40 Integrated nematode management of *Pratylenchus penetrans* in onion: A versatile approach to control a versatile nematode

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Introduction

Pratylenchus penetrans is a common species on sandy and peaty soils in the Netherlands and is also found to a lesser extent in more clayey soil. On sandy and peaty soils, population densities above damage threshold levels are causing yield depressions of important arable crops, including onions. Originally, most onions in the Netherlands were grown on clay soils. However, because new cultivars have become available suitable for growing on sandy soils, the acreage cultivated on sand and peat is increasing rapidly. With this expansion the nematode problem has become more evident.

Economic importance

About 27,500 ha of onions, representing an average economic value of €150 million are grown in the Netherlands, of which up to 15% is grown on *P. penetrans* preferred sandy, peaty and light marine clay soils. Over the past 10 years the total acreage of onions has increased by an average of 2.5% per year, mainly in regions with sandy or peaty soils. Accurate data are not available, but a conservative estimate is that the financial loss exceeds €1.5 million per year.

Host range

P. penetrans has a very broad host range that includes major cash crops, cover crops and many weed species (Belair, 2007). Potato, maize, wheat, barley, rye, onion, carrot, beans, broccoli and ryegrasses are known as good host plants. Sugar beet is one of the few economic crops that is a poor host for *P. penetrans*. Ornamental plants like tulip, lily, daffodil and rose are also known to be good hosts for *P. penetrans*. Important cover crops like fodder radish, yellow mustard, clovers and vetch are also hosts for *P. penetrans*. *Tagetes patula* (marigold) is known to be a very effective catch/trap crop (Evenhuis *et al.*, 2004). Detailed information can be found in the databases of the EU Best4Soil project (www.Best4Soil.eu/database, accessed 2 February 2021).

Distribution

In the Netherlands, *P. penetrans* is found in all regions but almost all reports of damage come from sandy soils in the south-east part of the country in the province of Noord Holland (light marine clay) and the sandy and peaty soils in the

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north-east part of the Netherlands. A survey in 2005 and 2006 assessed the distribution of *Pratylenchus* spp. in the Netherlands. *Pratylenchus penetrans* was present in all regions; however, it was found in less than 8% of the samples taken from more clayey soil compared to approximately 40% of the samples from sandy and peaty soil. Numbers of *P. penetrans* in more clayey soils were always very low (<5 juveniles/100 ml soil), levels at which no damage to important crops is expected, whereas high numbers of *P. penetrans* were found in sandy and peaty soils.

Symptoms of damage

Pratylenchus penetrans causes reductions in yield of important crops like potato, onion, chicory, peas and strawberry. The yield and quality of bulbs (e.g. lily, daffodils and tulip) and ornamentals (e.g. roses) can be limited by *P. penetrans*.

Infestations of *P. penetrans* can lead to severe quality losses in carrot and black salsify due to forking or stunting of the taproot. Onion is also rather intolerant to *P. penetrans* and infested roots show typical elongated (brow) necrotic spots (Fig. 40.1). Depending on population density, root growth can be retarded strongly and patches of stunted onion plants are the above-ground visible symptoms. Even at low pre-sowing densities, between 25-100 *P. penetrans* per 100 ml of soil, yield is reduced significantly. Pang *et al.* (2009) reported yield reductions of 30% and 73% at pre-sowing densities of 200 and 1600 juveniles per 100 ml of soil, respectively. In field experiments in the Netherlands on a peaty soil the marketable yield of onions was reduced by 15% and 25% at infestation levels of 250 and 500 *P. penetrans* per 100 ml soil, respectively. Complete crop failure was observed at pre-sowing densities of 1000 nematodes per 100 ml of soil or more; onion seedlings died off within a couple of weeks after emergence due to a totally degraded root system.

The damage caused by *P. penetrans* is enhanced when the crop also suffers from other stress such as a deficit of water and/or nutrients.

Fig. 40.1. Necrotic lesions on roots of daffodils caused by infestation of *Pratylenchus penetrans*. Symptoms are similar to those found on *P. penetrans* infested roots of onion. Photograph courtesy of Wageningen University & Research, Field Crops.

Biology and life cycle

Pratylenchus penetrans is a migratory endoparasite. Reproduction is sexual and the nematode completes its life cycle in 30 to 86 days, depending on temperature. The life cycle is shortest at 30°C, but fewer eggs are produced compared to 20°C–24°C. Feeding and migration by *P. penetrans* degrades root cells and root surface symptoms appear as necrotic spots or lesions. Longer periods of feeding may result in cell death (Zunke, 1990), causing a reduction of fine roots and leading to above-ground symptoms of water and nutrient deficiency, such as chlorotic foliage and reduced growth.

P. penetrans is capable of penetrating tubers of host plants such as potato, turning seed potatoes into a potential source of dispersal. The nematode is also spread due to root infection of propagation material such as strawberry, fruit trees, lilies and roses. Winter population decline in the absence of a host plant can vary from less than 10% to about 50%. There are indications that there are strains/pathotypes of *P. penetrans* (France and Brodie, 1996).

Interactions with other nematodes and pathogens

Alternaria porri, Fusarium oxysporum f.sp. *cepae* and *Sclerotium cepivorum* are common soil-borne fungi pathogenic to onion in the Netherlands. Interactions with *P. penetrans* are known for other

subspecies of these fungi in other crops but we are not aware of proven interactions in onion. A very harmful and well-known interaction of *P. penetrans* is that with the fungus *Verticillium dahliae* in strawberries and in potato causing potato early dying (see Chapter 50 in this volume).

Recommended integrated nematode management (INM)

There are a number of INM tools that can be used to manage *P. penetrans* in onion. The most important management tool at present is crop rotation with non or poor-host cover crops. Additional measures include black fallow, anaerobic soil disinfestation, flooding/inundation and the use of nematicides, depending on the level of infestation.

Prevention of spread

INM starts with prevention and quarantine to prevent spread to uninfested fields. The use of certified, nematode-free planting material is therefore of the utmost importance to prevent introduction. *Pratylenchus penetrans* can be spread by infested seed potatoes as well as in infested strawberry, fruit trees, lilies and rose transplants. Farm hygiene, including weed control and cleaning machinery, is also important to avoid spread.

Proper analysis of the problem

Also important is knowledge of which nematodes (in addition to *P. penetrans*) are present in a field and at what densities, so appropriate control measures can be taken. Crop inspection and soil sampling can reveal the nematode species and population densities in a field. Accurate estimation of population densities of *P. penetrans* requires extraction of nematodes present both in the mineral and organic fraction containing root fragments in the soil samples. An incubation time of 2 to 4 weeks is needed to extract most of the *P. penetrans* from the organic fraction.

Crop rotation

P. penetrans has a very wide host range, including many cash and cover crops. Reducing populations of *P. penetrans* by a properly chosen crop rotation is therefore complicated. Onions are commonly grown in rotations with barley or wheat (moderate to good hosts), potato (good host) and sugar beet. Sugar beet is a poor to moderate host and one of the few major cash crops that can be included in a crop rotation to control *P. penetrans.*

Marigold, as a catch-crop (discussed later), and resistant black oat (*Avena strigosa*) cultivars are also recommended as good cover crops. Most other major cover crops such as fodder radish, yellow mustard, clovers and rye grasses are very good hosts for *P. penetrans*. It should be noted that black oats is a host of *Fusarium oxysporum* f.sp. *cepae* (www.best4soil.eu/database, accessed 2 February 2021) and may increase fungal disease damage in a succeeding onion crop. Information can be found on the host status and sensitivity of cash crops and cover crops for design of rotation schemes for both plant parasitic nematodes and soil fungi on the 'best4soil' website. This INM tool is available in more than 20 European languages.

Nematicides

The fumigant Monam (a.i. metam sodium), the granular nematicide Vydate (a.i. oxamyl) and Nemguard, a biological-based granular nematicide containing active ingredients of garlic (*Allium sativum*), are registered in the Netherlands for control of *P. penetrans* in onion. Due to government-imposed restrictions and requirements for sealing the soil surface with virtually impermeable plastic or compressed soil films to avoid evaporation, the fumigant metam sodium is no longer an economic alternative treatment for onion growers. A pre-sowing broadcast application of oxamyl can improve yield by 10–25% depending on pre-sowing population density.

Inundation and anaerobic soil disinfestation (ASD)

Inundation and ASD are two different methods of disinfesting the soil by creating anaerobic soil conditions.

ASD is carried out by incorporation of organic material, irrigation and tarping the soil with airtight foil for at least 6 weeks at soil

temperatures >16°C. Maximum potential of inundation is reached when the field is flooded for 10–14 weeks in summer. Both methods are very effective for the control of weeds, volunteer host plants, several soil-borne pathogens and plant parasitic nematodes (Lamers, 2014). ASD and inundation will reduce *P. penetrans* populations by more than 99%. These approaches are still too expensive when *P. penetrans* is the only problem, and they are mainly used to suppress species like *Meloidogyne chitwoodi* (see Chapter 48) or *Ditylenchus dipsaci* (see Chapter 41).

Catch-crop

Marigold (*Tagetes patula*) has been known for decades as a very effective catch-crop for *P. penetrans* (Oostenbrink, 1957). A successful grown *Tagetes* will reduce a *P. penetrans* population by more than 95%, a decrease which is much stronger and longer lasting when compared to the natural decline by fallow or when a non-host is grown (c. 75% decrease of the population). Different species of *Tagetes* are used to control *P. penetrans* of which *T. patula* is the most effective species (Fig. 40.2). Under climatic conditions in the Netherlands, marigold has to be grown in the summer for at least 3 months (Evenhuis *et al.*, 2004). As a consequence, the income of a cash crop is lost. The technology was formerly only used for high-value crops like strawberry and roses, but long-term crop rotation experiments have shown that marigold is also an economically profitable measure in arable farming. In a rotation of barley–potato–sugar beet–potato, on fields naturally infested with *P. penetrans*, replacing barley with marigold reduced population densities of *P. penetrans* by more than 99%, and the populations remained extremely low for at least 3 years (Fig. 40.3). This raised the interest of arable farmers, and an increasing number of onion growers are now using *Tagetes* to control *P. penetrans* effectively.

To achieve a maximum and long-lasting control of *P. penetrans*, weed hosts must be controlled.

Fig. 40.2. Field of marigold, *Tagetes patula*. Photograph courtesy of Wageningen University & Research, Field Crops.

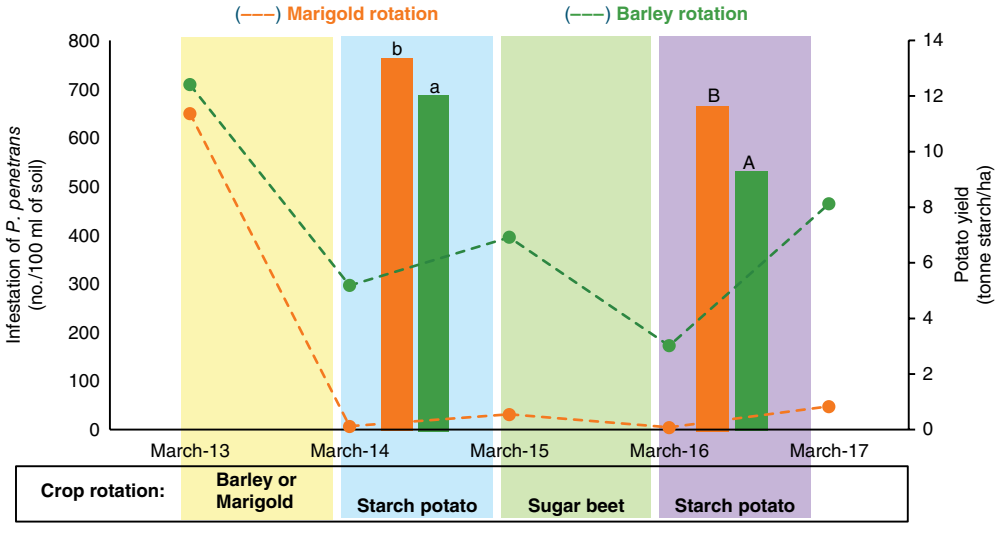

Fig. 40.3. Population dynamics of *Pratylenchus penetrans* in a crop rotation of barley–potato–sugar beet–potato and a rotation in which barley is replaced by marigold (*Tagetes patula*) and yield (bars) of starch potato in these rotations. Figure courtesy of Wageningen University & Research, Field Crops.

Soil compaction

Observations in commercial onion fields and in field experiments (unpublished data) showed that compacting the upper 15 cm of the soil prior to seeding can reduce damage significantly. In two field experiments on peaty soils naturally infested with *P. penetrans*, soil compaction, a granular nematicide (Vydate, a.i. oxamyl, 20 kg/ha) and a combined treatment of soil compaction and oxamyl were compared. Compressing the soil prior to sowing improved seedling emergence, crop growth and yield of onions significantly (Fig. 40.4). Soil compaction, oxamyl and the combined treatment improved yield by 7%, 10% and 13%, respectively, compared to untreated at a pre-sowing population density of 250 *P. penetrans* per 100 ml of soil.

Optimization of nematode management

A more integrated approach is necessary to sustainably improve the quality of arable soils used for onion production. A so-called boost year could be an important part of such an integrated strategy. This is a year in which a farmer does not grow a cash crop but takes the opportunity to implement multiple measures to control plant parasitic nematodes and soil-borne pathogens as well as improve other aspects of soil quality like soil structure or organic matter content. When marigold is grown as a main crop in summer it could be an important part of such a boost year. In spring and at the beginning of summer, before marigold is sown in July, measures like growing potato as a catch-crop for control of potato cyst nematodes, control of volunteers, mechanical weed management, applying organic amendments in the right circumstances, improving the drainage system, and so on, should be undertaken. In autumn, a second green manure crop could be grown. A prerequisite is that the costs of the boost year are recuperated in the further crop rotation. To make marigold use more attractive to growers, new herbicides are necessary. Most weeds are hosts for *P. penetrans* and therefore successful weed control in marigold is of utmost importance.

In order to expand control of *P. penetrans*, properly designed rotations with non-hosts or resistant cultivars of cash crops and cover crops are needed. Crops used in onion rotations, such as maize, need new cultivars that have resistance

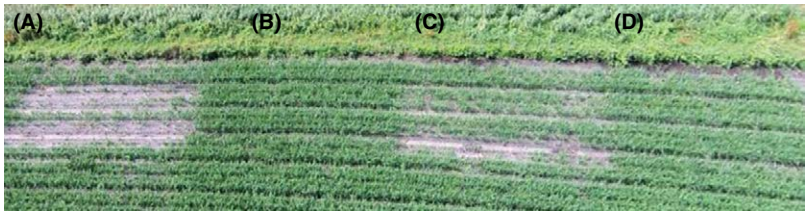

Fig. 40.4. Experimental field, showing the effect of **(A)** untreated, **(C)** soil compaction, **(D)** oxamyl and **(B)** the combined treatment of oxamyl and soil compaction on the emergence of onion seedlings. Photograph courtesy of Wageningen University & Research, Field Crops.

to *P. penetrans*. Even if the resistance is not directly beneficial for maize production it would aid control of *P. penetrans* on other crops in the rotation scheme.

Biofumigation

The use of green manures, which, after chopping and incorporation, release bionematocidal compounds, have not been shown to be effective in reducing densities of *P. penetrans*. Field research has shown that many crops (*Brassica* species) used for biofumigation are very good hosts for *P. penetrans*, causing an increase in the population, and that the amount of toxic compounds (ITCs) produced after incorporation of a biofumigation crop is far from sufficient to control plant parasitic nematodes (Vervoort *et al.*, 2014).

Future research requirements

The mode of action of soil compaction leading to reductions of *P. penetrans* on onion is still not researched in detail. Understanding this mechanism would help to improve the method and to make it applicable for onion and other cash crops.

Furthermore, the damage threshold of *P. penetrans* is much lower on dune sand than on sandy soils. There are indications that this is due to both physical and biological soil properties, in which the amount of organic matter and content/quality may play an important role. Understanding this mechanism can contribute to the development of environmentally friendly management measures and are topics for further investigation.

Mixtures of cover crops should be investigated because multiple aspects of soil quality can be improved and their use reduces the damage caused by nematodes. More information on the effect of these mixtures on population densities of plant parasitic nematodes and on initial damage thresholds is needed.

The bioagent *Bacillus firmus* is registered for control of *P. penetrans* in maize. It is worth exploring the potential of this and other biocontrol agents for management of *P. penetrans* in onion and other crops.

Outlook: anticipating future developments

Changing climate conditions will lead to warmer summers and milder winters, and therefore periods of drought and also locally more extreme precipitation. When summers get warmer, more generations of *P. penetrans* per year will be formed. Population densities will increase and the extent of damage caused by this nematode species on a succeeding crop will change. On the other hand, milder winters could also affect natural nematode decline during winter. Due to locally less precipitation during the growing season, water deficits could occur and increase the level of damage caused by *P. penetrans* because of restricted uptake of water and nutrients in infested and reduced root systems. A warmer climate may also lead to a shift in the incidence of other species like *P. thornei* that favour warmer soil temperatures.

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