Chapter 6

# Nematodes Affecting Soybean and Sustainable Practices for Their Management

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http://dx.doi.org/10.5772/67030

**Abstract**

Plant-parasitic nematodes are one of the limiting factors for soybean production worldwide. Overall, plant-parasitic nematodes alone cause an estimated annual crop loss of $78 billion worldwide and an average crop yield loss of 10–15%. This imposes a challenge to sustainable production of food worldwide, since there has been increasing demand for food supply and food security. Unsustainable cropping production systems with monocultures, intensive use of soils and expansion of crops to newly opened areas have intensified problems associated with new pests and diseases. Thus, finding and applying sustainable methods to control diseases associated with soybean are in current need. Over hundred nematode species, comprising fifty genera, have been reported in association with soybean. Of these, the root-knot nematode *Meloidogyne* spp., cyst nematode *Heterodera glycines*, lesion nematode *Pratylenchus brachyurus* and the reniform nematode *Rotylenchulus reniformis* are major nematode species limiting soybean production. Here, we report an up-to-date literature review on the biology, symptoms, damage and control methods used for these nematodes species. Additionally, unusual and emergent nematode species affecting soybean are discussed.

**Keywords:** control, damage, lesion nematode, plant parasitic nematodes, RKN, yield loss

## 1. Introduction

Soybean (*Glycine max L.* Merr) is the most important oilseed crop worldwide. Over the past 20 years, soybean production worldwide has doubled reaching ca. 210 million tons. In addition, consumption has increased faster than its production. It is estimated that this trend will continue in the near future and that the increased demand for soybeans will reach 300 million tons by the year 2020. Soy is used for food and feed, production of raw materials for the industry of vegetable oil and other purposes such as the manufacture of plastics, lubricants, candles, varnishes, soaps, biodiesel and lecithin [1].

According to the United States Department of Agriculture (USDA), in the 2013/2014 cropping year, USA, Brazil and Argentina accounted for 81.40% of the total world production of soybeans, and China by 64.26% of all world imports. Brazil accounted for the production of 86.27 million tons of soybeans, that is, 44.50% of the Brazilian production of grains with Brazilian average productivity of 3000 kg/ha, which is the second largest producer and processor of grains into meal and oil [1].

Currently, the rationality of production and the use of alternative fuels derived from biomass, especially bio-ethanol and vegetable oils, are being increasingly recommended to complement or improve the energy matrices worldwide. Among the producing crops for energy biomass used for biodiesel production features the soybean that is being currently studied as a promising crop for the production of biodiesel. However, in addition to economic feasibility studies including energy efficiency, organization of production system and crop adaptation, it is necessary to take into account policy studies related to diseases and pests in agricultural systems where crops are or will be implemented in order to decrease losses due to pathogen attack.

There has been increasing demand for food supply and food security. Unsustainable cropping production system with monocultures, intensive planting and expansion of crops to newly opened areas has increased problems associated with new pests and diseases. Among these problems, plant parasitic nematodes are one of the limiting factors for soybean production worldwide. Plant parasitic nematodes alone cause an estimated annual crop loss of $78 billion worldwide and an average crop yield loss of 10–15%. Nonetheless, soybean yield loss due to nematode parasitism is quite variable and mostly depends on factors such as nematode species, their population levels, susceptibility of the cultivars, cropping systems, temperatures, time of the year, region and soil factors including soil texture, pH and fertility. The yield loss can reach up to 30–100% in some reported cases [2, 3].

More than 100 nematode species, comprising 50 genera, have been reported in association with soybeans. In Brazil, the species that cause the most damage to soybean are *Meloidogyne javanica, Meloidogyne incognita, Heterodera glycines* [4, 5], *Pratylenchus brachyurus*, the reniformis nematode *Rotylenchulus reniformis* [6] and *Tubixaba tuxaua* [7].

Since pathogens such as plant parasitic nematodes represent major losses in agricultural systems, especially when the systems are not managed sustainably, the searches for information on the occurrence of nematodes in the production system, population density, species, levels of damage, and monitoring and management of these populations are essential in regions where crops will be implemented.

The goal of this chapter is to report a literature review of main nematode species affecting soybean worldwide and the methods used for their sustainable management in the field. Although there are numerous nematode species associated with soybean, few of them have been continuously reported as major constraint to soybean production worldwide. These include: (i) *Meloidogyne* spp.; (ii) *H. glycines*; (iii) *Pratylenchus brachyurys* and (iv) *R. reniformis* (**Table 1**).

| Common name | Species name |
|---|---|
| Root-knot nematodes | *Meloidogyne* spp. |
| | *M. incognita* |
| | *M. javanica*[*] |
| Soybean cyst nematode | *Heterodera glycines*[*] |
| Root lesion nematode | *Pratylenchus brachyurus*[*] |
| Reniform nematode | *Rotylenchulus reniformis*[*] |
| Lance nematodes | *Hoplolaimus* spp. |
| Spiral nematodes | *Helicotylenhus* spp. |
| | *Helicotylenchus dihystera* |
| Sting nematodes | *Belonolaimus* spp. |
| **Other emerging nematode species** | *Aphelenchoides* sp. |
| | *Scutellonema brachyurus* |
| | *Tubixaba tuxaua* |

[*]Indicate the most damaging nematodes on soybean.

**Table 1.** Most common plant parasitic nematodes associated with soybean worldwide.

## 2. Major nematode species affecting soybean

### 2.1. Root-knot nematodes (*Meloidogyne* spp.)

Root-knot nematodes (RKN), *Meloidogyne* spp., are the most economically important group of plant parasitic nematodes worldwide. Currently, there are more than 90 described RKN species [8] parasitizing more than 2000 plant species, which represent a real threat to the agriculture worldwide [9]. RKN species that are associated with soybean in Brazil include *M. incognita, M. javanica* and *M. arenaria* [10–12]. *M. javanica* and *M. incognita* have wide distribution in soybean-growing areas in Brazil, whereas *M. javanica* is the most aggressive species with broad geographic distribution, due to favorable conditions for its multiplication in susceptible hosts [11].

In several field surveys for RKN nematodes in main regions of soybean production in Brazil, *M. javanica* was reported as the most prevalent species (64%) [13]. In Ref. [4], the authors found that *M. javanica* (77%) and *M. incognita* (31%) were the most prevalent two RKN species on soybean fields. Other RKN species have also been reported in soybean fields with lesser extents, including *M. morocciensis* [13], *M. paranaensis* [14] and *M. ethiopica* [15].

In a survey of more than hundreds of soybean fields in USA, it was found [16] that *M. incognita* was the most prevalent species (70%), followed by *M. javanica* (24%) and *M. arenaria* (6%). In a study carried out in South Africa [17], the study found that 91% of soil and root samples were infested by *Meloidogyne* spp. including *M. incognita*, *M. javanica*, *M. arenaria, M. hapla* and *M. ethiopica*. Studies carried out in Argentina [18] reporting the distribution and frequency of

RKN nematodes in soybean fields found that the *Meloidogyne* spp. were widely distributed in the country and that *M. incognita* and *M. javanica* were the most species frequently detected. Other species were *M. arenaria*, *M. cruciani*, *M. decalineata*, *M. hapla* and *M. ottersoni.*

Symptoms in the field include yellowing and sub-development of infested plants. RKN nematodes induce hypertrophy and hyperplasia of infected cells leading to swelling of tissues commonly known as galls. The number and sizes of galls vary depending on the susceptibility of the cultivar, population density and favorable temperatures [19]. RKN-infected roots change their nutrient and water uptake, leading to decreased yield. Commonly, there are high levels of intraspecific variation within *Meloidogyne* genome, and this variability may play an important role in changes in morphology and cytogenetics and ultimately their capacities to reproduce in certain hosts [20].

RKN are endo-sedentary parasitic nematodes. The second-stage juvenile (J2) is the infective stage. After RKN hatch from eggs, the J2 migrates through the soil toward suitable root and uses special enzymes and the stylets to force penetration into the vascular cylinder where RKN establish their feeding site by inducing hypertrophy and hyperplasia of a group of cells leading to swelling and formation of giant cells. On this site, nematode goes through three more molting to become a swollen young female. Mature females begin laying eggs in the root, forming mass eggs wrapped in a gelatinous matrix. Each egg mass contains 400–500 eggs on average, and it is formed in the midst of cortical parenchyma or on the surface of the roots. The embryonic development of the nematode results in the first stage (J1) passing through an ecdysis in the egg, followed by the second stage (J2). Adult males do not feed on soybean roots; they leave the root and move freely in the soil until they die [20].

To control RKN is extremely difficult. Currently, the most effective and environmentally sound way to control RKN is the use of resistant cultivars that stand good yield and have been tested in a particular region where soybeans are planted [11], the use of tolerant genetic materials and rotation/succession with non- and poor host crops [10, 12]. The use of nematicides at planting or via seed treatment is an option. However, they are costly, not very effective, and have side effects to human and to the environment [21].

Currently, several soybean genotypes have been described as resistant or moderately resistant to *M. javanica* and *M. incognita*, even though the levels of resistance are not very high [11]. Almost all soybean cultivars are descended from a single source of resistance from the cultivar 'Bragg' from USA. In the cultivar Bragg, there are other sources of resistance that is used in breeding programs, such as Hartwig, Kirby, Cordell and Leflore cultivars that exhibit resistance to the soybean cyst nematode *H. glycines* [11] in addition to the resistance to *Meloidogyne*.

For the 2014/2015 cropping year, the following soybean cultivars were released by Embrapa with reported resistance to *M. javanica* (BRS Corisco), *M. incognita* and *M. javanica* (BRS 7980), *M. incognita* (BRS 8180RR), *M. javanica*, *M. incognita* and the cyst nematode *H. glycines* (BRS73800RR) [22, 23].

Prior to using resistant soybean cultivar in a certain area, grower should consider the nematode species present in the field, because, although there may be predominance of one species of nematode over another, the presence of mixed populations is very common, which may limit the use of resistant varieties. In addition, in the choice of soybean cultivar, grower must take into consideration the adaptation and yield potential of the cultivar.

However, other control methods for RKN should also be considered. For instance, the use of antagonistic non-host plants such as *Crotalaria spectabilis, C. grantiana, C. mucronata, C. paulinea, Stizolobiun aterrinnum, S. cinereum* or *Raphanus sativus* has been shown to reduce *M. javanica* and *M. incognita* nematode population density and improve soil quality [24]. Therefore, the use of these combined management methods may be effective to reduce initial nematode population in soybean-growing areas and enhance soybean yield.

### 2.2. Soybean cyst nematode (*H. glycines*)

The soybean cist nematode, *H. glycines,* is one of the most yield-limiting nematode species, which affects soybeans, *Phaseolus vulgaris*, *Vigna angulares* and *Vigna radiata* in several regions worldwide [11, 25, 26]. This nematode was first reported in 1915 in Japan, since then it has been disseminated to most areas where soybean is cultivated. In Brazil, soybean cyst nematode was first reported in 1991, and nowadays, it is present in most areas where soybean are planted covering an area of ca. 2–3 million hectares [11, 26, 27]. Yield losses associated with this nematode can be as high as 30% depending on the region, soybean system and genetic background of the cultivar [11, 28].

Mature females of soybean cyst nematode retain their eggs inside their bodies after their deaths. The body is formed by a cuticle embedded with polyphenol tanning, resulting in a hard protective structure name cyst which is viable overwintering in the soil for up to 6–8 years. Thus, once the nematode is introduced in soybean fields, it is almost impossible to eliminate it completely. Females can also lay eggs in egg sacs. With stimuli of host root exudate, moisture and temperature, juvenile nematode (J2) hatches from eggs or emerges from cyst and moves freely in the soil. This is the only life stage that is able to infect plant. Following the stimulus of root exudate, J2 can use its stylet and degrading enzymes to penetrate the root and gain access into vascular tissue. There, J2 injects special enzymes that modify and transform a group of cells into specialized feeding sites (nurse cells). Female nematode then becomes lemon shape and eventually breaks through the root tissue and becomes exposed on the root surface. Mature female produces eggs (200–400) either in egg sac or inside the body (cyst) [24, 28]. The cyst then persists in the soil for several years. The entire cycle is completed in 24–30 days depending on optimal conditions, such as moisture and temperature (23–28°C) [26, 28, 29].

Usually, the nematodes can complete three to six generations a year. The cyst nematode reproduces by sexual reproduction (amphimixis), and its genome is characterized by an extremely high diversity, leading to several races of the pathogen. Soybean cyst nematodes can be spread to long distances effectively by means of infested soil particles, farm machinery, vehicles, tools, wind, water and animals among others [29, 30].

Symptoms of soybean cyst nematode can be mistaken for other disease symptoms as well as for management-associated problems, including iron and other nutrient deficiencies, herbicide toxicity and drought stress [29]. The appearance of cyst nematode symptoms attributed to other causes may lead to non-detection of the nematode for several years until its population builds up. Soybean infected with cyst nematode appears in the field as irregular patches of stunted, yellowed, less developed plants. Usually, symptoms are more severe in light sandy soils, but it also occurs in heavy soil. The root system infected with soybean cyst nematode is smaller and stunted, and the infection affects nodule formation and decreases nitrogen fixation. In addition, nematode-infected roots are more prone to soilborne fungi and bacterial pathogen secondary infection. The presence of adult females and cysts attached to soybean roots is typical of soybean cyst nematode infection [25, 26, 29].

Since soybean cyst nematodes can survive inside cysts for several years, once the nematodes have been introduced into soybean field, they are not likely to be easily eradicated. Nonetheless, there are recommended cropping management practices that minimize the problem. For instance, the use of soybean resistant varieties is the most effective way to control this nematode and have been used successfully. Several soybean cultivars have been released, and their sources of resistance come from the parental cultivars PI88788 or the Peking. To avoid breakdown of resistance, it is recommended to use cultivars alternately [11, 29]. It is recommended to use alternately among susceptible and resistant cultivars. For instance, use one susceptible cultivar after two to four years of cultivation with resistant cultivars [29]. In Brazil, most resistant soybean cultivars are specific to races 1 and 3 and are not well adapted to every soybean-growing region. Besides, due to soybean rust disease, growers are choosing early maturity varieties which are more susceptible to cyst nematode [11].

Another effective method in controlling soybean cyst nematode is the use of rotation with non-host crops. Soybean cyst nematode has a narrow host range which facilitates rotation with other non-host crops. The pathogen levels in the soil significantly decrease, once there is no suitable host for infection. Good examples of non-host crops are maize, sorghum, oat, alfalfa, rice, cotton, sunflower and castor bean. Rotation for 1 year with one of these crops significantly decreased the population level of cyst nematode, allowing planting of susceptible soybean cultivar in the following cycle [11].

Although the use of soybean resistant cultivars and crop rotation has worked well, growers should be careful to provide good management practices in soybean areas, including good pH levels and soil fertility in order to maintain the effects of these disease control methods [11, 25, 29]. In summary, the scheme using crop rotation and resistant and susceptible varieties is the best way to manage soybean cyst nematode. For example, the use of maize, resistant soybean cultivar and susceptible soybean cultivar has been one of the best approaches to manage the nematode in the field [11].

### 2.3. Root lesion nematode (*P. brachyurus*)

Root lesion nematode, *P. brachyurus,* has become an increasingly important parasite of soybean in the tropics and subtropics [31]. It has a broad host range and is widely distributed in tropical and subtropical regions, especially in Brazil [32], Southern United States and Africa [32, 33]. Its occurrence in soybean fields has been increasing lately due to expansion and cultivation of soybean in newly opened area of native savannas in Brazil contributing to the overall losses observed in soybean field due to nematode attack [10, 34, 35].

More than 50% of soybean in Brazil are produced in the Cerrado region (vegetation like savanna), with an increase in production over 100% in the central and northeast region [35]. The expansion in areas planted with soybean in the Cerrado region has contributed to intensive agriculture, leading to agronomic challenges, including nematode infection [35]. Among plant parasitic nematodes that infect soybean, *P. brachyurus* is one of the most important species, especially in these newly opened areas in the Cerrado region. Recently, its incidence has been rising with overall losses of soybean estimated at ca. 10–30%, especially under sandy soil and irregular rainfall [6, 35].

*Pratylenchus* species is commonly referred to as the root lesion nematode due to the typical symptoms of necrosis it causes in the roots. The species is considered a migratory endoparasitic nematode, normally found within the roots and between the roots and soil particles [31]. *Pratylenchus* species is smaller than 1 mm length. Males and females are wormlike, differing only in the sexual characters. Females have one ovary (monovarial) and reproduce by sexual reproduction called amphimixis or by mitotic and meiotic parthenogenesis. They are easily recognized by the sclerotized labial region and ventral overlapping esophageal glands and usually by dark intestinal contents. The stylet is well developed with broad basal bulbs. Most species are polyphagous, showing the ability to parasitize cultivated plants—perennials, semi-perennials, annuals as well as weeds [31].

Root lesion nematodes are more common on sandy soils and regions with high temperatures. Eggs are deposited in the roots (cortex) or in the soil. The incubation period ranges from six to eight days at a temperature of 28–30°C. The first molt takes place inside the egg and the other three occur out of the egg. Males and females emerge in 29–32 days. However, at low temperatures the life cycle may be longer. Usually, this nematode occurs in low population in the soil and at high population inside root tissue [33].

*P. brachyurus* population levels usually decrease in dry season and increase at optimum soil moisture. However, under greenhouse this nematode was able to survive 21 months in soil without any host or moisture, indicating its increased ability to persist in the soil [31]. In the evaluation for the survival of *P. braqhyurus* at different substrates with low moisture content, it was found [36] that even after 90 days in dry soil, there were a high number of viable nematodes in the substrates. This finding indicated that the nematode was able to survive in the off season in the absence of host, contributing to new source of inoculum for the following crop.

All *P. brachyurus* adult and juvenile stages are infective and migratory and move freely within the roots and between the roots and soil. The nematode uses its stylet to penetrate by means of mechanical force or using degrading enzymes. However, the nematode easily leaves the root system when conditions become unfavorable, switching to the soil [31]. Therefore, when the nematode parasitizes soybean roots, it causes lesions in the roots, causing damage to the cortical parenchyma and forming galleries in the tissue due to intense feeding and movement of the nematode, and these lesions lead to secondary infection by fungi and bacterial pathogens [37].

Symptoms of *P. brachyurus* infection in soybean are nonspecific and can easily be overlooked or confused with symptoms caused by other pathogens, nutritional deficiencies or water stress. Infected soybean plants are less developed and less bulky, with root necrosis and discolored roots (reddish-brown to dark-brown), due to the coalescence of many necrotic lesions internally caused by the nematode. Such symptoms limit water and nutrient uptake in the roots, leading to aerial symptoms that can be seen in stunted plants with chlorosis, wilting and overall yield losses [38].

Pathogenicity studies suggested that *P. brachyurus* is well adapted to parasitism. For instance, even at an extremely high population levels in the soil, it usually is not enough to kill host plant. Moreover, damage threshold varies greatly depending on environmental factors and combination of *Pratylenchus* species and host plant, ranging from 0.05 to 30 individuals per $cm^3$ of soil [37].

*P. brachyurus* is common in soybean fields in Central and Northern Brazil and is associated with soybean yield losses in the fields. Studies on the soybean yield losses under the field conditions are difficult to carry out, since several factors may occur simultaneously masking the real effect of the nematode. For instance, factors such as weeds, low soil fertility, uneven distribution of rainfall as well as other diseases may result in low soybean yield [38]. Nonetheless, surveys in this area have shown a positive correlation of increased nematode incidence with a drop in soybean yield. For example, in Central Brazil, soybean yield was normally around 2600 kg per ha, while during cropping season of 2008/2009 it dropped to 2400 kg per ha and to 1850 kg per ha during 2009/2010 [39]. In this region, yield losses of up to 30% due to the nematode have been reported.

In Northern Brazil, *P. brachyurus* has commonly been found in soybean fields, especially in the Cerrado region of Tocantins State. Nematode infestation in this region has been increasing and certainly has interfered with soybean yield due to high population densities mainly due to monoculture systems and use of newly opened areas. The population densities of *P. brachyurus* observed in different soybean areas located in Tocantins State ranged from 23 to 8482 individuals per 10 g of roots and were negatively correlated with soybean yield losses [35].

To assess the effect of *P. brachyurus* on soybean variety MONSOY 9144 under field conditions in an area located in the Cerrado region with sandy soil, Lima et al. [35] determined the nematode population level inside and outside infestation pattern and correlated it to soybean production parameters (number of internodes, stem diameter, leaf number, root dry weight, shoot dry weight, pod number and plant height). They observed that the higher the population density of the nematode, the less the performance of soybean, thus showing that the nematode had negative effect on soybean. They also reported that the impact of *P. brachyurus* was severe in fields with sandy soil causing reductions in plant height (ca. 82%), dry weight of seeds (85%), dry weight of stems (81%) and pod number (39.7%) in nematode infestation foci compared with plants outside the foci. Results of a study carried out in 2011/2012 in Vera, Mato Grosso state by Franchini et al. [40] indicated that there was a highly negative correlation between soybean yield and nematode population, with 50 kg loss in yield for every 82 nematodes per gram of soybean roots. Overall, yield losses ranged from 50 to 1400 kg/ha, with an average of 600 kg/ha (21%) yield reduction.

*P. brachyurus* is highly polyphagous, of which control is difficult. According to Santana Gomes et al. [24], it is difficult to control this nematode in soybean field, especially when using soybean in rotation or succession with other economically important agronomic crops that may also reproduce the nematode. These crops usually are cotton, pasture, corn, bean, sorghum, peanut, potato, tobacco, eucalyptus, rubber, pigeon pea, pineapple, some vegetables, sugarcane, coffee and rice [41].

Among these economically important crops, maize is the main one used in succession or rotation especially with soybeans. However, this management strategy enables increase in *P. brachyurus* population, since most maize hybrids tested have controversial results for resistance to this nematode. Furthermore, only a fraction of the commercial genetic material currently available has been evaluated, and generally the most productive hybrids multiply this nematode [41].

The use of soybean resistant varieties is probably the best way to control nematode infection, because it is easy, cheap, effective and environmentally safe. Host resistance has been explored. However, no *P. brachyurus*-resistant soybean varieties have been identified so far [42]. Although several soybean genotypes have been studied regarding their resistance against this nematode [43], breeding resistant cultivars against *P. brachyurus* is difficult due to the fact that this nematode is polyphagous and lacks a close interaction with their hosts [41]. Hence, current management recommendations for reducing *P. brachyurus* in soybean include crop rotation or succession with non-host, as well as fallow [35].

Seed treatment with nematicides has also been suggested to control *P. brachyurus*. According to Bessi et al. [44], seed treatment with nematicides can be an effective control method for this nematode, since it avoids damage in early stages of plant development, which stimulates the development of roots and minimizes the effect in case of drought stress. Several studies reported the effect of the seed treatment in reducing *P. brachyurus* population level in soybean [45]. Nonetheless, studies reporting the effectiveness of the seed treatment in controlling this nematode are still quite rare, and its use is questionable due to high cost of nematicides and low effectiveness due to short period of time in which plants are protected.

### 2.4. Reniform nematode (*R. reniformis*)

The reniform nematode, *R. reniformis,* was first described in 1940 infecting cowpea roots (*Vigna sinensis* Endl.) in Hawaii [46]. As a plant parasitic nematode, it was first reported in cotton in Georgia and in tomato in Florida [47]. This nematode belongs to the phylum of Nematoda, class of Chromadorea, subclass of Secernentia, order of Rhabditida, superfamily of Tylenchoidea, family of Hoplolaimidae, genera of *Rotylenchulus* and species of *R. reniformis,* reviewed in Ref. [48].

*R. reniformis* has a broad host range and parasitizes more than 140 plant species within 46 plant families. It parasitizes ca. 57 plant species with economic importance. Among the plants, cotton, pineapple, sweet potato and soybean are the most affected ones [49]. Other crops have been rated as good hosts to *R. reniformis*, including tea, tomato, kidney bean, cowpea, pigeon pea, castor bean, passion fruit (purple/yellow), melon, papaya, potato, okra, citrus, coffee, banana and a significant number of weeds. The nematode *R. reniformis*, therefore, is considered a cosmopolitan species and is currently widely distributed in tropical, subtropical and temperate areas of South America, North America, Caribbean, Africa, southern Europe, the Middle East, Asia, Australia and the Pacific [50].

Sikora et al. [51] studied *R. reniformis* survival in soybean fields in Alabama/USA and found that the nematode showed a 32% survival rate, being the most common plant parasitic nematode present in the area and that the nematode may significantly reduce soybean yield and cause economic losses as well. The authors also hypothesized that the high incidence of the nematode was probably due to a change from cotton to soybean.

*R. reniformis* is widely distributed in Brazil and is found to parasitize soybean, pineapple, banana, coffee, castor bean, passion fruit, tomato and cotton [48]. From the end of the 1990s, the reniform nematode has increased its importance in soybean, especially in the west of Brazil where soybean is planted following cotton crop. It is estimated that currently, the nematode occurs at high population densities in about 29% of areas planted with soybeans in Mato Grosso State, one of the main soybean-producing states in Brazil [11]. *R. reniformis* has also been reported in other soybean-producing regions in Brazil. However, information about yield losses and economic damage is scarce [19].

The genera *Rotylenchulus* have 10 species, and they are considered semi-sedentary endoparasitic nematodes whose life cycle comprises the following sequence of events: worm shape sexually immature females are the infective stage. Females migrate in the soil searching for soybean roots or another suitable host and penetrate them until reaching the anterior region of the parenchyma pericycle. There, the nematodes inject special proteins to induce specialized cells (nurse cells) to feed them until the end of their life cycle. Once nematodes begin to feed, they become sedentary and have gradually swollen bodies, until they reach sexual maturity. The portion of the female body that stays out of the root acquires a shape similar to a kidney, from which the nematode name 'reniform' comes. Females lay eggs in egg masses (50–120 per mass) on the surface of rootlets. The optimum temperature is around 30°C. The proportion of males and females is approximately 1:1, and they reproduce by sexual reproduction called amphimixis. However, some populations can reproduce by parthenogenesis, and in this case, the males are rare or absent. *R. reniformis* males do not parasitize roots of soybean, and their stylets and esophaguses are much less developed compared to females, reviewed in Ref. [48].

Symptoms caused by *R. reniformis* in soybean somewhat differ from those caused by other nematodes. Soybean crops grown in infested soils are characterized by uneven growth, with large areas of undeveloped plants, which resembles mineral deficiency or soil compaction. There is also no occurrence of typical yellowing spots. Roots parasitized with *R. reniformis* do not show hypertrophy and hyperplasia of cells and do not form galls. The root system shows poorer development and in some points of the root can be seen a layer of soil adhered to the egg masses of the nematode, which are produced outside the root tissue. Yet, unlike other nematode species occurring in soybeans, the reniformis nematode does not seem to have its occurrence limited by soil texture, occurring in sandy soils as well as in clay soils. *R. reniformis* usually is the predominant species in clay soils [11].

The wide host range of *R. reniformis* is a limiting factor for the use of crop rotation to manage this nematode species. An alternative is the use of cover crop such as *C. spectabilis* or its use in consortium with maize which has shown good results in decreasing nematode population level. In fact, this consortium was the most effective way to reduce this nematode population [31]. The reniform nematode is one of the major nematode species infecting cotton, maize and soybean in central Brazil. Considering its high aggressiveness to cotton and the increase in areas planted in rotation/succession with cotton, soybean and maize in central Brazil, it is very important to know which cultivars are indicated for planting in these areas [52].

A promising alternative control to *R. reniformis* is the use of crops such as rice and peanut and the *Brachiaria* grass at an integration scheme with crop/animal husbandry or in rotation with soybean or cotton. In addition, crops grown in autumn/winter that are used as cover crop in tillage systems and are resistant to *R. reniformis*, including *Brachiaria*, turnip, sorghum, black oat, millet and the Indian goose grass are good option as well. Growers should avoid the cultivation of amaranth and quinoa, which are both susceptible. Due to variation observed within varieties/hybrids of different plant species, it is recommended to test for host suitability prior to planting these varieties. The reniform nematode is well persistent in the soil, and depending on its population density, there may be a need for at least two years of cultivation with non-host species in order to decrease its population level [11].

Considering the host resistance, some soybean varieties are recommended against *R. reniformis*. For example, soybean cultivar BRS 399RR is tolerant to glyphosate and resistant to multiple nematode species, including the root-knot nematodes *M. incognita* and *M. javanica*, the reniform nematode *R. reniformis* and races 3 and 14 of the cist nematode *H. glycines*, and shows tolerance to the lesion nematode *P. brachyurus* [22]. Soybean cultivars BRS 359RR and BRS 360RR have also been reported as resistant to *R. reniformis*. These are short-cycle cultivars allowing planting of second maize cropping within a planting year besides being resistant to this nematode [23].

Additionally, other sources of resistance have been assessed against *R. reniformis*. For instance, Asmus [52] reported some soybean cultivars as resistant to this nematode, which had similar performance in comparison with the resistant control cultivar Custer. Except for the PI88788, soybean cultivars that have been rated as resistant to the cyst nematode also conferred resistance to *R. reniformis* [52]. The soybean cultivars 'M-SOY 8001' and 'CD 201' have also been reported as resistant to *R. reniformis* [53].

## 3. Other emerging nematode species threatening soybean production

Lately in Brazil cases of unusual, emergent nematode species affecting soybean fields have been reported. For instance, the nematodes *Aphelenchoides* sp. [54], *T. tuxaua* [7], *Scutellonema brachyurus* [55] and *Helicotylenchus dihystera* have been found in high population densities with fast dissemination in soybean fields, in which infected plants have shown pronounced symptoms typical of nematode infection.

A new soybean disease named 'crazy soybean' is caused by *Aphelenchoides* sp. [55] and characterized by reduced yield. Due to the disease, abortions of flowers and pods and distorted leaves have been seen in some regions of soybean-producing areas. The intensified land use with major monoculture crops and unsustainable management practices has resulted in new problems associated with nematode infection. In future studies, it is important to determine the real distribution of nematode in soybean fields, the mechanism by which nematode decreases soybean yield and the ways to manage nematode [56].

## 4. Concluding remarks

This review has shown that there are a significant number of plant parasitic nematodes negatively impacting soybean yield worldwide. Due to intensified land use, monocultures and the use of unsustainable management practices, uncommon nematode species are becoming a new threat to soybean production. This imposes a real challenge to researches to search promptly for new approaches to manage these nematode diseases. Researches and growers should recognize that in fact, nematode diseases negatively impact soybean yield and that sustainable management practices should be considered in order to decrease nematode population level and have a good yield performance. When deciding the management approaches, it is essential to consider them holistically.

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## References

[1] Fontana JD, editor. Biodiesel: para leitores de 9 a 90 anos. 1st ed. Curitiba, Brazil: UFPR; 2011. 253 p.

[2] Schmitt DP, Barker KR. Damage and reproduction potentials of *Pratylenchus brachuyrus* and *P. penetrans* on soybean. Journal of Nematology. 1981;**13**(3):327–332.

[3] Barker KR. Introduction. In: Barker KR, Pederson GA, Winhan GL, editors. Plant and Nematode Interactions. Madison, USA: American Society of Agronomy; 1998. pp. 1–120.

[4] Franzener G, Unfried JR, Stangarlin JR, Furlanetto C. Nematoides formadores de galhas e de cisto patogênicos a cultura da soja em municípios do Oeste do Paraná. Nematologia Brasileira. 2005;**29**:161–165.

[5] Santana HPE, Comerlato AP, Nasu EGC, Furlanetto C. Variabilidade genética em populações de campo do nematoide de cisto da soja provenientes dos estados do Paraná e Rio Grande do Sul. Tropical Plant Pathology. 2009;**34**:261–264.

[6] Dias WP, Ribeiro NR, Lopes ION, Garcia A, Carneiro GES, Silva JFV. Manejo de nematoides na cultura da soja. In: Congresso Brasileiro de Nematologia; 12 de Agosto; Goiânia, Brazil. Goiânia: Sociedade Brasileira de Nematologia. 2007. pp. 26–30.

[7] Furlanetto C, Seifert KE, Fenterseifer CE, Page EC, Davi JJS, Grabouski MMS. Desenvolvimento das culturas de soja, milho e trigo cultivadas em áreas infestadas com o nematoide *Tubixaba tuxaua no* Oeste do Paraná. Tropical Plant Pathology. 2010;**35**:295–302.

[8] Karssen G, Moens M. Root-knot nematodes. In: Perry RN, Moens M, editors. Plant Nematology. Wallingford, UK: CABI Publishing. 2006. pp. 59–90.

[9] Moens M, Perry R, Starr J. *Meloidogyne* species- a diverse group of novel and important plant parasites. In: Perry RN, Moens M, Star JL, editors. Root-knot Nematodes. Wallingford, UK: CABI International 2009. pp. 1–17.

[10] Almeida AMR, et al. Doenças da soja. In: Kimati H, et al, editors. Manual de Fitopatologia. São Paulo, Brazil: Ceres; 2005. pp. 569–588.

[11] Dias WP, Garcia A, Silva JFV, Carneiro GES. Nematoides em Soja: identificação e controle. Circular Técnica da Embrapa. 2010;**76**:1–8.

[12] Embrapa. Tecnologias de produção de soja na região central do Brasil. Londrina-Parana, Brazil: Embrapa; 2011. 262 p.

[13] Castro JMC, Lima R, Carneiro RMDG. Variabilidade isoenzimática de populações de *Meloidogyne* spp. provenientes de regiões brasileiras produtoras de soja. Nematologia Brasileira. 2003;**27**(1):1–12.

[14] Roese AD, Oliveira RDL, Lanes FF. Reação de cultivares de soja [*Glycines max* L. Merril] a *Meloidogyne paranaensis*. Nematologia Brasileira. 2004;**28**(2):131–135.

[15] Lima EA, Mattos JK, Moita AW, Carneiro RG, Carneiro RMDG. Host status of different crops to *Meloidogyne ethiopica* control. Tropical Plant Pathology. 2009;**34**:152–157.

[16] Garcia MR, Rich R. Root-knot nematodes in North-Central Florida soybean fields. Nematropica. 1985;**15**(1):43–48.

[17] Fourie H, Mc Donald AH, Loots GC. Plant parasitic nematodes in field crops in South Africa 6: soybean. Nematology. 2001;**3**:447–454.

[18] Doucet ME, Pinochet J. Occurrence of *Meloidogyne* spp. in Argentina. Supplemental Journal of Nematology. 1992;**24**:765–770.

[19] Dias WP, Asmus GL, Silva JFV, Garcia A, Carneiro GES. Nematoides. In: Almeida AMR, Seixas CDR, editors. Soja: doenças radiculares e de hastes e inter-relações com o manejo do solo e da cultura. Londrina, Brazil: Embrapa Soja; 2009. pp. 173–206.

[20] Moens M, Perry RN, Starr JL. *Meloidogyne* species- a diverse group of novel and important plant parasites. In: Perry RN, Moens M, Starr JL, editors. Root Knot Nematodes. Wallingford, UK: CABI International; 2009. pp. 1–18.

[21] Gowen SR. Chemical control of nematodes: efficiency and side-effects. FAO Plant Production and Protection Paper. 1997;**144**:59–65.

[22] Embrapa. Cultivares de soja safra 2014–2015 macrorregiões 4 e 5: regiões Norte e Nordeste do Brasil. Embrapa. 2014;1:1–5.

[23] Embrapa. Cultivares de soja lançamento 2015–2016. Embrapa Soja. 2015;1:1–5.

[24] Santana Gomes SM, Dias-Arieira CR, Biela F, Cardoso MR, Fontana LF, Puerari HH. Sucessão de culturas no manejo de *Pratylenchus brachyurus* na soja. Nematropica. 2014;**44**(2):1–14.

[25] Riggs RD, Schmitt DP. Soybean cyst nematode. In: Sinclair JB, Backman PA, editors. Compendium of Soybean Diseases. 3rd ed. St. Paul, MN, USA: The American Phytopathological Society; 1989. pp. 65–67.

[26] Dias WP, Silva JFV, Garcia A, Carneiro GES. Biologia e controle do nematoide do cisto da soja (*Heterodera glycines*). In: Embrapa Soja, editor. Resultado de pesquisa da Embrapa Soja-Soja: ecofisiologia, biologia molecular e nematoides. Londrina, Brazil: Embrapa Soja; 2004. pp. 1–48.

[27] Grigolli JFJ, Asmus GL. Manejo de nematoides na cultura da soja. Circular Técnica. 2014;**1**:1–19.

[28] Moore WF, Bost SC, Brewer FL, Dun RA, Endo BY, Grau CR, Hardman LL et al. Soybean cyst nematode. Soybean Industry Resources Committee. 1984;**1**:1–23.

[29] Tylk G. Soybean cyst nematode [Internet] 1994. [Updated: January 1994]. Available from: http://nematode.unl.edu/scn/scnisu.html

[30] Dias WP, Silva JFV, Carneiro GES, Garcia A, Arias CAA. Nematoides de cisto da soja: biologia e manejo pelo uso da resistência genética. Nematologia Brasileira. 2009;**33**(1):1–16.

[31] Ferraz LCCB. Gênero *Pratylenchus*: os nematoides das lesões radiculares. In: Luiz WC, editor. Revisão Anual de Patologia de Plantas. 1st ed. Passo Fundo: RAPP; 1999. pp. 158–195.

[32] Embrapa Soja. Tecnologias de Produção de Soja. Londrina, Brazil: Embrapa Soja; 2006. 217 p.

[33] De Waele D, Elser A. Migratory endoparasites: *Pratylenchus* and *Radopholus* species. In: Star JJ, Cook R, Bridge J, editors. Plant Resistance to Parasitic Nematodes. Wallingford, UK: CAB International; 2002. pp. 175–206.

[34] Ribeiro LM, Campos HD, Dias-Arieira CR, Neves DL, Ribeiro GC. Effect of soybean seed treatment on the population dynamics of *Pratylenchus brachyurus* under water stress conditions. Journal of Bioscience. 2014;**30**(3):616–622.

[35] Lima FSO, Santos GR, Nogueira SR, Santos PRR, Correa VR. Population dynamics of the root lesion nematode *Pratylenchus brachyurus* in soybean fields in Tocantins State and its effect to soybean yield. Nematropica. 2015;**45**:170–177.

[36] Neves DL, Ribeiro LM, Dias-Arieira CR, Campos HD, Ribeiro GC. Sobrevivência de *Pratylenchus brachyurus* em diferentes substratos com baixo teor de umidade. Nematropica. 2012;**42**:211–217.

[37] Castillo P, Vovlas N, editors. *Pratylenchus* (Nematoda: Pratylenchidae): Diagnosis, Biology, Pathogenicity and Management. Leiden: Brill; 2007. 529 p.

[38] Koenning SR, Schmitt DP, Barker KP. Influence of planting date on population dynamics and potential of *Pratylenchus brachyurus* on soybean. Journal of Nematology. 1985;**17**:428–434.

[39] Panorama R. Nematoides- a praga da safra. Panorama Rural. 2010;131:1-2.

[40] Franchini JC, Saraiva OF, Debiase H, Goncalves SL. Contribuição de sistema de manejo do solo para produção sustentável da soja. Circular Técnica. 2007;**46**:1–4.

[41] Inomoto MM, Siqueira KMS, Machado ACZ. Sucessão de culturas sob pivô central para controle de fitonematoides: variação populacional, patogenicidade e estimativa de perdas. Tropical Plant Pathology. 2011;**36**:178–185.

[42] Rios ADF, Rocha MR, Machado AS, Ávila KAGB, Teixeira RA, Santos LC, Rabelo LRS. Host suitability of soybean and corn genotypes to the lesion caused by nematode under natural infestation conditions. Ciência Rural. 2016;**46**:580–584.

[43] Machado ACZ. Host status of some selected Brazilian soybean cultivars to *Pratylenchus brachyurus*. In: Internacional Congress of Tropical Nematology; 15 de agosto; Maceió, Brazil. Maceió: Sociedade Brasileira de Nematologia; 2009. 1 p.

[44] Bessi R, Sujimoto RF, Inomoto MM. Seed treatment affects *Meloidogyne incognita* penetration, colonization and reproduction in cotton. Ciência Rural. 2010;**40**(6):1428–1430.

[45] Long DH. Mechanisms for movement of fungicides, nematicides and insecticides from seed coat to target region in cotton production. In: Proceeding of the Beltwide Cotton Conference; June 15; New Orleans. National Cotton Council; 2005. 239 p.

[46] Linford MB, Oliveira JM. *Rotylenchulus reniformis* nov. gen. n. sp. a nematode parasite of roots. In: Proceeding of the Helminthological Society of Washington; July; Washington; 1940;**7**:35–42.

[47] Robinson AF, Inserra RN, Caswell-Chen EP, Vovlas N, Troccoli A. *Rotylenchulus* species: identification, distribution, host ranges and crop plant resistance. Nematropica. 1997;**27**(2):127–180.

[48] Ferraz LCCB, Brown DJF, editors. Nematologia de plantas: fundamentos e importância. 1st ed. Manaus, Brazil: Norma Editora; 2016. 251 p.

[49] Rodriguez-Kabana R, Gazaway WS, Weaver DW, King PS, Weaver CF. Host suitability of selected tropical legumes and other crops for the reniform nematode, *Rotylenchulus reniformis*. Nematropica. 1940;**28**:195–203.

[50] Nemaplex. *Rotylenchulus reniformis*. The nematode-plant expert information system [Internet] 1990. [Updated: February 2008]. Available from: http//:plpnemweb.ucdavis.edu/nemaplex/Taxadata/G116S2.HTML [Accessed: September 2016].

[51] Sikora EJ, Lawrance KS, Murphy J. Survey of plant parasitic nematodes in soybean fields in Alabama. Nematode Management [Internet]. 2010. Available from: http://www.aaes.auburn.edu/comm/pubs/reseacrhreports/09soybeanrr.pdf [Accessed: October 2016].

[52] Asmus GL. Reação de genótipos de soja ao nematoide reniforme. Tropical Plant Pathology. 2008;**33**(1):69–71.

[53] Asmus GL, Schirmann MR. Reação de cultivares de soja recomendadas no Mato Grosso do Sul ao nematoide reniforme. Nematologia Brasileira. 2004;**28**:239–240.

[54] Favoreto L, Meyer MC, Klepker K, Campos LJM. Ocorrência de *Aphelenchoides* sp. em plantas de soja com sintomas de soja louca II. In: Congresso Brasileiro de Nematologia; 12 de Agosto; Londrina, Brazil. Sociedade Brasileira de Nematologia; 2016. pp. 81–82.

[55] Maceda A, Silva JF, Dias WP, Santos JM, Soares PLM, Marcondes MC, Lima CG. Ocorrência de *Scutellonema brachyurus* em soja no Brasil. In: Internacional Congress of Tropical Nematology; August 10; Maceió, Brazil. Maceió: ONTA; 2016. pp. 1–2.

[56] Machado ACZ. Current nematode threat to Brazilian agriculture. Current Agricultural Science and Technology. 2014;**20**:26–35.