculture, there are recent examples of rapid dispersion and pronounced damage on some crops due to emergent RKNs species, as *Meloidogyne enterolobii* Yang & Eisenback (=*M. mayaguensis*) on guava (*Psidium guajava*) (Carneiro et al., 2001).

More recently, a nematode species considered until then as a secondary pathogen, the lesion nematode *Pratylenchus brachyurus* (Godfrey) Filipjev & Schuurmans Stekhoven, has become one of the main problems on soybean fields, especially in the Cerrado region of Brazil (Ribeiro et al., 2010). Once more, nematologists faced with a problem of difficult solution and efforts to understand the pathosystem were needed.

Other emergent species, such as *Helicotylenchus dihystera* (Cobb) Sher, *Scutellonema brachyurus* Andrassy and *Tubixaba*

tuxaua Monteiro & Lordello appear as the potential next pathogens for soybean in Brazil, since their spread and population densities have increased on soybean growing areas (Maceda et al., 2009; Lima et al., 2009).

Many factors could be involved in the emergence of new nematode diseases. There is a high diversity of nematode genera and species in tropical countries. Plant-parasitic nematodes generally have shorter life cycles resulting in a rapid population explosion, and more often a crop is attacked by a number of damaging nematode species. Besides, the current intensified use of agricultural lands in Brazil have a significant paper in this case.

A BRIEF NARRATIVE: HISTORICAL NEMATOLOGICAL PROBLEMS IN BRAZIL

Historically, some events in the Brazilian agriculture involving plant-parasitic nematodes are well known. Here, only two of these events will be presented, mainly due to their historical importance and to high damage and efforts expended when they occurred.

Meloidogyne exigua Goeldi on coffee

In the final of the 19th century, at Rio de Janeiro State, the first damaged disease caused by a nematode was reported in Brazilian agriculture. The Swiss naturalist Dr. Emílio Augusto Goeldi, from the National Museum, published a report in which the disease that plagued coffee plants on this municipality was thoroughly described as a cause of root-knot infection on roots (Goeldi, 1892).

The species *Meloidogyne exigua* was described and it was the cause of the substitution of coffee to sugarcane crop at the Rio de Janeiro State, and the disease caused by this pathogen was included in the History as the first catastrophic disease caused by a nematode in Brazil. Until now, this nematode is responsible for high losses on coffee, especially in the State of Minas Gerais (Castro et al., 2008). Indeed, the root-knot nematodes, *Meloidogyne* spp., are globally the most economically important plant parasitic nematode, particularly in tropical regions.

The soybean cyst nematode, *Heterodera glycines*

Almost one century later the catastrophic report of *M. exigua* on coffee, in the final of the 20th century, the soybean cyst nematode (SCN) was found on soybean growing areas in Brazil. This nematode is one of the most limiting factor to soybean yield around the world and, until 1992, Brazil was considered a “free area”, in which all soybean cultivars had no level of resistance. *Heterodera glycines* spread rapidly in the Cerrado, the most important Brazilian soybean growing region, affecting an area of about 2,000,000 hectares, only five years after its first detection (Silva, 1999).

In this same period, another disease was a concern for soybean growers: the stem canker, caused by the fungus *Diaporthe phaseolorum* Lehman (Yorinori, 1990). Similar as SCN, no resistant cultivar to stem canker was available, forcing producers to diversify their crops. In this way, maize (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), rice (*Oryza sativa* L.), sunflower (*Helianthus annuus* L.), castor bean (*Ricinus communis* L.), sorghum (*Sorghum bicolor* L. Moench), and pastures were incorporated in the production system in Cerrado, improving the economic stability of municipalities, which was previously based only on the profitability of soybean (Silva, 1999). Fortunately, SCN is a non-polyphagous nematode with restricted host range, and the diversification of crops favored its management. Besides, there was a massive effort from nematologists and breeders for the development of resistant cultivars and nowadays there are a great number of cultivars with high levels of resistance to SCN.

However, the adopted management system for control SCN arising with the diversification of crops, was responsible, some years later, by the emergence of secondary

nematode species on Cerrado region such as *P. brachyurus*, which become the main nematological problem for soybean. This scenery will be discussed in the next item.

CURRENT NEMATOLOGICAL PROBLEMS

Luc et al. (2005) stated "the future for subtropical and tropical nematology will be long and full of complex and economically important problems". Unfortunately, for Brazilian agriculture, this prognostic appears to be right.

The current intensified use of agricultural lands in Brazil, with monoculture of susceptible crops, is probably a cause of the increase in nematological problems, especially on Cerrado region, in which economy is based mainly on the profitability of soybean, maize, and cotton. The succession of these susceptible cultures allow species to maintain or increase their population in the soil along the crops. As the nematode management is a difficult job, many problems have been increasing year by year.

Here, will be discussed the current main nematological problems, with focus on soybean, a crop with frequent and intense damages and losses due to nematode attack on Brazil.

Minor and emergent root-knot nematodes

Root-knot nematodes (RKNs) (*Meloidogyne* spp.) represent one of the most polyphagous and economically important genera of highly adapted plant-parasitic nematodes worldwide (Moens et al., 2010). They are obligate endoparasites of the roots, tubers and corms of thousands of plant species, resulting in severe damages. The life cycle of RKNs takes three to six weeks to complete, depending on the environmental conditions. In Brazil, where temperatures in general are high and favor nematode development, a great number of cycles are possible in a single harvest. RKNs reproduce and feed on modified living plant cells, where they induce small to large galls, causing a disrupt of the host physiology.

'Major' *Meloidogyne* species, as *M. incognita* (Kofoid & White) Chitwood, *M. javanica* (Treub) Chitwoodand *M. arenaria* (Neal) Chitwood are recognized pathogens of a great number of plant species in Brazil and worldwide. However, the so-called 'minor' species, previously neglected, such as *M. enterolobii* (=*M. mayaguensis*), *M. paranaensis* Carneiro, Carneiro, Abrantes, Santos, & Almeida, *M. inornata* Lordello, and *M. ethiopica* Whitehead, have been developing recently into major problems for agriculture in tropical climate, including Brazil (Elling, 2013).

For instance, among the 17 *Meloidogyne* species that are currently known to infect coffee, *M. exigua* and *M. paranaensis* are the most damaging species on Brazilian coffee growing areas. The Paraná coffee root-knot nematode *M. paranaensis* does not cause typical galls on roots, but the cracks on cortical tissue on the taproot and necrotic spots along the roots are responsible for chlorosis, defoliation, reduced growth and often plant death (Carneiro et al., 1996). Losses may reach up to 50% of the coffee yield (Carneiro et al., 1996). This nematode is widespread on coffee plantations mainly on Paraná State, which accounted for approximately 52% of all root-knot nematode infestations, varying according with the region sampled (Carneiro et al., 1996; Ito et al., 2013). Although coffee is the primary host of this species, *M. paranaensis* was also detected on soybean (Roese et al., 2004), tobacco, tomato and watermelon (Carneiro et al., 1996).

Another emergent root-knot nematode, with an exceptionally wide host range comparable to that of *M. incognita*, *M. enterolobii* (=*M. mayaguensis*) has become a significant problem for Brazilian agriculture. This nematode become one of the main diseases in guava (*Psidium guajava* L.),with estimates of an infestation of over 5,000 ha of the guava production area (Pereira et al., 2009), causing, together with *Fusarium solani* (Mart.) Sacc., the guava decline, with drastic root rot (Gomes et al., 2012; Gomes *et al*., 2010). Besides guava is not the unique plant species showing problems with *M. enterolobii*; on

a recent survey on tobacco fields at Paraná, Santa Catarina and Rio Grande do Sul States, *M. enterolobii* was the third principal species based on percentage of occurrence (25.6%) (Araújo Filho, 2012). Added to this work, previous report from Gomes et al. (2008), regarding to a sample in Rio Grande do Sul and Santa Catarina States, showed a massive presence of *M. enterolobii* on tobacco fields, associated with plants exhibiting yellowing leaves and poor root systems, with root galling and decay. These recent works demonstrated the importance of this RKN species on the current tobacco nematology scenery, due to this high incidence and wide distribution, especially at Santa Catarina State. The South Brazilian region is responsible for about 95% of the national tobacco yield and Santa Catarina State occupies the second position on tobacco production, accounting for 30% of the Brazilian tobacco yield (Marcondes, 2014). These data gives us an idea of the potential drastic effect of this nematode to the tobacco growing areas in Brazil. Besides, this RKN is an important pathogen for tomato and pepper, even on cultivars carrying the resistance gene *Mi* (Cantu et al., 2009; Oliveira, 2007).

Another emergent RKN species in Brazil is *M. ethiopica*, first described in 1968 in Southern Africa, a polyphagous nematode that is able to parasitize a wide host range from herbaceous to woody plants (Carneiro et al., 2007). Recent reports of *M. ethiopica* on kiwi [*Actinida deliciosa* A. Chevallier (C. F. Lang & A. R. Ferguson)] in Rio Grande do Sul (Carneiro et al., 2003; Gomes et al., 2005), on soybean (*Glycine max*) in São Paulo (Castro et al., 2003), on tobacco (*Nicotiana tabacum* L.) and guanxuma (*Sida rhombifolia* L.) in Rio Grande do Sul (Gomes et al., 2005), and yacon (*Polymia sonchifolia*) and tomato (*Lycopersicon esculentum* Mill.) in the Federal District of Brazil (Carneiro and Almeida, 2005), showed the high potential of dissemination of this nematode in the country, whose introduction probably was given through kiwi plantlets imported from Chile in the final of the 80's years (Carneiro et al., 2003).

In the past, *Meloidogyne inornata*was reported on soybean plants (Lordello, 1956) and tobacco in São Paulo (Figueiredo, 1958). Recently, this RKN was detected in São Paulo State on yacon (Carneiro et al., 2008), tobacco fields on the South region of Brazil (Araújo Filho, 2012) and its widespread have been showed throughout Paraná, parasitizing common bean (*Phaseolus vulgaris* L.) (Machado et al., 2013). One of the probable causes of this emergence of 'minor' RKN species is the high morphological variability in the perineal patterns, which could led to a misidentification of these species in the past. In fact, with the easy access to more precise and not subjective techniques for identification, as the isozyme phenotyping, reports of 'minor' species have been frequent, crescent in a short lapse of time in Brazil, and worldwide. Indeed, the majority of these emergent species were described originally as another species such as *M. enterolobii* and *M. paranaensis*, which were identified as atypical populations of *M. arenaria* (Rammah and Hirschmann, 1988) and *M. incognita* (Carneiro et al., 1996), respectively, due to the morphological similarities.

Root lesion nematode, *Pratylenchus brachyurus*

The occurrence of nematodes on soybean dated since the beginning of the agricultural exploitation especially in the Cerrado region. After the impact caused by *H. glycines*, two important changes occurred, i.e., the use of alternative plants for crop rotation and the increase in the no-tillage system (Silva, 1999). Following these changes, the frequency and damages caused by *M. incognita* and *Rotylenchulus reniformis* Linford and Oliveira increased considerably, considering that cotton assumed a part in the management systems.

However, in a nematological survey carried out on Mato Grosso State, Silva et al. (2004) observed an alteration in this scenery: the high frequency of *P. brachyurus* on cotton fields, until that moment a nematode with secondary importance. Similar situation was reported at

Bahia State, an important cotton producer (Santos et al., 2009). Ever since, *P. brachyurus* has become a concern among cotton and soybean growers in the Cerrado region and nowadays is considered the main nematological problem to soybean (Ribeiro et al., 2010).

According to Asmus (2013), the high frequency and population densities of this nematode have been caused by the increase in the area cropped with maize, a good host for *P. brachyurus*that has been used in crop rotation or succession, after the detection of *H. glycines*; by the expansion of the no-tillage system using cover crops as grasses mainly which favoring the parasitism of nematode on their vigorous root systems during a great part of the season; and by the favorable temperatures and soil conditions occurring in the Cerrado for the *P. brachyurus* development and reproduction.

*Pratylenchus brachyurus*is a migratory endoparasite that penetrate into the root for feeding and reproduction and moves freely within the tissue, causing destruction of tissues of the root system and predisposing the parasitized tissues to secondary infections by fungi and bacteria (Figure 1a). Its life cycle has a duration of approximately 3-8 weeks and the effects on plant growth and yield are largely resulted from the disruption caused to the normal process of root growth and exploration of the soil for water and nutrients (Loof, 1991).

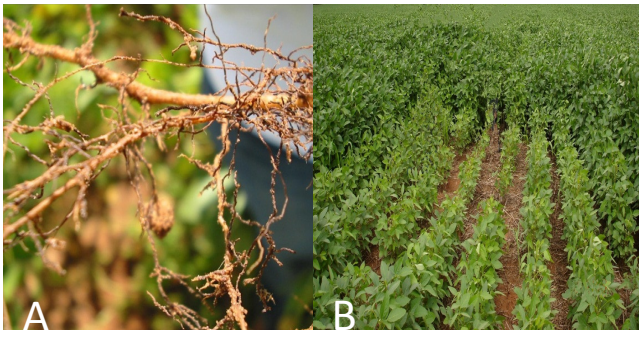

Figure 1. Symptoms caused by *Pratylenchus brachyurus* on soybean: (A) Root lesions (Picture by Rosângela Aparecida da Silva); (B) Stunting soybean plants at field (Picture by Jaime Maia dos Santos).

On soybean, losses caused by this nematode can reach to 30 to 50% of the yield, in which higher damages are observed on sand soils (< 20% clay) (Antonio et al., 2012). Symptoms on plants are stunting and leaf yellowing (Figure 1b); however, non-specific symptoms can be easily overlooked or mistaken for damage caused by other soil pathogens, or attributed to other causes such as nutrient deficiency or lack of water (Castillo and Vovlas, 2007).Damage thresholds are quite different among *P. brachyurus*-host plant combinations and range from 400 nematodes per 200 cm^3 of soil on soybean (Inomoto et al., 2010) to 12,000 nematodes per 500 cm^3 of soil on cotton (Machado et al., 2006).

It is unlike that cotton, soybean and maize longer to be the main crops on Brazilian agriculture, especially in the Cerrado, the principal growing area of these crops. An increase in the sugarcane area as well as the incorporation of new growing areas of soybean in the States of Maranhão, Piauí and Tocantins suggest that this scenery will remain for the next years and could anticipate the increase of new nematode diseases (Asmus, 2013). By this way, the presence of high population densities of unconventional nematode species on soybean, as *Tubixaba* sp. Monteiro & Lordello, *Scutellonema brachyurus* Andrassy, and *Helicotylenchus dihystera* (Cobb) Sher appears as the next potential problems to this crop, as discussed below.

Ectoparasitic nematodes on soybean

The genera *Tubixaba* was described by Monteiro and Lordello (1980) to include a new species, *T. tuxaua* Monteiro & Lordello, reported on Paraná State, in the municipality of Marechal Cândido Rondon, as a possible parasite of soybean. Nowadays, this nematode is widespread over the state of Tocantins (Lima et al., 2009); a non-identified *Tubixaba* sp. population was reported recently parasitizing soybean in four municipalities from Maranhão state, (Silva, Gilson S./UEMA, personal communication, cited by Ferraz, 2012). *Tubixaba tuxaua* was reported

parasitizing soybean, in addition maize, wheat and cassava plants on Paraná state (Antonio and Carneiro, 1981; Carneiro and Carneiro, 1983; Lima et al., 2009); yield losses of about 42.5% was observed on wheat (Carneiro and Carneiro, 1983). Besides, soybean and maize are also damaged by this nematode, under field conditions, on Paraná state (Furlanetto et al., 2010). Damages on soybean have been reported for researchers from some states as Mato Grosso, Maranhão (Tania de Fátima Silveira dos Santos, personal communication) and Paraná (data from Laboratório de Nematologia, IAPAR) (Figure 2).

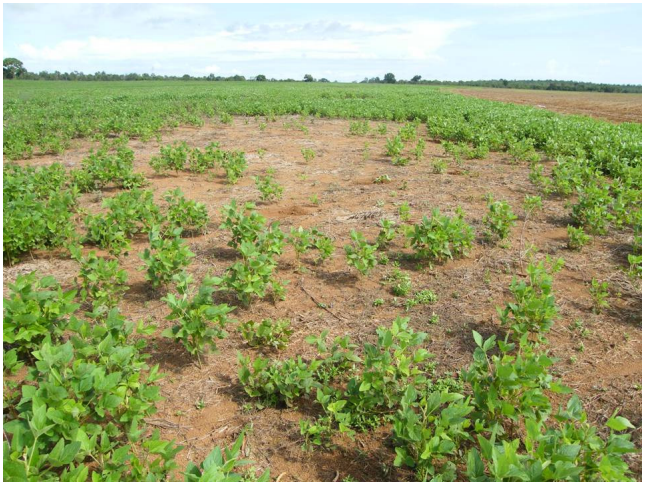

Figure 2. Soybean field infested with *Tubixaba tuxaua*.(Picture by Neucimara Rodrigues Ribeiro).

Until now, *Tubixaba* sp. is an unsolved problem, as there is a lack of available information about its real relationships with its host plants, especially soybean. Management appears difficult, once green manures usually used for nematode control, as velvet beans [*Mucuna aterrima* Piper and Tracy, *M. deeringiana* (Bort) Hanelt], crotalaria (*Crotalaria juncea* L.) and jack bean (*Canavalia ensiformis* L.) showed damages caused by *T. tuxaua* under field conditions (Furlanetto et al., 2008).

In different regions from the States of Paraná, Mato Grosso do Sul and Maranhão, soybean fields showing plants with unequal and reduced growth, associated with low yields were observed by growers in the last seasons. In the samples collected on these regions it was detected the presence of *S. brachyurus*, another ectoparasitic nematode until now associated with damages only on sugarcane and cocoa (Starr and Bendezu, 2002). The nematode populations observed on these samples were higher than 5,000 specimens per 100 cm^3 of soil and, although *S. brachyurus* is not an endoparasite, even higher on 10 g of roots (Maceda et al., 2009). Further studies should be undertaken to assess its potential pathogenicity in soybean, but apparently, damages are associated with dry periods and the use of precocious cultivars (Maceda et al., 2009).

Helicotylenchus dihystera, associated with damages only on sugarcane (Starr and Bendezu, 2002) and maize (Pinto, 2006), has increased its population densities and frequency of occurrence on soybean growing areas in Brazil. In a survey performed in different soybean cultivars in Acre State, *H. dihystera* was found at rate 85% of the samples (Sharma et al., 2001). Generally, its presence has been associated with stunted plants, but direct damages are not quantified, as well as the threshold levels. Population densities of about 5,000 specimens or higher have been found on soybean fields, but no reductions on productivity were observed until now (Jaime Maia dos Santos, personal communication).

These reported species are ectoparasitic nematodes generally described to have brief and non-invasive relationships with their hosts and to have a primitive mode of parasitism that typically results in cell death (Wyss, 1981) due to the high number of nematodes simultaneously feeding from the same area (Starr and Bendezu, 2002).

Studies about chemical control, host ranges, biology on different hosts, and management of these nematodes are urgent and of extremely importance in order to clarify if these ectoparasitic species constitute a real problem for Brazilian agriculture. However, for successful screening of germplasm for resistance is important to have a thorough knowledge and understanding of the biology of the nematode in question, an unclear area until now, considering the pathosystem involving soybean especially.

CONCLUDING REMARKS

The information presented here show us that nematological problems always existed in Brazil and, due to the current agricultural system adopted widely in the country, with intense use of land and a succession of susceptible crops to nematodes, there are no promising future for the nematode management. Frequently, emergent species arise, associated with high losses and struggle from the researchers in order to understanding and control the diseases caused by these pathogens. While there is no awareness of growers that nematodes are a great problem, researchers will have to continue our efforts in solving immediate problems. The presence of nematodes only will be friendly when integrated and sustainable management tools will be widely adopted, minimizing losses and increasing the income of the growers.

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