EC MICROBIOLOGY
Review Article

Review of Integrated Management of Plant Parasitic Nematodes in Sudan

GAA Elbadri[1]*, AB Ziedan[2] and AM Yassin[3]

[1]*Agricultural Research Corporation, Crop Protection Centre, Plant Pathology Section, Wad Medani, Sudan*

[2]*Professor of Nematology, Faculty of Agriculture Sciences, Gezira University, Wad Medani, Sudan*

[3]*Former Professor of Nematology, Agricultural Research Corporation, Wad Medani, Sudan*

***Corresponding Author:** GAA Elbadri, Agricultural Research Corporation, Crop Protection Centre, Plant Pathology Section, Wad Medani, Sudan.

Received: May 19, 2026; **Published:** July 14, 2026

Abstract

Plant-parasitic nematodes are harmful to many economic important crops, but their damage is often overlooked. Many plant-parasitic nematode species are capable of inflicting severe above-ground damage. Investigations started in Sudan since the late sixties. Some 80 species of plant-parasitic nematodes have been detected in and around the roots of many cultivated and weed plants in various localities throughout the country. There is substantial evidence that the impact of the nematode upon the yield is underestimated, at least in the Gezira. In this review we tried to report the most common control of plant parasitic methods used in Sudan. A number of nematicides, including fenamiphos, aldicarb and Nemagon, were all tested in soil under cotton cv. Barakat, at a site at the Gezira Research Station (GRS). containing relatively high densities of *Pratylenchus sudanensis*. All three nematicides resulted in up to 72 to 90 percent increase in the yield of seed cotton and up to 36 to 88 percent reduction in nematode densities over the control. The majority of investigations were undertaken on *Meloidogyne javanica* and *M. incognita* in tomato as it is the most important pest in this very popular and widely grown vegetable crop. Recently we tested many herbal extracts to control root knot nematodes to avoid chemical hazards and we found that this method can be as alternative to chemical control and/or one of the integrated pest management tools.

Keywords: *Plant Parasitic Nematodes; Meloidogyne javanica; M. incognita*

Introduction

Nematodes successfully colonize a greater variety of habitats that any other group of multicellular animals [19,29]. Plant-parasitic nematodes live in soil, or in plant tissues, and typically do not move actively over great distances [4]. Nematode movements over great distances may occur as a result of man's activities, through infected plant parts or as contaminants on machinery, crates, bags or other containers [31]. Plant-parasitic nematodes are harmful to many economic important crops, but their damage is often overlooked [37]. Many plant-parasitic nematode species are capable of inflicting severe above-ground damage (stunting, wilting, chlorosis, reduced yield), they cause direct root damage (Galls, lesions, root-pruning, stubby roots) which are indirectly responsible for above ground symptoms [47]. Destructive nematode species in main pistachio cultivation areas of Iran, and adversely affect crop quality and yield. So far, *Meloidogyne incognita* and *M. javanica* have been reported infecting pistachio [34].

To satisfy the needs of the increasing human population, yield of many of the major crops has had to be continually increased, leading to crop production on massive scale and often in monoculture systems [28]. As plant-parasitic nematodes are damaging these crops, control measures are needed to minimize the economic losses which can lead to save human food and environments beauty.

A variety of plant parasitic nematode species usually occur under diversified natural vegetation, with individual species population densities being relatively small consequently, no apparent damage occurs to the plant hosts. However, under human influence a particular nematode species can rapidly become a pest species when, for example, a plant is grown continuously for several years, viz, monoculture, thus presenting a somewhat optimum opportunity for multiplication by the nematodes species. Also, intensive cropping, in which only a few plant species are grown in a relatively short crop rotation, provides a similar opportunity for a few species to multiply rapidly to reach population densities that can result in plant damage. This fundamental precept is the basis for all control measures with the principal objective being focused on preventing large population densities of parasites from developing.

It should be realized that some crops are more susceptible than others to nematode attack. In some circumstances even very small numbers of nematodes can have a major deleterious effect on crop species, e.g. when their feeding facilitate the entry of a secondary pathogen such as bacteria, fungi into the plant. Control of nematode pests of plants can be achieved in a variety of ways or means of control carried out together, thus adopting an “Integrated Control Programme”.

Integrated plant parasitic nematodes management

This is a strategy accomplished by using the best combination of available control systems and tactics for the pest complex at hand (nematodes, insects, disease organisms and weeds) including economic and environmental aspects constitutes an integrated crop protection system [12]. It is a system approach to reduce pest damage to tolerable levels through a variety of techniques, including predators and parasites, genetic resistance hosts, environmental modification, and when necessary and appropriate the use of pesticides [40]. Because of the nature of nematodes, their management procedures are well suited and used for Integrated Pest Management (IPM) programmes.

IPM system requires flexibility and varies accordingly to the specific pest problem and management options available locally. A fixed set of recommendations may keep a pest complex in check for a limited period of time, but as pest populations shifts, recommendation must change also. Controlling nematodes in the soil is difficult and sometimes expensive, but often necessary for a profitable crop production. Usually, a combination of methods is needed to reduce the population to an economically acceptable level. One the nematodes are established in a field eradication is impractical. Disease losses can be minimised through the following aspects discussed below.

Correct identification of nematodes

Knowing which nematode species occur is the first step to proper management decisions. Therefore, correct species identification is efficient to nematode control [8]. Nematodes are described as morpho-species and are identified by studying their morphology and morphometrics. As between closely related species overlapping in morphometrics occurs, correct identification is not always easy. At sub-species level pathotypes and physiological races are known to occur in most of the species identified. Some of these races are genetically isolated and subsequent studies showed discrete morphological differences suggesting different evolutionary trajectories. These findings often resulted in establishing separate species for what were previously known as races or pathotypes [9].

Cropping sequences

Planting crops in special sequences, i.e. the use of rotation is an old but effective and widely used land management practice for reducing nematode populations in the soil [22]. To be effective, however, crops that are resistant, or preferably nonhosts for the nematodes to be controlled, must be rotated with susceptible crops. Growing a resistant or nonhost crop for only one year is helpful, but generally inadequate. Two resistant or nonhost crops between susceptible crops may give fair to good control; however, three or four years of resistant or non host between susceptible crops may be necessarily for effective control of some nematodes [25,43].

Among the important crop plants in the Gezira scheme Sudan rotated with cotton are dura, lubia, groundnuts and wheat, the first two were favourable and the second two were poor or non hosts of *Pratylenchus sudanensis* [54] (Table 1). The effect of dura and lubia in increasing nematode densities under the existing conditions in the Gezira scheme might therefore be mitigated by that of wheat and groundnuts [54]. As far as the genus *Meloidogyne* is concerned in cotton in the Gezira scheme [54] found that both cultivar Barakat of cotton and cultivar of Ashford groundnut were found to exhibit absolute immunity to wards *M. javanica* isolate from Central Sudan.

	Pigeon pea	Lubia	Cotton	Sorghum	Groundnuts	Wheat
6 weeks after sowing						
a	20	25	10	6	10	1
b	154	83	14	2	0	0
a+b	174	108	24	8	10	1
12 weeks after sowing						
a	463	218	122	85	3	9
b	26	74	4	14	1	1
a+b	489	289	126	99	4	0
Before harvest						
a	19	54	22	8	6	8
b	32	2	2	0	1	0
a+b	51	56	24	8	7	8
Mean total						
a+b	245	152	58	54	7	6
Degree of root necrosis						
	+++	+++	++	++	+	+

Table 1: *Effect of cropping on population levels of Pratylenchus sudanensis at Gezira Research Station farm during three seasons [54].*

a: Denotes number of P. Sudanensis per one g soil.

b: Denotes number of P. Sudanensis per one g root.

+: Mild; ++: Medium; +++: Severe.

Generally, crop rotation in spite of its effectiveness, has important limitations. The amount of damage inflicted on a crop depends on the level of resistance in the crop used in the rotation, and on the number of years of planting of these crops between susceptible crops. Furthermore, the nonhost or resistant crops, which effectively control specific nematodes, may be a host for another plant parasitic nematode species existing in the same field [46]. Another disadvantage is that is the low commercial value of some nonhost or resistant crops. Moreover, some farmers have inadequate land to rotate crops.

Resistant cultivars

Extensive breeding works has been undertaken in tomato against root knot nematodes in many countries throughout the world [20,27,42,48]. 11 tomato cultivars imported from USA, France, Italy, Holland and India, were found be highly resistant to the local race of *M. javanica*, but resistance of many of them degraded after 2 - 3 seasons of test as shown in table 2 [56] and in table 3 [54]. This is perhaps due to the occurrence of more than one species in the locality, or else due to the presence of physiologic races or biotypes. In another green house experiment undertaken in the department of Plant pathology, Gezira research station (Agricultural Research Corporation) using resistant tomato cultivars (local lines and imported ones) (Table 4) [17].

In the USA, commercial varieties of cotton, cowpea, grape, lima beans, beach, soybean, sweet potato, tomato and tobacco resistant to root-knot nematodes and cultivars of alfalfa, oats and barely resistant to the stem nematodes are grown extensively [53].

Tomato variety	% heavily infested plants	Plant size	Fruit yield
Nemared	0 (0 - 0)	41 x 67	207 (177 - 256)
Kalohi	0 (0 - 0)	44 x 64	152 (100 - 200)
Healani	0 (0 - 0)	38 x 53	146 (65 - 175)
Royal Chico	0 (0 - 0)	45 x 67	136 (90 - 238)
Romilus	0 (0 - 0)	35 x 61	122 (64 - 180)
Tobol	0 (0 - 0)	42 x 60	109 (62 - 146)
Nandel	0 (0 - 0)	45 x 53	92 (55 - 129)
Roforto	0 (0 - 0)	34 x 46	00 (00 - 00)
Rossol	38 (30 - 50)	55 x 82	222 (192 - 275)
Marsol	43 (40 - 50)	55 x 82	197 (150 - 233)
VFN-8	51 (40 - 63)	46 x 68	187 (133 - 250)
Piersol	53 (50 - 59)	49 x 58	152 (133 - 225)
Romano - NR	56 (50 - 67)	48 x 77	200 (179 - 267)
Chico III	72 (57 - 100)	32 x 40	88 (57 - 167)
Manaluice	77 (66 - 100)	34 x 35	41 (33 - 50)
VF - 145 - 21 - 4	87 (60 - 100)	35 x 47	112 (00 - 175)
S - 120 - NR	100 (100 - 100)	34 x 48	167 (144 - 171)
Money Maker	100 (100 - 100)	34 x 47	25 (22 - 42)
Strain B	100 (100 - 100)	27 x 34	23 (20 - 33)

Table 2: *The performance of selected tomato cultivars under natural conditions of root-knot infestation at a site at Hillat Hassan, central Sudan. The figures represent the % mean (and range) of heavily infested plants, mean plant size (height and circumference) in cm and mean (and range) of fruit yield as kg/1000 plants [56].*

**Previous tests showed a possible mixture of M. javanica and M. incognita in the ratio of 2 :1, respectively.*

Variety	First test	Second test	Third test
1. VFN - (USA)	0	0	0
2. VFN - Bush (USA)	0	1	2
3. Motabo (France)	0	0	3
4. Rossol (France)	0	0	4
5. Piersol (France)	0	0	5
6. MON- 144 (USA)	_	0	5
7. Romano NR (Holland)	_	_	5
8. Ronita (Italy)	0	0	6
9. Marsol (France)	0	0	6
10. 68N - 144 (USA)	_	0	7*
11. Anahu (USA)	0	_	_
12. Local (Sudan)	9*	7*	_

Table 3: *Performance of various tomato cultivars towards the local race of M. javanica (Wad Medani). The figures refer to mean root-knot index: 0 = no infestation; 1 - 3, 4 - 6, and 7 - 9 = mild, moderate, and severe infestation respectively [54].*

*- = Not tested, *Root function largely impaired, often wilted plant.*

Tomato cultivars and lines	Average root-knot index and (range)
1. SDL 11	2.3 (0 - 3)
2. SDL 12	1.0 (0 - 2)
3. SDL 14	1.3(0 - 4)
4.SDL 15	1. (0 - 2)
5.SDL 16	1.5 (0 - 3)
6. Peto Seed	3.5 (0 - 6)
7.Satle Rock	1.0 (0 - 1)
8. Money Maker	6. (0 - 8)
9.Strian B	7. (0 - 8)
10. Ace	4.5 (0 - 4.5)
11. VF 145	7.8 (0 - 9)

Table 4: *Root-knot nematodes index for the tested tomato cultivars and lines. The figures refer to mean root-knot index, 0 = no infestation; 1 - 3, 4 - 6, and 7 - 9 = mild, moderate and severe infestation, respectively [15].*

Biological control

Organisms with an antagonistic effect on phytonematodes are present in many groups: bacteria, fungi, protozoa, nematodes, annelids and arthropods. They are part of the natural flora and fauna and abundant in most soils [30]. However, attempts to develop their use as a generally effective technology have thus far largely failed. An exception is the bacterium *Pasteuria penetrans* [52] that can be mass-produced and is available commercially. However, a difficulty with *P. penetrans,* as with most other bacterial and fungal antagonists, is the great diversity in virulence caused by genetic differences [38]. One strain can be highly virulent against some populations but a virulent against other populations of the same nematode species. Also, many soil organisms usually are in dynamic equilibrium and the addition of large amounts of a single agent with activates the "biological buffering system" with the consequence that the introduced organism is rapidly reduced to small numbers, and may even disappear. There appears little possibility, certainly in the near future, that a single agent will be successfully mass-produced and applied to protect crops from nematode damage. A more realistic possibility is to favour the total group of antagonists and oxygen competitors of phytonematodes by increasing the microbiological activity in soil, e.g. by adding organic material [5]. The fungi that prey upon nematodes have been known for longer time. In 1852 *Arthrobotrys oligospora* was initially described. Baron in his book [6] classified the nematodes destroying fungi as either predatory or endoparasitic, and defined the endoparasitic fungi as those'' fungi which form spores which stick to the passing nematodes'' Once these spores hatch, the sporoplasm enter the body and consumes its contents to form a mass of hyphae. Barron also included the egg parasites as special group of endoparasites specialized in the parasitism of eggs.

The fungus *Paecilomyces lilacinus* has been introduced and gave successful results in controlling root-knot nematodes *Meloidogyne* species [2]. However, their results have been confirmed by [16,21] (Table 5). Tow predatory fungi have been produced commercially in France, these are: Royal 300 a preparation of isolate of *Arthrobotrys robusta* for control of *Ditylenchus myceliophagus* on mushrooms, and Royal 350 a different isolate of *Arthrobotrys spp*. For control of *Meloidogyne spp*. On tomato. *Verticillium chlamydosporium* is the most effective fungus against nematodes eggs especially against *H. avenae* and *H. schachtii* and is found in many European countries and across the world [26]. It was also found to attacks cyst nematodes and *Meloidogyne* eggs [10].

	M. javanica		*M. incognita*	
Treatments	**Eggs**	**Females***	**Eggs**	**Females***
P. lilacinus	45.4 ± 6.1^{a}	20 ± 0^{a}	67.2 ± 3.96^{a}	20 ± 0^{a}
G. roseum	25.0 ± 4.0^{b}	3.2 ± 3.4^{b}	31.4 ± 4.93^{b}	4.6 ± 2.3^{b}
F. solani	0.0 ± ^{c}	0.4 ± 0.55^{c}	1.2 ± 1.3^{c}	0.8 ± 0.84^{c}
Control	0.0 ± ^{c}	0.0 ±0 ^{c}	0.00 ^{c}	0.0 ± 0^{c}

Table 5: *The parasitism of M. javanica, and M. incognita eggs and females by Paecilomyces lilacinus, Gliocladium roseum and Fusarium solani on agar plate [16].*

*Mean followed by the same number in the column do not differ significantly from each other at P = 0.05 according to Newman-Keuls comparison test. *Means of five replicates (20 female/replicate).*

The use of cultural practices

The use of soil amendments

A number of plants contain, or produce, substances toxic to Phytonematodes, e.g. Dura straw (*Sorghum vulgare*) and Lubia Bean straw (*Cajanus cajan*) (Table 6) [56] and *Datura stramonium*, neem (*Azadirachta indica*) and *Khaya spp.* [14,17] when used as soil amendments were found very effective in reducing the infestation level. Nematodes invading the roots of such plants may be killed. These plants can also be used as green manure to provide a double beneficial effect: toxic substances can damage harmful nematodes and the organic matter facilitates a higher diversity and density of the soil micro-flora and- fauna, among them many antagonists of phytonematodes [57].

An inexpensive and effective method of phytonematode control is the incorporation of soil cakes into the soil. They are the residues (by-products) of the production of oil from seeds of cotton, sesame, mustard or castor bean [14]. By microbial degradation toxic substances such as ammonia are produced in sufficient quantity to damage phytonematodes without being harmful to other soil inhabitants and plants [51]. Similarly, chitin-containing waste from the food industry, e.g. carapaces of crustaceans, and pharmaceutical factories e.g. fungal residues from antibiotics production, can be successfully incorporated into the soil to reduce nematode populations. It appears likely that in addition to ammonia production the chitinase activity of the soil is increased which provides a deleterious effect on the chitin-containing nematode eggs hells [18,51].

Type of amendment	R.I.	S.E. ±
Dura straw	3.5*	0.87
Lubia straw	4.4	1.73
None	4.7	0.45

Table 6: *The effect of soil amendment on the infestation level of the root-knot nematodes from Central Sudan+. The figures represent the mean root-knot ratings, R.I., from 0 - 5; 0 = no infestation, 1 - 3 = moderate infestation, 4 - 5 = heavy infestation [54].*

+Previous tests showed a possible mixture of M. javanica and M. incognita in the ratio of 2 :1, respectively.

** = Significance at 0.05 P.*

The use of watering intervals

This is another effective method of control used by [56] (Table 7) which proved to be very effective. The pot experiment carried out during two seasons (1978/79 and 1979/80) confirmed that flooding could be regarded as one of the most effective cultural methods for the control of root-knot nematodes especially in places with abundant water supply, however, this practice does not seem very feasible in areas like Sudan where the majority of agricultural production is concentrated in the arid and semi-arid areas. The control of nematodes by flooding has been advocated in certain locations [23]. When flooded all the soil pore spaces are filled and the oxygen supply for the soil microflora and fauna becomes limiting. Many plant-parasitic nematodes are intolerant of oxygen starvation and soon die. Similar effects are observed when nematodes are stored in deep water in the laboratory, but often they can be revived by aeration. To be effective in the field therefore, the anaerobiosis has to be of sufficient duration to kill the nematodes. In Côte d'Ivoire banana fields are flooded for at least five weeks. Flooding is not a technique that can be widely used for nematode control and whether it is equally efficacious against all plant-parasitic species is not known [32].

Watering Regime	Season 1978/79		Season 1979/80	
	R.I.	S.E. ±	R.I.	S.E. ±
Complete Flooding (CF)	1.8***	1.17	2.6***	0.29
Heavy (3 waterings/Day) (H)	2.2***	1.19	4.0**	0.21
Conventional (Once/Day) (C)	4.7	0.50	4.9	0.07
Light (Once/2 Days) (L)	4.8	1.64	4.8	0.11

Table 7: *The effect of watering interval on the infestation level of the root-knot nematodes M. javanica from Central Sudan+, for the seasons 1978/79 and 1979/80. The figures represent the mean root-knot ratings, R.I., from 0 - 5; 0 = no infestation, 1 - 3 = mild - moderate, 4 - 5 = heavy infestation [56].*

+ M. javanica was originally isolated from mixture of M. javanica and M. incognita from root samples from Central Sudan.

***, *** = Significance at 0.01 and 0.001 P, when compared with (C).*

Chemical control measure

Chemicals nematicides are used:

a) When other methods of control are too costly or difficult to apply;

b) When other methods of control are inadequate since they do not sufficiently suppress the nematode populations;

c) When the crop is most valuable and the equality of utmost importance;

d) When other methods are not economical like fallowing and flooding;

e) When growing export products, nematicide along with other methods provide a handy tool for providing a nematode free products and

f) When other purpose are also envisaged like controlling fungi, weeds or insects.

The limited number of nematicides, and their almost non-existence prior to 1943, provided nematology which a sound background in exclusion and nonchemical nematodes population modification procedure [41]. The modern era of nematology developed concomitantly with chemo technology resolution, following the discovery of the nematicidal properties [39]. This led to the development of other soil fumigants, nonfumigants nematicides and increased the understanding role of nematodes in agriculture.

Now a day's insecticide manufacturers are searching of those compounds, which can have the advantage of being non-phytotoxic, and have direct killing effect on nematodes. Most of them influenced neuro-transmission, thus disturbing neural co-ordination needed for movement, orientation, feeding and partner and host recognition. The objective was to protect plants from nematode attack and not necessarily to eradicate the nematodes, which, as explained, is an almost impossible expectation. As a result of their high mammalian toxicity the nematicides with systemic action also are mostly banned, or their use severely restricted. A complete ban has had serious consequences for potato growers in several countries, as no alternatives are available to control trichodorid nematodes that transmit tobacco rattle virus that causes "TRV-spraing" disease in potato.

Several nematicides were recognised and tested against the most important nematode species; [56] tested six nematicides in an orchard naturally infested with root-knot nematodes *M. javanica* and *M. incognita* in Central Sudan and recommended the use of Vaydate and Nemacur as the best in reducing the infestation level, resulting in more healthy plants with the highest yield of Tomato, var. Strain B (Table 8). [54] found that Phenamiphos, Aldicarb, and Nemagon were very effective in increasing cotton yield and reducing *Pratylenchus sudanensis.* Infestation in an experiment undertaken at the Gezira Research Station during two seasons (Table 9). They were tested against c.v. Barakat containing relatively high number of the lesion nematodes. All three nematicides resulted in up to 72 - 90% increase in the yield of seed cotton and up to 36 - 88% reduction in the nematodes densities over the control. Although very effective, yet many technical and economic difficulties might be entailed in their application on a large scale at present.

Can we expect development of novel nematicides not burdened with toxic and pollution risks for non-target organisms? For the last 20 years no such substance have been brought onto the market, not least as a result of the costs of developing such compounds. However, some research is currently being undertaken and several target sites presently are under investigation e.g. hormonal processes (moulting, reproduction); enzyme production (feeding sites); energy metabolism (respiratory processes); transport systems (membrane function); neuro-transmission; synthesis of collagen (body wall formation) and DNA synthesis [50,53]. Some of these are also being studied in connection with engineered resistance. Nevertheless, the prospects of having efficient new nematicides in the near future than can meet increasingly rigid toxicological and environmental requirements appear remote [11].

Treatment	% Heavily infested plants	Plant Size (cm) (Ht. X Circum)	Yield (Kg/1000 plants)
Vydate	9 (0 - 25)***	34 x 57	184 (153 - 243)***
Nemacur	22 (20 - 28)***	33 x 68	157 (137 - 192)***
Bunema	30 (21 - 44)**	32 x 67	155 (135 - 178)***
Furadan	33 (16 - 53)*	30 x 63	152 (132 - 164)***
Temik	46 (32 - 62)	33 x 67	135 (87 - 171)**
None	51 (45 - 57)	30 x 59	73 (55 - 107)
S.E. ±	3.659	2.600	13.30

Table 8: *Nematicidal tests in tomato, c.v. Strain B, against root-knot nematodes from naturally infested soil at a site at Hillat Hassan, Central Sudan. The figures represent the % mean (and range) of heavily infested plants, mean plant size (height and circumference) in cm and mean (and range) of fruit yield as kg/1000 plants [56].*

*+Previous tests showed a possible mixture of M. javanica and M. incognita in the ratio of 2:1, respectively. *, **, *** = Significance at 0.05 P 0.01 and 0.001 P.*

	Season, 1973/74			Season, 1974/75		
Nematicides	Mean yield	% of yield increase over control	Final + nematode number	Mean yield	% yield increase over control	Final + number
Phenamiphos	499**	88	6** (88)	287*	90	49** (36)
Aldicarb	424*	60	5** (74)	275*	82	36** (53)
Nemagon	415*	57	6** (68)	259*	72	9*** (88)

Control	265	0	19 (0)	151	0	076 (0)
SE ±	24.62					

Table 9: *The effect of three different nematicides, applied at standard dosage rates, on mean seed cotton yield (Kg/acre) and final P. sudanensis nematodes numbers per 200 gm soil and 1 gm root sample for two consecutive seasons (% decrease of nematodes in parentheses [54].*

+ = Mean of the three replicates.

, **, * = Significant at 0.05, 0.01, and 0.001 probability level, respectively.*

Thermotherapy

Soil solarisation or "solar heating" is a non-chemical disinfestation practice that may serve as a component of a sustainable Integrated Pest Management (IPM) programme. Solarization effectively controls a wide range of soil-borne pathogens, insects and weeds [7]. Phytonematodes cannot survive temperatures higher than about 50 - 55°C, therefore, the application of heat is a very efficient way to kill them. In warm climates, nematodes in top of soils out of doors and in green house are killed by solarization for 4-8 weeks [7]. Covering the soil with one or two layers of polyethylene film and allowing the sun to raise soil temperature sufficiently to kill nematodes can be effective as fumigating the soil.

Hot water dipping can kill plant nematodes in or adhering to plants [49]. However, the temperature and time of exposure must be carefully observed to avoid plant injury. Banana corms, bulbs, and even woods chips and various seeds can be successfully treated this way [24].

Cultivation

Plant-parasitic nematodes are one of the economically most important pathogens, and how rising soil temperatures due to climate change impact their ability to damage crops is poorly understood. Some nematodes may be killed mechanically or desiccated in period of drought by soil cultivation, epically if you repeat the number of ploughing under direct sunrays. In this way the sunrays deeply penetrate to the soils, therefore rising the soil temperature which kills most nematodes [44]. Study was conducted to evaluate the reproduction biology (reproduction and virulence) of *Rotylenchulus reniformis* and *Meloidogyne floridensis* on tomato at soil temperatures of 26°C (control), 32°C, 34°C, and 36°C. The reproduction and virulence of both nematode species were differentially impacted by soil temperature. Relative to the control, the increase in reproduction of *R. reniformis* ranged from 20% to 116% while that of *M. floridensis* ranged from 22% to 133%. [33,45] approaches of direct as well as indirect heat exposure to evaluate nematode biology. The direct heat exposure assay involved the exposure of nematodes to hot water in a heating block at 32, 33, and 34°C for 7h, and subsequent evaluation of their survival after 18h. The indirect exposure assay employed a commercial heat mat to raise soil temperatures to 32, 33, and 34°C for 7h during the daytime, and subsequent evaluation of nematode reproduction, virulence, and/or disease severity over the period of 6 weeks after inoculation [33]. A significant reduction in the reproduction of *M. floridensis* occurred when soil temperature was increased from 33 to 34°C, however, the same condition did not significantly affect *R. reniformis* reproduction suggesting the latter species has a greater ability to adapt to increasing soil temperature. Additionally, the virulence of *R. reniformis* was greater at 33 and 34°C relative to that at 30°C indicating increased aggressiveness of the nematode at higher soil temperatures [33,45].

The use of herbal extracts to control plant parasitic nematodes

Use of synthetic chemicals creates significant environmental dangers, which is a significant global issue. As a result, researchers have looked into plant materials and taken on the challenge of finding more environmentally friendly alternatives [3]. The demand for natural pesticides has been driven by the need for a better but faster alternative, and the knowledge that is currently available indicates that plants have great potential as a source of natural pesticides [55].

Twenty-seven different samples that included various plant components (leaves, fruits, and stems) were collected from 21 tree and herbal species in 19 genera from Gezira locality, Sudan [14]. Methanol or hexane extracts of the 27 samples were screened for nematicidal activity against second-stage juveniles of *Meloidogyne incognita* in the laboratory. The juveniles were exposed to 500 ppm of each plant extract for 24, 48 and 72h. Five plant extracts exhibited highly promising mortality rates of 95 - 99% after 72h of exposure, which were statistically different from the other extracts. These extracts were from *Dinebra retroflexa* (leaves), *Cucumis melo* var. agrestis (fruits), *Eucalyptus microtheca* (leaves), *Acacia nilotica* (Pods), and *Chenopodium album* (leaves) (Table 10). Six extracts derived from the leaves of *Solenostemma argel*, *Aristolochia bracteolata*, and *Ziziphus spina-christi* and the seeds of *Argemone mexicana*, *Datura stramonium*, and *Azadirachta indica* produced relatively high mortality rates of 94 - 80% after 72h of exposure. The 5 most nematicidal plant extracts listed above were further screened against similar stage juveniles of the nematode species using only 50 ppm for 24, 48, and 72h. Three plant extracts, *C. melo* var agrestis (fruits), *A. nilotica* (fruits), and *C. album* (leaves), exhibited 41, 42 and 45% mortality rates, respectively. The mortality rate increased with increasing exposure time for most of the extracts [14,35,36].

In a study demonstrated that many herbal extracts like *D. retroflexa* (leaves), *C. melo* var. agrestis (fruits), *E. microtheca* (leaves), *A. nilotica* (pods), and *C. album* (leaves) can be used for the bio-control of plant parasitic nematodes, especially root-knot nematode populations (Table 11). Thus, this method of control can contribute to minimizing the risks and hazards of toxic nematicides, especially on vegetables produced for fresh consumption.

Further research into these extracts will identify the active compounds responsible for their nematicidal activity. Therefore, commercial bio-nematicides can be developed for global use.

Family	**Plant species**	**Tissue sampled***	**Yield (%)[b]**
Aristolochiaceae	*Aristolochia bracteolate*	L	13.0
Apocynaceae	*Nerium oleander*	L	9.3
	Solenostemma argel	L	4.7
Asclepiadaceae	*Calotropis procera*	L	9.3
Caesalpiniaceae	*Cassia senna*	S	6.0
Cucurbitaceae	*Cucumis melo* var. *agrestis*	L	10.7
	Cucumis melo var. *agrestis*	F	8.7
Fabaceae	*Trigonella foenum-graecum*	S	3.8
Meliaceae	*Azadirachta indica*	L	6.3
	Azadirachta indica	S	34.8
Mimosaceae	*Acacia nilotica*	F	33.6
Rhamnaceae	*Ziziphus spina-christi*	L	5.1
Myrtaceae	*Eucalyptus microtheca*	L	14.0
Lamiaceae	*Ocimum basilicum*	L	10.6
	Ocimum basilicum	S	16.2
	Ocimum spp	L	11.3
Lythraceae	*Lawsonia inermis*	L	25.7
	Lawsonia inermis	S	4.0
Poaceae	*Cymbopogon nervatus*	L	3.8
	Dinebra retroflexa	L	62.8
Salvadoraceae	*Salvadora persica*	L	13.4

Solanaceae	*Datura stramonium*	L	8.2
	Datura stramonium	St	13
	Datura stramonium	S	6.3
Verbenaceae	*Lantana camara*	L	2.1
Papaveraceae	*Argemone mexicana*	S	33.6
Amaranthaceae	*Chenopodium album*	L	6.1

Table 10: *List of plant species used for methanol or hexane extraction, the portion used and their yields [13].*

[a]*L: Leaves; S: Seed; St: Stem; and F: Fruit.*

[b]*(Dried weight of methanol or hexane extract/dried weight of the sample plant) × 100.*

Plant species	24 hr	48 hr	72 hr
Acacia nilotica	66.5 ± 6.4 ab*	89 ± 2.8 ab	94.7 ± 1.3 ab
Argemone mexicana	21.5 ± 0.7 jklmn	21.5 ± 0.7 jkl	91.8 ± 1.7 abc
Aristolochia bracteolate	35 ± 8.5 ghij	77 ± 2.8 abcd	90 ± 2.1 abcd
Azadirachta indica (leaf)	20.5 ± 6.4 jklmn	23.5 ± 2.1 jkl	46 ± 6.2 lm
Azadirachta indica (seed)	55.5 ± 9.2 bcde	62 ± 7.1 defg	80.5 ± 3.9 cdefg
Calotropis procera	16 ± 2.8 klmno	53 ± 8.5 fgh	72 ± 6.6 efghi
Cassia senna	16 ± 1.4 klmno	20 ± 4.2 jklm	50 ± 2.6 klm
Chenopodium album	52 ± 1.4 bcdef	85 ± 2.8 abc	96.8 ± 3.3 a
Cucumis melo var. *agrestis* (fruit)	78 ± 7.1 a	83 ± 2.8 abc	98.8 ± 1.3 a
Cymbopogon nervatus	60 ± 4.2 bcd	74.5 ± 10.6	83 ± 4.0 bcde
Cucumis melo var. *agrestis* (leaf)	2.5 ± 0.7 o	21 ± 11.3 jkl	39.3 ± 3.3 mn
Datura stramonium (leaf)	43 ± 2.8 efghi	55 ± 2.8 efgh	68.8 ± 4.5 ghi
Datura stramonium (seed)	26.5 ± 2.1 jklmn	34 ± 7.1 ij	81.8 ± 2.9 cdef
Datura stramonium (stem)	28 ± 1.4 ijklm	28 ± 1.4 ijkl	70.8 ± 6.4.3 fghi
Dinebra retroflexa	44.5 ± 0.7 defg	72.0 ± 2.8 bcde	94.5 ± 1.2 ab
Eucalyptus microtheca	31 ± 2.8 hijkl	92.5 ± 0.7 a	96.0 ± 2.6 a
Lantana camara	32 ± 1.4 hijk	44 ± 1.4 ghi	79 ± 4.5 defg
Lawsonia inermis (leaf)	11.5 ± 0.7 no	13.5 ± 0.7 lm 32.3 ± 3.6 n	13.5 ± 0.7 lm 32.3 ± 3.6 n
Lawsonia inermis (seed)	12 ± 1.4 mno	15 ± 2.8 klm	46 ± 5.3 lm
Nerium oleander	29 ± 1.4 hijkl	31.5 ± 2.1 ijkl	60.3 ± 12 ijk
Ocimum basilicum (leaf)	15.5 ± 0.7 lmno	33 ± 8.5 ijk	66.5 ± 3.9 hij
Ocimum basilicum (seed)	11.5 ± 0.7 no	14 ± 2.8 lm	55.5 ± 3.4 jkl
Ocimum spp.	36.5 ± 3.5 fghij	37 ± 2.8 hij	70.3 ± 1.3 fghi
Salvadora persica	23 ± 1.4 jklmn	68 ± 1.4 cdef	73.3 ± 6.1 efgh
Solenostemma argel	49.5 ± 2.1 cdefg	92 ± 1.4 a	94.5 ± 4.2 ab

Trigonella foenum-graecum	25 ± 2.8 jklmn	26.5 ± 2.4 ijkl	73.3 ± 4.2 efgh
Ziziphus spina-christi	61 ± 8.5 bc	79.5 ± 0.7 abcd	89.5 ± 3.5 abcd

Table 11: *Mortality rates of root-knot nematode juveniles induced by herbal extracts at concentrations of 500 ppm in X-plate Petri dishes [14].*

Means with the same letter(s) in the column are not significantly different at P = 0.0001 according to Tukey's studentized range test. For each replicate, 100 root-knot nematode juveniles were treated with extract.

Conclusion

In conclusion we can end up that integrated nematodes management, can be defined as a methods that approach to reduce nematode populations to tolerable levels through a variety of techniques including nematophagous fungi, genetically resistant hosts, herbal extracts and/or whole plants that can be buried in the soil, cultural practices and when it is very necessary and appropriate chemical nematicide (s) can be used.

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