REVIEW

THE CONTROL OF NEMATODES INJURIOUS TO SOYBEAN [COMBATE DE NEMATODOS DAñINOS DE SOYA].

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ABSTRACT

The principal nematode pathogens of soybean are *Heterodera glycines* Ichinohe, *Meloidogyne incognita* (Kofoid and White) Chitwood, *M. javanica* (Treub) Chitwood, and *M. arenaria* (Neal) Chitwood. Also injurious to soybean are *Rotylenchulus reniformis* Linford and Oliveira, *Hoplolaimus columbus* Sher, and *Belonolaimus longicaudatus* Rau. Lesser known potential pathogens include *Pratylenchus* spp. *Tylenchorynchus claytoni* Steiner, *Paratrichodorus christiei* (Allen) Siddiqi, and *Xiphinema americanum* Cobb.

The most productive advance in nematode control on soybean has been the development of cultivars resistant to many of the important nematode species. In many instances, nematicidal treatments are required as a necessary or complementary means of control. Fumigant nematicides have generally been more effective than nonfumigant nematicides in comparative tests. Crop rotations are employed for the control of soybean cyst nematode and reniform nematode. The monoculture of cultivars resistant to the soybean cyst nematode is not recommended due to the probability of selecting resistance breaking races.
Key Words: Glycine max, resistant cultivars, nematicides, crop rotations.

INTRODUCTION

The soybean, *Glycine max* (L.) Merril is an erect annual legume that is harvested mainly for its seed. It is an important cosmopolitan crop whose harvested area has increased from 12 to 48 million hectares world-wide since World War II. The majority of this increase has taken place outside of the crop's native east Asia. The major areas of production are USA (50.9% of world hectareage), China (18.9%), Brazil (16.5%), Argentina (3.5%), USSR (1.7%), and Indonesia (1.3%) (3).

The rapid expansion of the world's production has been accompanied by an increase in the diseases affecting soybean (12), not the least of which are those caused by nematodes.

PRINCIPAL NEMATODE SPECIES

Several nematodes are recognized as major pathogens of soybean. Their presence in soil planted to soybean will usually require management decisions to avert serious yield losses. The nematode most closely identified with soybean culture is the soybean cyst nematode, *Heterodera glycines* Ichinohe. It is found in Japan, Korea, China, Egypt, and USA. In the USA, this nematode is present in 18 states from Minnesota south to Florida. A review of the world distribution and economic importance of the soybean cyst nematode has been recently published (56).

Root-knot disease of soybean has been reported from most of the soybean producing areas of the world. Several species of root-knot nematodes parasitize soybean *Meloidogyne incognita* (Kofoid and White) Chitwood is the most prevalent in the USA, being endemic through most of the southeastern States (52, 54, 66). *M. arenaria* (Neal) Chitwood is increasing in importance in the same region, probably resulting from the widespread use of *M. incognita* resistant soybean cultivars. *M. javanica* (Treub) Chitwood is less widespread in USA, being more of a local problem in the extreme southeast. *M. javanica* appears to be the most prevalent root-knot nematode found with soybean in Brazil (4).

M. incognita, which is also common in Brazil (38), is a serious problem on soybean in Peru (1). Root-knot disease of soybean has been reported from Nigeria (49) and Japan (42).

In many locations on the coastal plain soils of the southeastern USA, the reniform nematode, *Rotylenchulus reniformis* Linford and Oliveira, is an acknowledged pathogen of soybean (8, 19). Its importance in world soybean production will undoubtedly increase as the soybean crop gains acceptance among tropical growers (32).

The lance nematode, *Hoplolaimus columbus* Sher, first reported as damaging to soybean in 1968 (20), is now recognized as a severe and spreading pathogen of the crop in adjoining areas of South Carolina and Georgia in USA (40).

The sting nematode, *Belonolaimus longicaudatus* Rau, is an extremely damaging pathogen of soybean in the deep sands of the Florida peninsula and in other scattered locations in the southeastern USA (29, 43).

CONTROL WITH RESISTANT CULTIVARS

The use of resistant soybean cultivars has been the most important aid in the defense against several nematodes. Their development has been mostly from germplasm material maintained in USA (27). However the development of resistant cultivars is also being accomplished in Japan (37), Korea (50), and Brazil (26).

The growth and maturity of the soybean plant is responsive to daylength (photoperiod). Consequently cultivars have different zones of geographical latitude within which they are most productive. The cultivars that have the same region of adaptation are referred to as a maturity group. In North America, Groups 00, 0, and I are adapted to the long days in the northern latitudes, whereas toward the other end of the scale Groups VI, VII, and VIII are adapted to the shorter days further south. Group IX soybeans are adapted for cultivation in the tropics.

Nematode resistant cultivars have been developed for the various latitudes where nematode problems are the most severe. Table 1 lists the nematode resistant cultivars that have been recently released or are currently in extensive use in North and South America. As yet, resistant cultivars are not available for controlling *Hoplolaimus columbus* nor *Belonolaimus longicaudatus.*

When resistant soybean cultivars are available for a particular nematode problem, their use is not a panacea in all cases. At least four physiologcal races of the soybean cyst nematode are recognized according to their abilities to reproduce on selected soybean lines (25). Populations of the soybean cyst nematode are not homogenous and the continued planting of a resistant cultivar increases the potential for the selection and increased reproduction of pathogenic populations (57, 71). Thus, race 4 of the soybean cyst nematode has become prevalent in several US states, where cultivars with resistance to race 3 have been grown repeatedly, necessitating the development of a cultivar with resistance to this race (28).

Host differential testing has identified races within the root-knot nematode species, *M. incognita* and *M. arenaria* (63). However, despite the widespread monoculture of

Table 1. Widely grown and recently released nematode resistant soybean cultivars.

Cultivar	Maturity group	Year of release	Resistant to:				
Custer	IV	1967	Hg 1, 3	Rr			
James	IV	1975			Mi		
Franklin	IV	1977	Hg 1, 3	Rr			
Dyer	V	1967	Hg 1, 3	Rr			
Mack	V	1971	Hg 1, 3				
Forrest	V	1972	Hg 1, 3	Rr	Mi		
Bedford	V	1977	Hg 1, 3, 4	Rr			
Pickett	VI	1965	Hg 1, 3	Rr			
Pickett 71	VI	1971	Hg 1, 3	Rr			
Centennial	VI	1976	Hg 1, 3	Rr	Mi		
Bragg	VII	1963			Mi		
IAS-1	VII	1973				Mj	
Govan	VII	1977			Mi		Ma
Braxton	VII	1979			Mi		Ma
Hutton	VIII	1972			Mi		
Cobb	VIII	1973			Mi		
Santa Rosa	IX	1968				Mj	

Hg = *Heterodera glycines* - races 1, 3, 4
Rr = *Rotylenchulus reniformis*
Mi = *Meloidogyne incognita*
Mj = *Meloidogyne javanica*
Ma = *Meloidogyne arenaria*

M. incognita resistant cultivars over the last 10 years in the southern USA, there have been no reports of extensive damage to these cultivars due to development of resistance breaking races. Resistance to root-knot disease is not complete in these cultivars. When they are grown in severe root-knot nematode infestations, maximum yields are not attained due to some infection by the nematode (31, 34).

A Louisiana population of *M. incognita,* now recognized as subspecies *wartellei* (24), is very damaging to cultivars normally resistant to *M. incognita.* This is likely a native population rather than one that has been selected from a typical population of *M. incognita* by the planting of resistant cultivars. A threatening situation arising from the extensive use of *M. incognita* resistant cultivars is the increasing incidence of these cultivars being damaged by *M. arenaria* in South Carolina, Alabama, Georgia and Florida (58).

Soybean breeding has been successful in developing several cultivars that have resistance to more than one nematode species. Cyst and reniform nematode resistance is combined in several cultivars. This was originally thought to be a linked phenomenon (7). This theory was discarded with the development of cv 'Mack' which is resistant to the cyst nematode only. Recent cultivars that have received widespread acceptance by growers are 'Forrest' (Grp V) and 'Centennial' (Grp VI) which have resistance to cyst (races 1 and 3), reniform and southern root-knot nematodes. New introductions have combined resistance to two species of root-knot nematode in

'Braxton' and 'Govan', both belonging to Grp VII.

In many fields, particularly in the southeastern USA, more than one severe nematode pathogen may be present to damage a soybean crop. Fortunately, in some situations, this may be answered by growing cultivars with multiple nematode resistance. Where nematodes are present against which there are no resistant cultivars or where there is a combination of nematode pathogens for which no single cultivar has the proper combination of resistances, other complementary control practices must be employed to insure adequate yields. These may also be required where populations of root-knot nematodes are very high.

CONTROL WITH NEMATICIDES

The increased value of the soybean crop over the last 10 years has allowed many growers the option of using a nematicide when no resistant cultivar is available or where nematode infestations are so severe that a nematicide is a needed complement to a resistant cultivar.

Several nematicides, both fumigants and nonfumigants, are presently available for use on soybean. In general, the use of fumigants has resulted in higher yields than the use of nonfumigants in comparative testing. In extensive field studies in Georgia (45), soybeans grown in soils variously infested with root-knot, sting, lance, and stubby-root nematodes and treated with the fumigant dibromochloropropane (5.78 l ai/ha) outyielded ethoprop (2.24-6.73 kg ai/ha) treated soybeans in 8 out of 10 tests; outyielded carbofuran (2.24-6.73 kg ai/ha) treated soybeans in 7 out of 7 tests; and outyielded aldicarb (2.2 kg ai/ha) treated soybeans in 4 out of 5 tests. In Florida (34), the yields of 5 soybean cultivars, grown in *M. incognita* infested soil, were consistantly greater from a 6.7 l ai/ha dibromochloropropane fumigation than from 3.4 kg ai/ha treatments of either funsulfothion, ethoprop or carbofuran. The fumigants dichloropropene and dibromochloropropane provided better average control of *Hoplolaimus columbus* than nonfumigant nematicides in 5 years of testing in South Carolina. However, the nonfumigants carbofuran and phenamiphos, effectively controlled this nematode and outyielded the fumigants in one test (10).

The nonfumigant nematicides, phenamiphos, carbofuran, aldicarb, oxamyl, and ethoprop at 2.2 kg ai/ha have been found to be as equally effective as dibromochloropropane (7.75 l ai/ha) and dibromoethane (16.5 l ai/ha) in reducing populations of *Belonolaimus longicaudatus* and significantly increasing soybean yields (55).

The effectiveness and low cost of dibromochloropropane led to its widespread use in the USA, particularly in the southeastern States for the control of lance, root-knot and mixed infestations of root-knot and cyst nematodes. Its use against cyst nematode and reniform nematode was less widespread in USA due to the greater reliance placed on rotational programs and resistant cultivars for control of these nematodes. The use of dibromochloropropane on soybean and many other crops has been eliminated in USA due to environmental problems (2). This has led to a re-evaluation of the efficacy of other fumigants for nematode control soybean.

In field studies in South Carolina and Florida, dibromoethane at rates of 4.2 l ai/ha were equal to or better than dibromochloropropane (6.0 and 8.1 l ai/ha, respectively) in at-planting treatments for the control of *Hoplolaimus columbus* (9) and *Meloidogyne incognita* (35) and for influencing yields. In extensive testing in Alabama, dibromoethane was judged as effective as dibromochloropropane for increasing the yield of soybean grown in the presence of either *Meloidogyne hapla* Chitwood, *M. arenaria*, or *Heterodera glycines*. Rates of 8.4 l ai/ha dibromoethane were considered sufficient for controlling low infestations of root-knot nematodes. However, severe

Table 2. Yields of soybean (kg/ha) from at-planting treatments of dichloropropene applied to infestations of different nematodes.

dichloropropene liters active/ha	I *Hoplolaimus columbus*	II *Meloidogyne incognita*	III *Meloidogyne incognita*	IV *Meloidogyne arenaria*	V *M. arenaria + H. glycines*	VI *Heterodera glycines*
77.5	----	----	----	1484A	----	----
68.4	1764X	----	----	----	----	----
60.3	----	----	----	----	1079A	----
51.6	----	----	----	1507A	848	----
46.3	----	----	----	1631A	----	----
43.1	----	----	1818BX	1052A	694	3047A
41.1	----	2278AX	----	----	----	----
36.0	----	----	----	----	847	----
35.7	2075A	----	----	----	----	----
34.4	----	2359A	----	1010A	732	----
34.2	1895A	----	----	----	----	----
30.9	----	----	----	1256A	925	----
25.9	----	----	2568X	----	----	2556X
25.8	----	----	----	1025A	771	----
25.7	----	----	2476	1136A	809	2394BX
25.6	1701	----	----	----	----	----
25.5	1581	----	----	----	----	----
20.6	----	2406A	----	1068A	848	----
17.2	----	2318A	2628	836	809	2805
17.1	1481	----	----	----	----	----
15.5	----	----	2669	----	----	2368BX
15.4	----	----	----	929	771	----
15.3	1368	----	----	----	----	----
10.3	----	2238A	2672	929	694	2764
8.6	----	2117	3019	----	----	2986
5.2	----	----	2644	----	----	2818
3.9	----	1848	----	----	----	----
CK	1348S	1788S	2892R	779S	656S	2590R

A Significant increase over check; B Significant decrease below check; S Susceptible cultivar; R Resistant cultivar; X Phytotoxicity indicated by yield or stand reduction.

infestations of either root-knot nematodes or cyst nematodes required twice that rate of fumigant (59). In a Georgia field test (44), dibromoethane, at 4.2 l ai/ha, significantly outyielded untreated controls by 443 kg/ha in *M. incognita* infested soil. There were no significant yield differences from several dibromoethane treatments ranging from 4.2 to 50.4 l ai/ha. All significantly reduced the incidence of soil populations of *M. incognita* juveniles at late season. In the forementioned studies, field observations gave no evidence of phytotoxic effects by at-planting treatments of dibromoethane even at rates as high as 50.4 l ai/ha.

The fumigant dichloropropene has been traditionally recommended for nematode control on soybeans at rates varying from 45-60 l ai/ha. These dosages are applied at least 10 days before planting to avoid the phytotoxic effects of the chemical. This practice has not received wide acceptance by growers due to the high cost and volume of material to be applied and the practical problems presented by the preplant treatment. The latter is especially troublesome when soybeans are to be planted immediately following a winter cereal, a practice that is in widespread use in the southeastern USA. Recent field studies have been conducted to determine the efficacy of lower dosage rates of dichloropropene and the possibility of applying them at planting without phytotoxic effects (9, 35, 44, 60). Results are summarized in Table 2. Responses to these treatments were variable. However, some general conclusions can be made. Significant yield responses occur when low dosage rates of dichloropropene (10-40 l ai/ha) are applied at planting to susceptible soybeans when nematode pressure is not too severe (CK yields of 1000-2000 kg/ha, Tests I, II). With increased nematode pressure, low rates do not give adequate yield responses (Tests IV, V) and have no influence on the yield of resistant cultivars (Tests III, VI). Although no direct comparisons can be made among these tests, it is notable that the check yields in the tests using resistant cultivars outyielded all fumigant treatments of the susceptible cultivars. Phytotoxic effects of at-planting fumigation were not generally evident, except in Tests III and VI. These were distinguishable from the other tests by being subject to considerable rainfall immediately following planting (35). Heavy rainfalls are usually credited with promoting fumigant phytotoxicity by preventing the fumigants' escape from the soil surface.

A cross-reference is presented featuring published reports on the efficacy of several nematicidal chemicals against the principal nematode pathogens of soybean (Table 3).

CONTROL WITH CROP ROTATION

Nematode problems in soybean generally arise after several years of monoculturing cultivars susceptible to the nematodes present in the soil. Consequently, breaking the planting cycle by rotating soybean with other crops immune or less susceptible to the problem nematode has often been recommended as a means of reducing nematode populations enough that a successful soybean crop can be harvested.

Several factors govern the success of any rotation program. Nematode species with a narrow host range are more amenable to rotational control than species with a wide host range, as are soil infestations harboring one nematode pathogen rather than several. Furthermore, non-host crops must be available that can be grown economically to maintain a grower's interest in their production.

The soybean cyst nematode has a very narrow host range among agricultural crops, and soybean rotations with maize, a non-host, have been a common practice in the midwestern states of USA where maize can compete economically with soybean. The soybean cyst nematode is known to survive in the soil in the absence of a host from 4 to 8 years (17, 70). Recommended rotation programs vary from a frequency of planting a

Table 3. Published reports on the efficacy of nematicides for the control of nematodes on soybeans. Numbers refer to the citations given at the end of this review.

Nematicide	*Meloidogyne spp*	*Heterodera glycines*	*Hoplolaimus columbus*	*Belonolaimus longicaudatus*
dibromochloropropane	6 34 35 45 46 59 60	6 14 15 16 35 59 60	9 10 45 46	55 64 69
dibromoethane	6 11 35 44 45 59	6 14 35 59	9	55
dichloropropene	22 34 35 46 60	5 6 14 15 18 35 60	9 10	
ethoprop	6 34 45 46	6 13	10 45 46	55 64 69
fensulfothion	6 34	6	10	69
phenamiphos	34 44 45	6	10	55 69
carbofuran	34 45	6	10 45	55 64
aldicarb	34 45		10 45	55
oxamyl	34 45	6	10 45	55

susceptible cultivar from every 3 years (48) to 6 years (30). Studies in North Carolina have shown that soybean in a 2 year rotation with nonhost crops yielded 2-3 times more than monocultured soybean in cyst infested soil, whereas those in 3 and 4 year rotations outyielded monocultured soybean by 7-8 times. (61). The frequency of soybean planting will depend on the severity of the nematode infestation. Cyst resistant soybean cultivars (Table 1) are considered as nonhosts for rotational purposes but it is generally advised that these should not be planted in two successive years, but rotated with other non-host crops and susceptible soybean cultivars to prevent the build up of populations of resistant breaking races of *H. glycines* (47, 62).

Rotational studies in Louisiana have shown that alternating a reniform nematode resistant cultivar with a susceptible cultivar was effective in reducing reniform nematode populations and maintaining yields of the susceptible cultivar such that chemical control could be elimated (23).

The root-knot nematodes have wide host ranges among agricultural crops. Thus their control on soybean with rotational practices has not been generally advised. However, rotational studies (Unpublished) on *M. incognita* infested soil in Florida show that a 2 year rotation between a susceptible soybean cultivar and maize, a less susceptible host, became increasingly effective in maintaining the yields of the soybean as the nematode population increased in the soil (Fig. 1). Short term rotations between soybean and maize were ineffective in maintaining soybean yields where *M. incognita* and *Heterodera glycines* were both present (33).

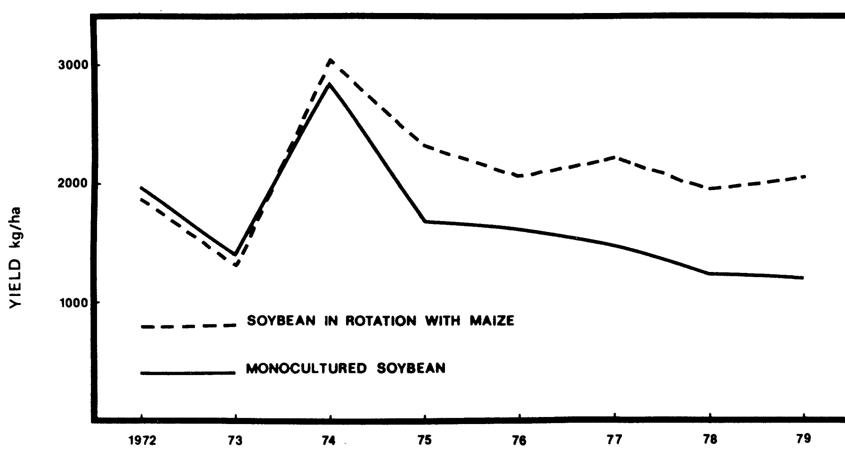

Fig. 1. Yields of susceptible soybean grown in monoculture and in a two-year rotation with maize in soil infested with *Meloidogyne incognita*. No nematicides applied. Mean of four replicates. Differences significant (P = 0.01) from 1975 onward.

CONCLUSION

Considerable success has been achieved in the field of nematode control on soybean. This has allowed production of the crop in areas where nematode predation would have seriously restricted the development of a soybean industry. This is particularly true of the southeastern USA. A prime factor has been the introduction and grower acceptance of nematode resistant cultivars. It is in this area of nematode control that future research efforts could be the most productive. A greater emphasis must be placed on the development of multiple nematode resistant cultivars, available in many maturity groups. Of particular need are cultivars resistant to *Hoplolaimus columbus* and *Belonolaimus longicaudatus*. Future advances in the research for soybean nematode resistance will require a continuing close working relationship between the nematologist and the plant breeder (36).

There are plant-parasitic nematodes, other than the principal species mentioned in this review, that are frequently found in association with soybean. Their role in soybean production has not been fully investigated, primarily because attention has been directed mostly towards the more obviously troublesome species. However, several species have been implicated as possible economic pathogens that merit research attention. These include the lesion nematodes *Pratylenchus spp* (21, 39, 41, 53, 67), the stunt nematode *Tylenchorhynchus claytoni* Steiner (51), the stubby-root nematode *Paratrichodorus christiei* (Allen) Siddiqi (65), and the dagger nematode *Xiphinema americanum* Cobb (68). With the expected increase in hectareage planted to cultivars resistant to the princiapal nematodes, the importance of these lesser known pathogens may become more apparent.

It is likely there will be a continued and increasing use of nematicides for soybean nematode control. The efficacy of any nematicide will depend on local conditions such as rainfall, soil type, pH, severity of nematode infestation, and the susceptibility of the soybean cultivars available for planting. Thus regional research data will be of paramount importance in determining the dosage rates of recommended nematicides, their formulation, and the most effective techniques for their application.

The rising concerns for environmental quality and reduced energy expenditures will likely place constraints on any needless applications of pesticides. Thus there is an increasing need for the simultaneous development of more definitive field sampling procedures to determine nematode distribution and the improvement of prognostic yield loss estimates through correlation with preseason nematode density levels in the soil.

RESUMEN

Los principales nematodos patógenos de la soya son *Heterodera glycines* Ichinohe, *Meloidogyne incognita* (Kofoid y White) Chitwood, *M. javanica* (Treub) Chitwood, y *M. arenaria* (Neal) Chitwood. También son dañinos para la soya *Rotylenchulus reniformis* Linford y Oliveira, *Hoplolaimus columbus* Sher, y *Belonolaimus longicaudatus* Rau. Otros nematodos menos conocidos pero con potencial de patogenicidad en la soya son *Pratylenchus* spp, *Tylenchorhynchus claytoni* Steiner, *Paratrichodorus christiei* Allen, y *Xiphinema americanum* Cobb. El adelanto más significativo en el combate de los nematodos de la soya ha sido el desarrollo de cultivares resistentes a muchas de las especies importantes de nematodos. Aún así, en muchos casos, el uso de tratamientos con nematicidas es necesario para efectuar el combate de los nematodos o para complementarlo. En pruebas de campo los nematicidas fumigantes han sido generalmente más efectivos que los no fumigantes. Rotaciones de

cultivos se emplean para combatir el nematodo enquistador de la soya y el reniforme. El monocultivo de cultivares resistentes al nematodo enquistador de la soya no es recomendable dada la probabilidad que se seleccionen de esta manera nuevas razas del patógeno.
Claves: Glycine max, Heterodera glycines, Meloidogyne spp, Rotylenchulus reniformis, Hoplolaimus columbus, Benololaimus longicaudatus, cultivares resistentes, nematicidas, rotación de cultivos.

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