IRAC
Insecticide Resistance Action Committee
South Africa

Nematodes, nematicides and resistance management

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Introduction

Nematodes are aquatic, unsegmented, microscopic invertebrate organisms, often referred to as roundworms, and some of the most abundant organisms found in soil and water. They are found throughout the world and their activity is influenced by environmental conditions, especially soil moisture and temperature. About 10% of nematode species are plant-parasitic and are usually found within the crop rooting zone or the top 15 to 30 cm of soil. The life cycle of plant-parasitic nematodes has six stages and consists of eggs, juveniles (four phases) and adults.

Plant-parasitic nematodes can be classified based on motility during feeding and site of feeding, into migratory and sedentary nematodes, with migratory nematodes being mobile during their lifecycle and sedentary nematodes being mostly immobile. Plant-parasitic nematodes can furthermore be grouped into endo-parasitic (entire body inside the root), ecto-parasitic (entire body outside the root) and semi-endo-parasitic (partially enters root). Endo-parasitic nematodes are further subdivided into two additional categories, sedentary or migratory.

Damage and economic importance

Plant-parasitic nematodes are associated with a variety of crops, including cereals, vegetables, and fruit. Damage caused by plant-parasitic nematodes on plants is due to direct feeding where the nematode uses a stylet to puncture host plant cells, which also promotes infection by secondary pathogens such as fungi, bacteria and viruses. Below-ground symptoms on the rooting system include the formation of galls, stunted root growth, knots, lesions, excessive branching, injured or destroyed root tips and root rotting. Above-ground symptoms vary and are not specific to attack by nematodes. Symptoms are very similar to other abiotic (water and nutrient deficiencies) and biotic (pathogens) stresses and infection can thus easily be overlooked. Symptoms may include chlorosis (yellowing), stunted growth, small or sparse foliage, dieback of larger branches, early wilting compared to non-infected plants, failure to respond normally to fertilizers and ultimately a reduction in crop yield.

Worldwide, an estimate of about USD $157 billion in yield losses on an annual basis (Singh *et al*., 2015), has been reported. However, because growers often fail to recognise nematode damage, and many countries do not report nematode induced crop losses, the actual number may be much higher (Nicol *et al.,* 2011; Singh *et al.,* 2013). In South Africa, the estimated annual loss in yield per specific crop, that can be attributed to plant-parasitic nematodes, can be seen in the Table 1 below.

Economically important plant-parasitic nematodes of major crops include root-knot nematodes (*Meloidogyne* spp.), cyst nematodes (*Globodera* spp., *Heterodera* spp.), root lesion nematodes (*Pratylenchus* spp.), stubby root nematodes (*Trichodorus* spp. and *Paratrichodorus* spp.), dagger nematodes (*Xiphinema* spp.), citrus nematodes (*Tylenchulus semipenetrans*), pin nematodes (*Paratylenchus* spp), ring nematodes (Criconematidae), sheath nematodes (*Hemicycliophora* spp.), spiral nematodes (Hoplolaimidae), stem nematodes (*Ditylenchus* spp.), reniform nematodes (*Rotylenchulus* spp.) and burrowing nematodes (*Radopholus similis*).

Table 1: Estimated losses of some crops in South Africa due to plant-parasitic nematode (PPN) damage.

Crop	PPN type	Effect of PPN	Reference
Maize	Various PPN species Root-knot nematode	12% yield reduction 60% yield losses	(Keetch, 1989) (Riekert, 1996a; Riekert, 1996b; Riekert & Henshaw, 1998)
Soybean	Various PPN species Root-knot nematode	9% yield losses 25-70% yield losses	(Keetch, 1989) (Riekert & Henshaw, 1998; Fourie & Mc Donald, 2001, 2007; Fourie *et al*., 2010)
Groundnut	Groundnut-pod nematodes	40-60% pod losses	(Jones & De Waele, 1988)
Potato	Various PPN species	17% loss in production 9% loss due to tuber downgrading	(Keetch, 1989) (Vermeulen, 2015)
Carrot	Various PPN species	9.3% loss	(Keetch, 1989)
Sugarcane	Various PPN species	1.6 million metric tonne annual loss	(Spaull, 1995; Spaull & Cadet, 2003)
Tobacco	Stubby-root nematodes	>25% reduction in income	(Fourie *et al*., 2017)
Grapevine	Various PPN species	15% yield losses	(Hugo, 2003)
Banana	Various PPN species	19% loss in production	(Willers, 1998)
Pineapple	Various PPN species	15% yield loss	(Keetch, 1989)

The adult females of root-knot nematodes (*Meloidogyne* spp.) are swollen but remain soft-walled. They are sedentary and once inside the roots are surrounded by giant cells giving rise to the characteristic galls on the roots or tubers. Root-knot nematodes are obligate parasites. Under favourable conditions in the warmer summer months the life cycle can be completed within 3-4 weeks. In the absence of a host the eggs or larval stages can remain in the soil for up to two years.

Root-knot nematodes (Figures 1 to 4) are found throughout South Africa on many crops including indigenous plants and weeds. Root-knot nematodes are more prevalent in sandy soils where they can cause extensive damage on plants. There are many different species, and the root-knot nematodes have a very wide host range. There are very few crops which are not parasitized by root-knot nematodes and key examples are apples and pears and some grain crops such as wheat and sunn hemp. Brassicas are also less susceptible.

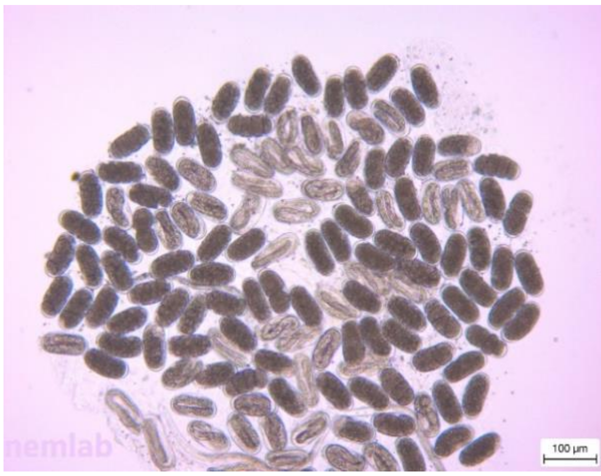


Figure 1 and 2. Left: A root-knot nematode juvenile between root-knot nematode eggs that were extracted from tomato roots and soil. Right: Root-knot nematode eggs from the gelatinous egg-sac of a root-knot nematode female.

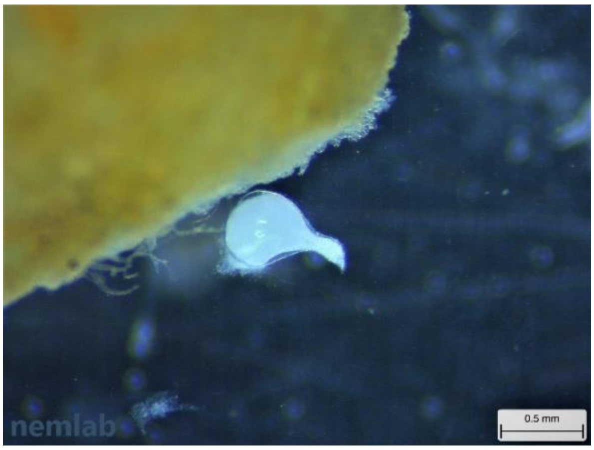


Figure 3 and 4. The swollen body of a root-knot nematode female removed from tomato plant roots.

Cyst nematodes (*Heterodera / Globodera*) (Figure 5) are endo-parasites. The eggs are retained inside the female body which then forms a hard wall creating a brown, protective cyst. The cysts are pear-, lemon- or oval-shaped. Cyst nematodes are obligate plant-parasites and do not cause galls or specific symptoms on the roots. They mostly have a restricted host range and can be a major threat to some crops. The golden cyst nematode, *Globodera rostochiensis,* found on potatoes is a quarantine organism. The most common cyst nematodes in South Africa with their main host in brackets are *H. schachtii* (brassicas), *H. trifolii* (vegetables), *H. carotae* (carrots), *H. fici* (figs), *H. humuli* (hops) and *H. avenae*, *H. filipjev* and *H. mani* (small grains).

Figure 5. Cyst nematodes

There are many species of lesion nematodes (*Pratylenchus* spp.) (Figures 6 and 7) in South Africa and they are common and many are endemic. They are obligate, migratory endo-parasites. Given their movement in and out of the roots they are often associated with plant diseases since they create entry points for fungi and bacteria. The feeding by these nematodes results in necrotic lesions on the roots and hence the name. On potatoes they cause brown sunken lesions which reduces the market value. For this reason they also have the name ‘skin nematode’ on potatoes. They have a very wide host range which include field crops, fruit trees, vegetables, shrubs etc. Crops on which they have been found in large numbers and can cause considerable damage include, amongst others, apples, pineapples, potatoes, tobacco, bananas, maize, wheat and canola.

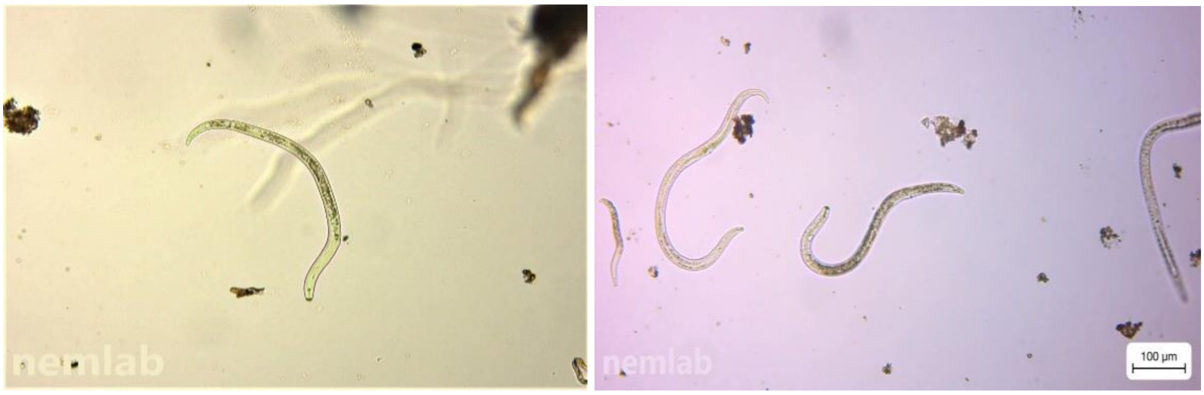


Figure 6 and 7. Lesion nematodes

Stubby root nematodes (*Trichodorus* spp.) (Figure 8) are migratory ecto-parasites feeding on the epidermal cells of plant roots very close to the root tips. This feeding results in rounded, stunted roots and hence the name stubby root nematodes. They are common in South Africa although very patchy in their distribution and never in large populations. They prefer very coarse sandy soils. The type of feeding results in extensive damage. They are known in South Africa for their damage on onions, carrots, pears, wheat (under irrigation), maize and many other crops where they are of great economic importance.

Figure 8. Stubby root nematode

Dagger nematodes (*Xiphinema* spp.) (Figures 9 and 10) are common in South Africa and found in all climatic regions and soil types. There are several species in South Africa. They are primarily plant parasites of herbaceous perennials such as vines and deciduous fruit trees and nuts. They are also found on sugarcane and grasses. Two species in South Africa transmit viruses of which *X. index* is a vector of the grapevine fan-leaf virus.

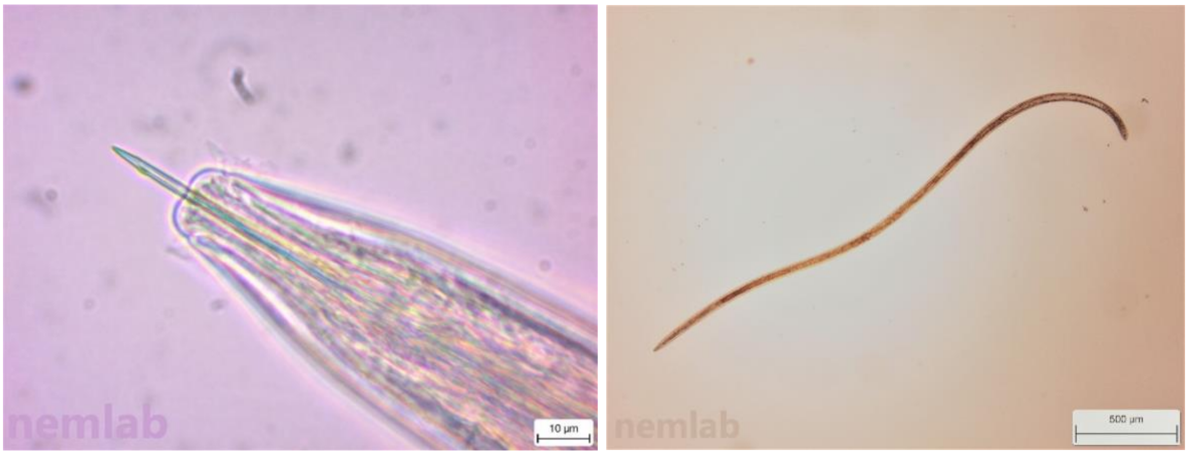


Figure 9. Dagger nematodes

Figure 10. Dagger nematode (*Xiphinema index*) tail

The citrus nematode (*Tylenchulus semipenetrans*) (Figure 11) is a single species but has three host types. In South Africa there is only one host type present which is also found on persimmons and grapevines. This nematode is a semi-endoparasite with the females attached to the roots with their head and neck embedded inside the roots. The eggs are in a gelatinous layer covering the egg sac. Soil and organic material sticking to this matrix gives the roots a dark, dirty appearance. Citrus rootstocks have varying degrees of resistance to the citrus nematode. They can cause severe damage to citrus when present in high numbers.

Figure 11. Citrus nematodes

Pin nematodes (*Paratylenchus* spp.) (Figure 12) are ecto-parasites of herbaceous annuals and woody perennials. They can be a problem on vines and stone fruit and are commonly found in sugarcane fields, vineyards and deciduous trees, pine plantations, bananas and pineapples.

Figure 12. Pin nematode

Ring nematodes (e.g. *Criconemoides xenoplax*) (Figures 13 and 14) are easily recognizable under the microscope due to their short stature and very heavy annulations giving rise to the name ring nematode. They are common in South Africa and found primarily in the Western Cape on vines, stone fruit and nut trees where their feeding can have devastating consequences. They are linked to the plum death syndrome on plums. They are also found in high numbers in grass (such as golfing greens). Ring nematode are also the main problem nematode on litchi.

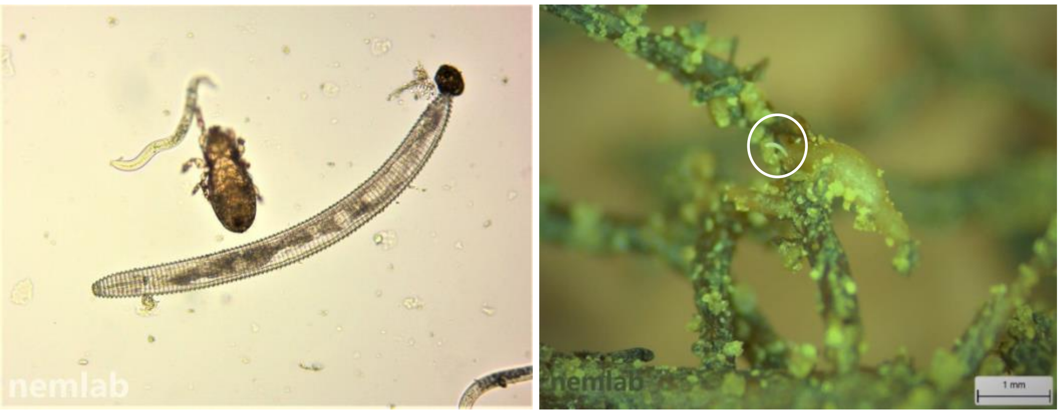


Figure 13 and 14. Ring nematode

Sheath nematodes (*Hemicycliophora* spp.) (Figures 15 and 16) are ecto-parasites which feed very near to the root tip. They cause uneven shaped galls on the roots of citrus, Swiss chard and are also pests of carrots, tomatoes, peppers and celery. They are also present on most deciduous fruit trees and litchi, but their damage potential is unknown on these crops.

Figure 15 and 16. Sheath nematode

Spiral nematodes (Hoplolaimidae) (Figure 17) are generally found in areas with high organic matter content. Some species are problematic on specific crops in very high numbers such as bananas and yams.

Figure 17. Spiral nematode

Management of plant-parasitic nematodes

Management of plant-parasitic nematodes requires the integration of several control methods such as cultural practices (crop rotation, cover crops, use of certified nematode free planting material, tolerant and resistant cultivars, fallowing and trap cropping), biological control and use of nematocidal (fumigant and non-fumigant) crop protection products.

The most vulnerable stage of plant parasitic-nematodes that is targeted by nematicides is the juvenile, J2 or active phase in the soil and plant. When selecting nematicides for the control of a specific plant parasitic nematode, it is important to be aware of the toxicological properties and mode of action of the nematicide.

Nematicides can be grouped into two main categories: fumigant and non-fumigant nematicides. Fumigant nematicides have a high volatility and disperses through the soil spaces as a gas. Non-fumigant nematicides, the category to which most nematicides belong to, are non-volatile and usually in a liquid or solid form and are applied to the soil surface, mixed into the topsoil, or even applied as foliar applications. The non-fumigant nematicides can further be classified into systemic or contact action nematicides, or nematicides that kill the nematode almost immediately or nematicides that are nematostatic, where continued exposure can lead to death. Nematostatic products affect the nematode’s neuromuscular activities, thereby inhibiting movement and feeding, and ultimately development and reproduction.

Pesticide resistance

Resistance is the phenomenon where populations of a pest species evolve to become less responsive and susceptible to pesticides and populations can no longer be controlled by a dose of a chemical which used to provide effective control. Resistance occurs through mutations in the genetic material of the pest species. These mutations usually occur at random, with most mutations having no impact on the pest's physiology or biochemistry. However, on occasion, a mutation confers resistance of the individual to a pesticide, resulting in a competitive advantage to the pest and its offspring. This occurs if the same pesticide is used repeatedly. If chemicals with different mode of actions are not rotated / used interchangeably, pests that carry the resistance mutation will survive and become more frequent in the population, ultimately resulting in the whole population carrying the resistance gene within a few generations. To prevent pest species with resistance mutations becoming dominant in the population, pesticides with different mode of actions should be used in sequence or rotation to ensure that consecutive pest generations are not exposed to chemicals with the same mode of action, decreasing selection pressure. However, cross-resistance may also occur when resistance to one pesticide confers resistance to another pesticide, even where the pest has not been exposed to the latter.

Nematicide resistance risk potential

Unlike many other pests, the risk of nematodes developing resistance to nematicides are considered to be very low and theoretically unlikely. The way in which nematicides are used in conjunction with nematode ecology, reduces the potential of sustained selection pressures on plant-parasitic nematode populations under field conditions. The factors that limit sustained selection pressure on plant-parasitic nematodes include:

- The relatively low frequency of nematicide use in a single cropping cycle, as a proportion of the duration of the crop and the number of plant-parasitic nematode generations. Typically, one nematicide application is made per growing season, and occasionally more in long season or perennial crops.
- The primary application methods used for nematicides in the field often target a small soil volume (e.g., crop root zone, crop beds or rows, or seed only), leaving untreated areas and host plants (weeds) that can act as refuge or source of recolonization for unexposed plant-parasitic nematodes.
- The various nematode species have life stages (dormant or living) in host plants (e.g., crop or weeds) that may remain in the field and are not exposed to or affected by nematicide treatments. It is noteworthy to mention that very few nematicides are effective systemically in the plant against nematodes.
- The complexity of the soil environment and chemical interactions with nematicides frequently reduces product persistence, mobility and/or bioavailability, thus minimizing the likelihood of a chemical product to reach a high percentage of the plant-parasitic nematode population present in the field, e.g., at different soil depths or distances from the point of application or causing exposure to multiple generations.
- The large diversity of naturally occurring organisms that may attack surviving life-stages of plant-parasitic nematodes in soil, reducing the overall selection pressure from a single nematicide application.

In cropping systems which require multiple nematicide applications within one crop cycle or on the same field over several cycles, rotation to a nematicide with a different mode of action is recommended to reduce the risk of sustained selection pressure on plant-parasitic nematode populations.

Reduced performance of chemical nematicides can be caused by the phenomenon of enhanced microbial biodegradation.

Enhanced microbial biodegradation

Repeated or frequent use of the same chemical nematicide in the same field soil may lead to an apparent reduction in plant-parasitic nematode control through enhanced microbial biodegradation of the product. Enhanced microbial biodegradation is the result of adaptation and increase of microbial populations that break down a particular product, therefore changing the amount of product available and/or duration of exposure of plant-parasitic nematodes. The microbes responsible for enhanced microbial biodegradation in soil may be different for different chemical classes or products, thus rotation of different nematicide types, or a reduction in the frequency of applications may decrease the likelihood of enhanced microbial biodegradation occurring.

Enhanced microbial biodegradation is well documented in the scientific literature and should not be confused with resistance development in plant-parasitic nematodes. Enhanced microbial biodegradation affects the level of product availability and duration of exposure of plant-parasitic nematodes to the product, thus reducing the apparent efficacy of a nematicide application. Rotation of nematicides from different chemical classes, as well as employing other control methods such as resistant varieties and cultural methods (e.g., crop rotations) should be considered.

Nematicide labelling

Although plant-parasitic nematodes have a low potential of developing resistance to nematicides, the phenomenon of enhanced microbial biodegradation demands the same resistance management principles to be followed as used for other insecticides, herbicides, and fungicides.

To delay the development of resistance:

- Know the mode of action of the chemical being used and alternate with chemicals with a different mode of action. In South Africa, the mode of action of the chemical is displayed on the front panel of the label:

GROUP	N2	NEMATICIDE

  In the example above, the chemical falls within the nematicide mode of action group N2 (Glutamate-gated chloride channel allosteric modulators). The mode of action classification of all insecticides and nematicides is available on the IRAC website: https://irac-online.org/
- Avoid treating consecutive pest generations with chemicals that have the same mode of action.
- Never apply chemicals at reduced rates or water volumes. Only apply chemicals at the recommended timings and number of applications.
- When making use of pesticide mixtures, always apply active ingredients at their individually registered rates.

Table 2**:** Global nematicide mode of action classification groups.

MoA group	Mode of action	Chemical Structure Group	IRAC / FRAC mode of action
N-1A **N-1B**	Nerve Action. Acetylcholinesterase (AChE) inhibitors	A. Carbamates, B. Organophosphates	IRAC: 1A, 1B
N-2	Nerve Action. Glutamate-gated chloride channel (GluCl) allosteric modulators	Avermectins	IRAC: 6
N-3	Mitochondrial complex II electron transport inhibitors. Succinate-coenzyme Q reductase.	Pyridinylmethyl-benzamides	FRAC: C2
N-4	Lipid synthesis, growth regulation. Inhibitors of acetyl CoA carboxylase	Tetronic and Tetramic acid derivatives	IRAC: 23
N-UN	Compounds of unknown or uncertain MoA	Various chemistries	
N-UNX	Compounds of unknown or uncertain MoA: Presumed multi-site inhibitor	Various fumigants	IRAC: 8
N-UNB	Bacterial agents (non-Bt) of unknown or uncertain MoA	Bacterium or Bacterium-Derived	
N-UNF	Fungal agents of unknown or uncertain MoA	Fungus or Fungus-Derived	
N-UNE	Botanical or animal derived agents including synthetic, extracts and unrefined oils with unknown or uncertain MoA	Botanical or Animal-Derived	

Colour key to mode of action

Nerve and muscle
Unknown
Pyridinylmethyl-benzamides
Biologicals
Tetronic and tetramic acid derivatives

Several nematicides are registered as both a nematicide and an insecticide or fungicide. In these cases, both classification schemes need to be included on the label. If the product has nematicide and insecticide or fungicide properties but are not registered for both uses, only the classification scheme for which the product is registered needs to be included on the label.

Example: Abamectin has insecticidal and nematicidal properties. If the specific abamectin-containing product is registered only as an insecticide, only the insecticide classification needs to be included on the label:

GROUP	**6**	**INSECTICIDE**

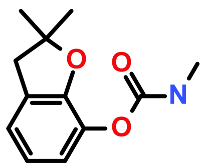
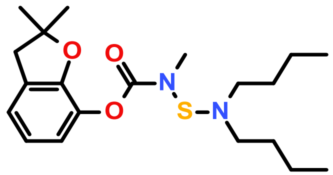
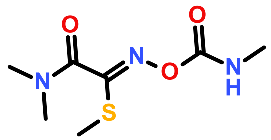
If the specific abamectin-containing product is registered only as a nematicide, only the nematicide classification needs to be included on the label:

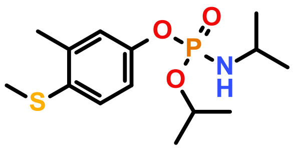
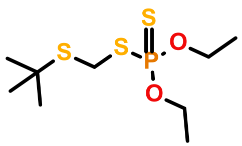
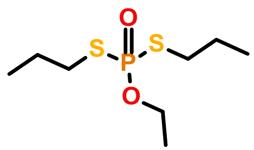
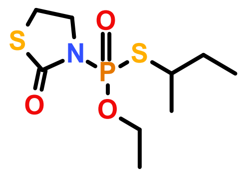
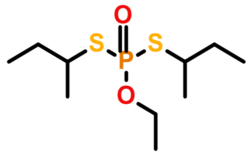
GROUP	N2	NEMATICIDE

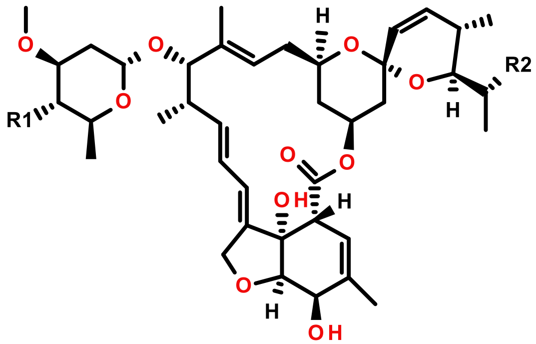
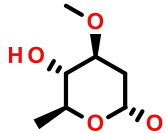
If the specific abamectin-containing product is registered as an insecticide and nematicide, both classifications need to be included on the label:

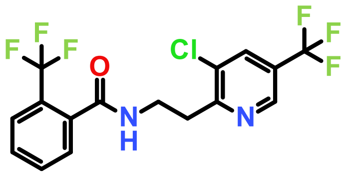
GROUP	6	INSECTICIDE
GROUP	N2	NEMATICIDE

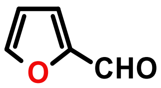
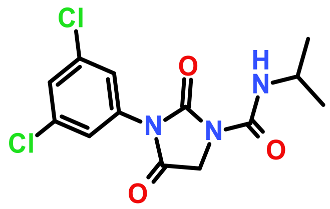
The active ingredients registered for nematode control in South Africa are listed in the tables below. The colour of the table heading is indicative of the mode of action as indicated in the colour key.

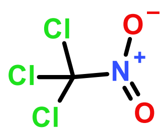
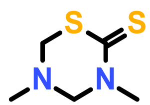
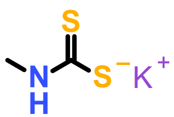
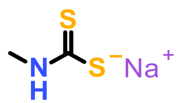
GROUP N-1: Acetylcholinesterase (AChE) inhibitors		
N-1A – Carbamates		
 Carbofuran	 Carbosulfan	 Oxamyl

N-1B – Organophosphates				
 Fenamiphos	 Terbufos	 Ethoprophos	 Fosthiazate	 Cadusafos

Group N-2: Nerve action. Glutamate-gated chloride channel (GluCl) allosteric modulators
Avermectins
 R1 =  Major component R2 = ethyl Mainor component R2 - methyl
Abamectin

Group N-3: Mitochondrial complex II electron transport inhibitors. Succinate-coenzyme Q reductase
Pyridinylmethyl-benzamides

Fluopyram

Group N-UN: Unknown mode of action	
Various chemistries	
 Furfural	 Iprodione

Group N-UNX: Presumed multi-site inhibitors		
Various fumigants		
 1,3-dichloropropene (halogenated hydrocarbon)	 Chloropicrin	 Dazomet (methyl isothiocyanate generator)
 Metam potassium (methyl isothiocyanate generator)	 Metham sodium (methyl isothiocyanate generator)	

Group N-UNB: Bacterium
Bacillus firmus (registered together with clothianidin)

Group N-UNF: Fungus
Myrothecium verrucaria

Unclassified (classification pending)
EDB (ethylene dibromide)

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Appendix

Nematicides registered in South Africa

GROUP N-1: Acetylcholinesterase (AChE) inhibitors			
N-1A – Carbamates			
Carbofuran	Agfuran 10G	L10183	Maize; Sugarcane; Sweetcorn
	Alvuran 100 G	L4881	Maize; Sorghum; Sugarcane; Sunflowers; Sweetcorn; Tobacco; Wheat
	Carbodan 10 GR	L7577	Maize; Sorghum; Sugarcane; Sweetcorn; Tobacco
	Carbofuran 100 GR	L6945	Maize; Sorghum; Sugarcane; Sunflowers; Sweetcorn; Tobacco; Wheat
	Carbofuran 10 G	L6649	Maize; Sorghum; Sugarcane; Sunflowers; Sweetcorn; Tobacco; Wheat
	Carbofuran 10 GR	L8547	Maize; Sugarcane; Sweetcorn
	Carboterr 100 GR	L7182	Maize; Sorghum; Sugarcane; Sunflowers; Sweetcorn; Tobacco; Wheat
	Curaterr 10 GR	L871	Maize; Sorghum; Sugarcane; Sunflowers; Sweetcorn; Tobacco; Wheat
Carbosulfan	Carbostem	L7859	Maize
	Marshal 48 EC	L3314	Maize
	Sharda Carbosulfan 400 SC	L8954	Maize

GROUP N-1: Acetylcholinesterase (AChE) inhibitors			
N-1A – Carbamates			
Oxamyl	Blockade G	L7552	Bananas; Potatoes; Sugarcane; Tobacco; Tomatoes
	Blockade SL	L7345	Groundnuts [syn. Peanuts]; Pineapples; Potatoes; Tomatoes
	Foxamyl 10G	L9877	Potatoes; Sugarcane; Tomatoes
	Foxamyl 310 SL	L9883	Groundnuts [syn. Peanuts]; Pineapples; Potatoes; Sugarcane; Tomatoes
	Harvest Oxamyl 100 GR	L10375	Potatoes; Sugarcane; Tomatoes
	Harvest Oxamyl 310 SL	L10333	Groundnuts [syn. Peanuts]; Potatoes; Tomatoes
	Oxadate	L7588	Groundnuts [syn. Peanuts]; Pineapples; Potatoes; Sugarcane; Tobacco; Tomatoes
	OxaMyl 310 SL	L9246	Groundnuts [syn. Peanuts]; Pineapples; Potatoes
	Oxatak SL	L7589	Groundnuts [syn. Peanuts]; Pineapples; Potatoes; Sugarcane; Tobacco; Tomatoes
	Oxygran 10 GR	L6406	Bananas; Potatoes; Sugarcane; Tobacco; Tomatoes
	Platoon 100 GR	L10559	Potatoes; Tobacco; Tomatoes
	Platoon 310 SL	L7913	Groundnuts [syn. Peanuts]; Maize; Potatoes; Tomatoes
	Stetson 310 SL	L7904	Groundnuts [syn. Peanuts]; Maize; Potatoes; Tomatoes
	Strangler SL	L10062	Potatoes; Tobacco; Tomatoes
	Vigour 310 SL	L8088	Groundnuts [syn. Peanuts]; Pineapples; Potatoes; Sugarcane; Tobacco; Tomatoes
	Vydate 100 GR	L3945	Bananas; Potatoes; Sugarcane; Tobacco; Tomatoes
	Vydate SL	L5057	Groundnuts [syn. Peanuts]; Nectarines; Peaches; Pineapples; Plums; Potatoes; Sugarcane; Tobacco; Tomatoes
Oxamyl + imidacloprid	Bandito GR	L10605	Sugarcane

GROUP N-1: Acetylcholinesterase (AChE) inhibitors			
N-1B – Organophosphates			
Fenamiphos	Atador	L7167	Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Mandarins; Navels; Nectarines; Onions; Oranges; Peaches; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
	Bonfire 400 EC	L7646	Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Mandarins; Navels; Onions; Oranges; Peas; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
	FarmAg Fenamiphos 400 EC	L10720	Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Mandarins; Navels; Nectarines; Onions; Oranges; Peaches; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
	Fenamiphos 400EC	L7647	Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Mandarins; Navels; Onions; Oranges; Peas; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
	Fenamiphos EC	L9196	Potatoes; Table grapes; Tobacco; Wine grapes
	Nemacur 100 GR	L2056	Bananas; Clementines; Cotton; Ginger; Grapefruit; Groundnuts [syn. Peanuts]; Guavas; Kumquats; Lemons; Limes; Litchies; Mandarins; Navels; Oranges; Papayas; Pecan nuts; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
	Nemacur 240 CS	L7247	Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Mandarins; Navels; Onions; Oranges; Peas; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Turf; Wine grapes
	Nemacur 400 EC	L0367	Apples; Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Mandarins; Navels; Nectarines; Onions; Oranges; Peaches; Pears; Peas; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Turf; Wine grapes

GROUP N-1: Acetylcholinesterase (AChE) inhibitors			
N-1B – Organophosphates			
Terbufos	Bitrad Terbufos 15 GR	L7123	Beans - Dry beans; Groundnuts [syn. Peanuts]; Maize; Sunflowers
	Counter 100 G	L1101	Beans - Dry beans; Groundnuts [syn. Peanuts]; Maize; Sunflowers
	Counter FC 15G	L5571	Beans - Dry beans; Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Maize; Mandarins; Navels; Oranges; Pummelos; Satsumas; Sunflowers; Tangelos; Tangerines
	Terbufos 15 GR (L6920)	L6920	Beans - Dry beans; Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Maize; Mandarins; Navels; Oranges; Pummelos; Satsumas; Sunflowers; Tangelos; Tangerines
	Terbufos 15 GR (L7186)	L7186	Beans - Dry beans; Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Kumquats; Lemons; Limes; Maize; Mandarins; Navels; Oranges; Pummelos; Satsumas; Sunflowers; Tangelos; Tangerines
	Terbufos GR	L5927	Beans - Dry beans; Groundnuts [syn. Peanuts]; Maize; Sunflowers
	Terfos 15G	L7582	Beans - Dry beans; Clementines; Groundnuts [syn. Peanuts]; Kumquats; Limes; Maize; Mandarins; Navels; Oranges; Pummelos; Satsumas; Sunflowers; Tangelos; Tangerines
Ethoprophos	AALbuster	L9356	Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Potatoes; Pummelos; Satsumas; Tangelos; Tangerines
	Mocap 150 GR	L6985	Baby marrows [syn. Courgettes; Zucchini]; Beans - Green beans; Butternuts; Cabbage; Clementines; Grapefruit; Kumquats; Lemons; Lettuce; Limes; Mandarins; Navels; Oranges; Patty pans; Peas; Potatoes; Pummelos; Satsumas; Spinach; Tangelos; Tangerines; Tobacco
	Phoscap 15 GR	L9119	Baby marrows [syn. Courgettes; Zucchini]; Beans - Green beans; Butternuts; Cabbage; Clementines; Grapefruit; Kumquats; Lemons; Lettuce; Limes; Mandarins; Navels; Oranges; Patty pans; Peas; Potatoes; Pummelos; Satsumas; Spinach; Tangelos; Tangerines; Tobacco
	Procap 15 GR	L9118	Baby marrows [syn. Courgettes; Zucchini]; Beans - Green beans; Butternuts; Cabbage; Clementines; Grapefruit; Kumquats; Lemons; Lettuce; Limes; Mandarins; Navels; Oranges; Patty pans; Peas; Potatoes; Pummelos; Satsumas; Spinach; Tangelos; Tangerines; Tobacco
	Successor	L9354	Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Potatoes; Pummelos; Satsumas; Tangelos; Tangerines
	Vanquish	L9355	Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Potatoes; Pummelos; Satsumas; Tangelos; Tangerines

GROUP N-1: Acetylcholinesterase (AChE) inhibitors			
N-1B – Organophosphates			
Fosthiazate	Nemathorin 100 GR	L5613	Bananas; Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Potatoes; Pummelos; Satsumas; Tangelos; Tangerines
Cadusafos	Hockey 100 EW	L9123	Apples; Apricots; Cherries; Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Nectarines; Oranges; Peaches; Pears; Pineapples; Plums; Potatoes; Prunes; Pummelos; Satsumas; Tangelos; Tangerines
	Rugby 10 G	L4110	Apples; Apricots; Bananas; Cherries; Chicory; Clementines; Grapefruit; Guavas; Kumquats; Lemons; Limes; Litchies; Mandarins; Navels; Nectarines; Oranges; Peaches; Pears; Pineapples; Plums; Potatoes; Prunes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Wine grapes
	Rugby 10 ME	L6368	Apples; Apricots; Bananas; Cherries; Chicory; Clementines; Grapefruit; Guavas; Kumquats; Lemons; Limes; Litchies; Mandarins; Navels; Nectarines; Oranges; Peaches; Pears; Pineapples; Plums; Potatoes; Prunes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Wine grapes
	Soccer 100 EW	L9122	Apples; Apricots; Cherries; Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Nectarines; Oranges; Peaches; Pears; Pineapples; Plums; Potatoes; Prunes; Pummelos; Satsumas; Tangelos; Tangerines

Group N-2: Nerve action. Glutamate-gated chloride channel (GluCl) allosteric modulators			
Avermectins			
Abamectin [syn. avermectin]	Avicta 500 FS	L9258	Cotton; Maize

Group N-3: Mitochondrial complex II electron transport inhibitors. Succinate-coenzyme Q reductase			
Pyridinylmethyl-benzamides			
Fluopyram	Velum Prime	L9565	Potatoes; Tobacco; Tomatoes
	Velum Prime 400 SC	L9965	Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Potatoes; Pummelos; Satsumas; Tangelos; Tangerines; Tobacco; Tomatoes

Group N-UN: Unknown mode of action			
Various chemistries			
Furfural	Crop Guard	L6864	Almonds; Apples; Apricots; Brazil nuts; Carrots; Cashew nuts; Cherries; Chestnuts; Clementines; Grapefruit; Groundnuts [syn. Peanuts]; Hazelnuts; Hops; Kumquats; Lemons; Lettuce; Limes; Macadamia nuts; Maize; Mandarins; Navels; Nectarines; Onions; Oranges; Ornamentals; Paprika; Peaches; Pecan nuts; Peppers; Peppers - Chillies; Pine nuts; Pistachio nuts; Plums; Potatoes; Prunes; Pummelos; Satsumas; Sugarcane; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Turf; Walnuts; Wine grapes
	Crop Guard 80	L9253	Apples; Apricots; Carrots; Cherries; Clementines; Flowers; Grapefruit; Groundnuts [syn. Peanuts]; Hops; Kumquats; Lemons; Lettuce; Limes; Maize; Mandarins; Navels; Nectarines; Onions; Oranges; Ornamentals; Paprika; Peaches; Pears; Peppers; Peppers - Chillies; Plums; Potatoes; Prunes; Pummelos; Quinces; Satsumas; Sugarcane; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Turf; Wine grapes
	Protect	L7534	Crops; Soil
	Turf Guard	L8367	Turf
Iprodione	Devguard 500 SC	L8883	Potatoes

Group N-UNX: Presumed multi-site inhibitors			
Various fumigants			
1,3-dichloropropene	Destroyer	L10461	Nurseries; Orchards; Pineapples; Potatoes; Seedbeds; Table grapes; Tomatoes; Wine grapes
	Dilone AL	L8936	Nursery stock; Orchards; Pineapples; Potatoes; Seedbeds; Table grapes; Tomatoes; Wine grapes
	Telone II	L5223	Crops; Nursery stock; Orchards; Pineapples; Potatoes; Seedbeds; Table grapes; Wine grapes
	Tolerance 1110 AL	L9223	Apples; Apricots; Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Pears; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
	Trimple 1110 AL	L9224	Apples; Apricots; Clementines; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Oranges; Pears; Pineapples; Potatoes; Pummelos; Satsumas; Table grapes; Tangelos; Tangerines; Tobacco; Tomatoes; Wine grapes
1,3-dichloropropene + chloropicrin	Telopic	L7164	Fruit; Seedbeds; Strawberries; Vegetables
	Tri-Form 60	L9839	Crops; Fruit; Potatoes; Strawberries; Tobacco; Vegetables
Chloropicrin	Pic Plus	L9554	Crops; Fruit; Potatoes; Strawberries; Tobacco; Vegetables
	Tripicrin	L8306	Potatoes
Dazomet	Basamid Granular	L0277	Apples; Apricots; Avocados; Carnations; Cherries; Chrysanthemums; Clementines; Coffee; Flowers; Forest trees; Grapefruit; Kumquats; Lemons; Limes; Mandarins; Navels; Nectarines; Oranges; Papayas; Peaches; Pears; Plums; Potting soil or mixtures; Proteas; Prunes; Pummelos; Quinces; Replanting trees; Rooibos tea; Satsumas; Shrubs; Strawberries; Table grapes; Tangelos; Tangerines; Tobacco; Vegetables; Wine grapes
Metam potassium [syn. metham potassium]	Tamifume K 690	L7704	Planting media; Seedbeds; Soil
Metham sodium [syn. metam sodium]	Ag-Fume	L7365	Potting soil or mixtures; Seedbeds; Soil
	Herbifume 510 SL	L138	Growing medium; Potting soil or mixtures; Seedbeds; Soil
	Nemasol	L6296	Growing medium; Potting soil or mixtures; Seedbeds; Soil
	Raisan 51	L8588	Growing medium; Potting soil or mixtures; Seedbeds; Soil
	Vapam	L7858	Potting soil or mixtures; Seedbeds; Soil
	Vault 510 SL	L9144	Growing medium; Potting soil or mixtures; Seedbeds; Soil
	Wabek 510 SL	L9145	Growing medium; Potting soil or mixtures; Seedbeds; Soil

Group N-UNB: Bacterium			
Bacillus firmus + clothianidin	Poncho Votivo	L9250	Maize

Group N-UNF: Fungus			
Myrothecium verrucaria	DiTera DF	L8477	Table grapes

Unclassified (classification pending)			
EDB [syn. ethylene dibromide]	EDB MO	L4431	Crops
	FarmAg EDB	L7228	Crops