Potato cyst nematodes

The worsening situation and how it might be resolved

Executive summary

Nematodes are microscopic organisms that have adapted to nearly every ecosystem on earth: from salt and freshwater to polar regions and the tropics and from the highest to lowest elevations, these needle-like roundworms eke out a life between particles of minerals and detritus. The exact number of species is unknown with estimates ranging from at least 40,000 to nearly a million. About one-third of the genera described so far occur as parasites of vertebrates while more than 4,100 species have been described as plant-parasitic (Decraemer & Hunt, 2006). As a group, plant-parasitic nematodes represent an important constraint on food security with the damage inflicted estimated to cost US$80 billion per year (Nicol, et al., 2011). Potato cyst nematodes (PCN) sometimes also called ‘eelworms’, *Globodera pallida* and *G. rostochiensis* are considered a significant pest of potatoes (*Solanum tuberosum*). Both species are distributed almost worldwide. Although capable of causing yield loss over 70% (Turner & Subbotin, Cyst Nematodes, 2013) the exact extent will depend on soil type and potato variety. Losses ranged from 1–35% in trials with infestations spanning 10–20 eggs per gram of soil (AHDB, 2018). In Great Britain, PCN is the second most significant economic threat to potatoes, after late blight (*Phytophthora infestans*). The impact these microscopic organisms inflict on crops is likely to worsen with climate change (Skelsey, Kettle, MacKenzie, & Blok, 2018). This combined with a limited range of resistant varieties with broad market acceptance and tight controls on the synthetic nematicides seen as offering effective control have served to highlight the need for an integrated approach to comprising all available means of control. Implementing such measures will carry a cost to the businesses affected, but these will be offset by reduced yield losses and cost savings in machinery and labour. Where a full range of measures are properly integrated, it is possible to protect both crop performance and the viability of the land.

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What are nematodes?

Nematodes are microscopic organisms that have adapted to nearly every ecosystem on earth: from salt and freshwater to polar regions and the tropics and from the highest to lowest elevations, these needle-like roundworms eke out a life between particles of minerals and detritus.

The number of species is unknown, with estimates in the published literature ranging from at least 40,000 (Anderson, 2000) to closer to a million (Blaxter, 2016). It is estimated that about 16,000–17,000 species have been described (Anderson, 2000).

Their ability to exist at the extremities of life, even at great depths—0.9–3.6 km below the surface of the earth (Borgonie, García-Moyano, & Litthauer, 2011)—and at great density, often in excess of a million per square metre, makes them one of the most abundant species on earth. They represent 80% of animals on land and, in the deep sea, this rises to more than 90% (Danovaro, et al., 2008).

There are roughly 2,271 described genera in 256 families (Anderson, 2000). About one-third of nematode genera which have been described occur as parasites of vertebrates, broadly equal to the percentage of genera known in salt and freshwater ecosystems (Anderson, 2000).

There are more than 4,100 species of plant-parasitic nematode described to date (Decraemer & Hunt, 2006). As a group, they represent an important constraint on food security with the damage inflicted by nematodes estimated to cost US$80 billion per year (Nicol, et al., 2011). When seeking to manage those species considered to be detrimental, however, a balance needs to be struck with those that make a positive contribution. For every species that is pathogenic to crops, there are likely to be six or seven that are beneficial (Bayer Crop Science, 2020).

Potato cyst nematodes

Cyst nematodes are obligate biotrophs—they extract nutrients only from living plant tissue and cannot grow apart from their hosts—and represent a specific economic threat. There are about 105 species within six genera spanning tropical and temperate regions. Cyst nematodes are serious pests of brassicas, cereals, potato and sugar beet (The Cyst Nematodes, 1998).

Two species, *Heterodera spp.*, which affect soybean and cereals, and *Globodera spp.*, which affect solanaceous crops, principally potato, tomato and aubergine, are significant pests in temperate regions.

The potato cyst nematodes (PCN) sometimes also called 'eelworms', *Globodera pallida* and *G. rostochiensis* are considered a significant pest of potatoes (*Solanum tuberosum*). Both species are distributed almost worldwide with *G. rostochiensis* being the more prevalent having been detected in 78 countries (EPPO, 2022) compared with 53 for *G. pallida* (EPPO, 2022).

Although capable of causing yield loss over 70% (Turner & Subbotin, Cyst Nematodes, 2013) the exact extent will depend on soil type and potato variety. Losses ranged from 1–35% in trials with infestations spanning 10–20 eggs per gram of soil (AHDB, 2018). Losses worldwide arising from PCN damage are estimated at 12.3% of production (Singh, Singh, & Singh, 2015).

PCN is responsible for direct and indirect yield loss. The damage caused to roots through feeding causes direct yield loss, even when symptoms are not obvious in the haulm. With severe infestations, roots are more seriously damaged and plant death can occur.

Severely infested plants are stunted, often chlorotic and typically occur in patches. The damage and stress inflicted serve to increase the risk of *Rhizoctonia* and other fungal diseases, which may also contribute to secondary yield loss (DEFRA, 2009).

Severe damage caused by potato cyst nematodes

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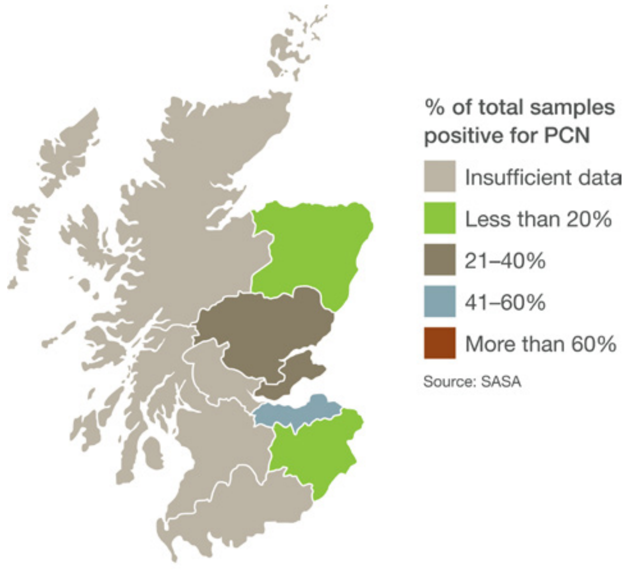


PCN distribution on ware land in Scotland 2010–2016

Distribution and occurrence

In Great Britain, PCN is the second most economically important crop threat of potatoes after late blight (*Phytophthora infestans*) with economic losses estimated to be about £26 million annually (Twinning, et al., 2009). Once the cost of yield protection measures is included, the total cost rises to more than £60 million per year (Thorpe, et al., 2018).

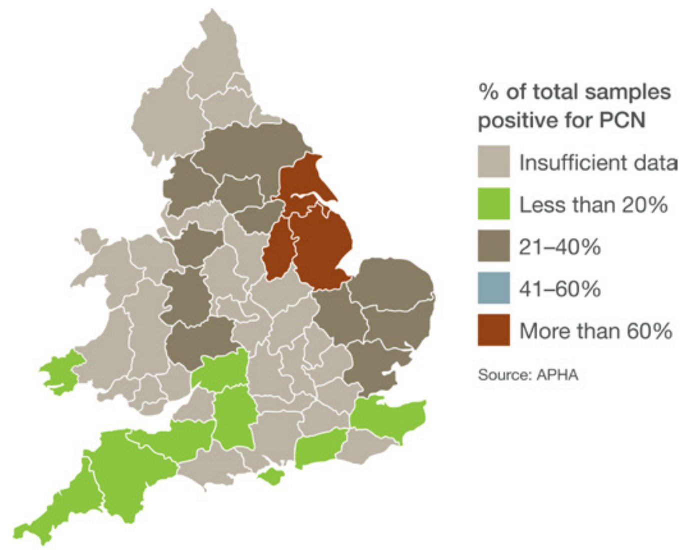
Across Great Britain, both species are distributed widely, with the area of land infested with PCN increasing steadily. Analysis of fields in the potato growing land of England & Wales showed PCN was present in 64% of sites sampled (Minnis, et al., 2002).

In Scotland, the situation is less severe, but the country's status as a producer of clean seed means the spread of PCN is more concerning. Scotland typically produces about 77% of Great Britain's seed potatoes and the EU PCN Directive, now enshrined in UK law, requires land to be tested and found free from PCN before seed potatoes can be grown (SASA, 2022).

In the 10 years to 2017, the area of land infested with *G. rostochiensis* in Scotland increased 6% to 14,217 hectares and *G. pallida* by 116% to 5,214 hectares (Eves-van den Akker, 2018). Analysis at the time by Science and Advice for Scottish Agriculture (since March 2019, simply 'SASA') concluded that the area of potato land thought to be infested with PCN to be over 13%. There has also been a shift in the incidence of *G. pallida* in statutory PCN tests (from 4% to 50%) at the expense of *G. rostochiensis* (Pickup, 2014). This poses difficulties for growers given the lack of durable resistance, principally to *G. pallida* in Scotland, but also *G. rostochiensis* in England, among those varieties with broad market appeal (see table 1).

Physiological factors, principally the long-term viability of the eggs—often 20 years or more for *G. rostochiensis* (Perry, Wright, & Chitwood, 2013) and up to 40 years in exceptional circumstances (AHDB, 2018)—and a wide host range spanning 170 species of *Solanaceae* family (Sullivan, et al., 2007) means both species pose considerable problems for control. The ease with which cysts are spread across parcels of land also makes efforts to protect uninfested land difficult. Most new infestations are likely to be the result of cysts adhering to potato seed, but these can also be spread when machines move fields, by mammals such as birds, and by water and wind (Scottish PCN Working Group, 2020).

As seed potatoes cannot be grown on land recorded as infested, the spread of PCN to previously clean land is a recognised threat to the future of the [seed] sector. At the current rate of spread—the area of infested land is doubling every seven to eight years—seed potato and bulb production in Scotland could end by 2050 (Scottish PCN Working Group, 2020).



PCN distribution on ware land in England and Wales 2012–2016

Cysts of potato cyst nematode (PCN) on root of a susceptible variety

The need for change

The need to slow or preferably stop the spread of PCN to uninfested land while simultaneously reducing the population burden on infested land is pressing and takes many forms.

First, the potato industry in Great Britain is worth £928 million (Scottish PCN Working Group, 2020). The production of clean seed from uninfested land is central to sustaining the sector and to ensuring that the annual per capita demand of 85 kg is largely met through domestic supply. Failure to stem the spread of PCN would also threaten the production of ware crops through reduced output and higher growing costs.

Second, the financial impact of PCN on enterprise performance is significant. On average, PCN is believed to inflict an opportunity cost on growers of £5,093 per hectare in lost output (Blok, et al., 2018). For growers in Scotland, this is equivalent to an aggregate cost of £25 million per year (Scottish PCN Working Group, 2020).

Finally, climate change is likely to exacerbate the situation. A warming climate will mean soils warm earlier in the spring and record higher average temperatures. One consequence of this is that more female PCN survive to maturity. In addition to reduced mortality, the longer season raises the risk that crops will be under attack for longer. The potential for earlier completion of first generations is widely recognised (Ebrahimi, Viaene, Demeulemeester, & Moens, 2014) and therefore two generations of PCN within a growing season are a concern (Greco, Inserra, Brandonisio, Tirrò, & Marinis, 1988).

Analysis of historical climate data overlaid with scenarios from the UK Met Office Climate Projections database (UKCP09) by the James Hutton Institute (Skelsey, Kettle, MacKenzie, & Blok, 2018) concluded that increases in soil temperature could result in increased female maturity survival.

Scotland would be most adversely affected, specifically by increases in *G. pallida*, while England and Wales would see large increases in *G. rostochiensis*. Mitigating this heightened threat to crops would require changes to production practices with a reduction in infestation levels of 40% needed to negate the projected increase in risk (Skelsey, Kettle, MacKenzie, & Blok, 2018).

Table 1: Varieties with resistance to PCN (Great Britain, 2016)

Variety	Area grown (to nearest 50 ha)	*G. pallida* Pa2/3, 1 (A)	*G. rostochiensis* Ro1 (A)	Market use
Taurus	2,800	3	8	Crisps
Innovator	2,450	Pa2 8*, Pa3 9*	Not resistant	Fries/chips
Royal	2,400	3	9	Fries/chips
Harmony	2,050	4	4	Fresh
Arsenal	1,300	8/9*	6	Crisps
Ramos	1,200	4	8	Fries/chips
Lanorma	800	5	9	Fresh
Saphire	700	3	4	Fresh
Eurostar	400	9*	9*	Fries/chips
Diva	<400	5	3	Fresh, fries
Panther	<400	8	2	Prepack
Leonardo	<100	Pa2 7* Pa3 3*	9	Fries
Crisps4all	<50	6	9	Crisps
Alcander	<50	Pa2 9* Pa3 8*	8/9*	Crisps
Performer	<50	9*	5*	Chips, crisps
Heraclea	<50	Pa2 6*, Pa3 1*	–	Crisps
Camel	<50	8*	9*	Fresh
Swift	<50	4	–	Fresh

Notes: (A) Rating on a 1–9 scale; 1 = least resistant, 9 = most resistant * Information from breeder.
Source: AHDB, *PCN grower guide*

The short list of resistant varieties

Resistant varieties are probably the most effective means of controlling PCN (Blok, et al., 2018). Unfortunately, many of the resistant varieties available lack commercial acceptance, are unsuitable for cultivation in the UK, especially Scotland where conditions preclude the production of those varieties described as ‘processing’ types, or resistance to both species of PCN. This is especially relevant to seed growers as variety choice is determined by market dynamics rather than by that which would best suit their situation.

The need for new varieties that combine broad market suitability with durable resistance, preferably to both pathotypes of *G. pallida* and also *G. rostochiensis,* has been made extensively at the highest levels of industry and government (Blok, et al., 2018). Despite the apparent urgency, such varieties have yet to come to market. This failure of breeding has led to suggestions from some academics that natural resistance and existing rotation controls are inadequate (Green, Wang, Lilley, Urwin, & Atkinson, 2012).

Table 1 lists varieties with high resistance to PCN. The areas grown should be contrasted with that for varieties with poor resistance to PCN in table 2.

Table 2: Resistance status of the top 12 ware varieties by area in Great Britain (2017)

Variety	GB planted area (Ha)	Resistance to *G. pallida* Pa2/3,1 (rating)	Resistance to *G. rostochiensis* Ro1 (rating)
Maris Piper	16,310	2	9
Markies	6,030	2	9
Maris Peer	5,000	2	9
Melody	4,300	2	9
Lady Rosetta	3,460	2	9
Estima	2,990	2	2
Taurus	2,770	3	8
Pentland Dell	2,750	2	2
Marfona	2,400	2	2
Innovator	2,470	8/9	Not resistant
Sagitta	2,440	Not resistant	Not resistant
Royal	2,390	3	9

Source: IVT. Data is available on the AHDB Potato Variety Database

Actions to address the threat

Promoting understanding among growers of the threat that PCN poses to the future of the sector is seen as first step towards tackling the situation. In many situations, however, growers feel unable to adopt measures considered to be beneficial. Specifically, the market preference for varieties with poor resistance, such as Maris Piper, serves to hamper adoption of varieties with better resistance. Nor is PCN the economic priority of many growers. The loss of production may be significant, but it is often hidden whereas skin diseases, such as blackleg (*Pectobacterium atrosepticum*), are highly visible and can result in significant financial deductions.

The use of biofumigant and catch crop species such as Indian mustard (*Brassica juncea*) and Sticky nightshade (*Solanum sisymbriifolium*) respectively has received widespread interest. The success of these crops in treating infestations, however, has been highly variable. In trials conducted in 2021 on a *G. pallida* infested site, a catch crop comprising Sticky nightshade and African nightshade (*S. scabrum*) reduced PCN populations by up to 56% but the wide range of 38-55% serves to highlight the inconsistency of control (Innovative Farmers, 2021).

The unsuitability of some biofumigant and catch crops is also a known impediment to wider adoption. As such, resistant varieties and long rotations are generally accepted as the best means of protecting PCN-free land for the long term. These are also important steps to managing PCN populations on infested land for the long term. Ensuring a clean break between crops, however, requires effective control of groundkeepers (volunteer potatoes).

In the Netherlands, for example, where PCN infestations are higher than in the UK, crops are monitored, and restrictions placed on land where too many ground keepers are recorded. If the tolerance is exceeded the land is treated as if a potato crop has been planted. Similar measures have been suggested in Scotland (Scottish PCN Working Group, 2020).

Promoting understanding of the threat that PCN poses to profitable potato production and especially potato seed, is fundamental to making progress.

Despite its significance, for many seed growers PCN is not the dominant issue when considering which variety to grow. A survey of seed growers in Scotland found that most considered blackleg as the main concern as it is the cause of most down-gradings and consequential price deductions (Blok, et al., 2018). PCN came third on the list of concerns with late blight control second.

Free-living nematodes

Free-living nematodes are distinct from PCN but the damage they inflict on crops is no less significant. The damage is most prominent in processing varieties (Samuel & Dines, 2022), though this may be a reflection of the preference among FLN species for sandy soils which also tend to be better suited to processing type varieties.

The term 'free-living nematodes' is used to describe four separate species of nematode. These migratory types move through the soil between bouts of feeding and are responsible for several diseases and disorders in a range of crops all of which are well described in the SAC technical note TN603.

In potato the principal free-living nematodes of concern are Stubby-root nematodes, which comprises the genera Trichodorus and Paratrichodorus. These species are vectors of Tobacco Rattle Virus (TRV), the cause of spraing, an internal disorder that reduces quality and in some cases makes them unacceptable for sale. Efforts to reduce the incidence of spraing are further complicated by pathogenic and beneficial species of FLN co-existing (Samuel & Dines, 2022). This can also make accurate species identification difficult.

Other forms of free-living nematode that are pathogenic to potatoes are:

- **Root-lesion nematodes** (*Pratylenchus spp.*). As the name suggests, these nematodes can cause severe root damage. In addition to direct damage, these nematodes have been linked with root disease complexes, *Rhizoctonia solani* and *Pythium spp.* and can facilitate entry of *Verticillium dahlia*;
- **Potato rot nematodes** (*Ditylenchus spp.*). The stem and bulb nematode (*Ditylenchrus dispasci*) is more commonly associated with flower bulbs and onions, but has also been associated with a tuber rot in potatoes, though occurrences are uncommon. *D. dispasci* can survive in infested tubers and in a desiccated state on stored potatoes for long periods of time. It does not spend significant time in the soil, so symptoms in potatoes should be investigated immediately (fera);
- **Needle nematodes** (*Longidorus spp.*). These nematodes cause yield loss by feeding on roots below cultivation depth, though the extent of the damage they cause is in potato crops less well understood.

Feeding damage to the skin of a potato caused by free-living nematodes

© Bayer

Feeding damage on the tuber surface can affect quality which can reduce the quantity of the crop destined for human consumption. This is of specific threat to crops produced for table consumption where appearance is an important indicator of quality.

Delayed emergence caused by free-living nematode damage

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Conclusion

Many growers might quietly acknowledge that the challenge they face can be best summed up as ‘a focus on short term profitability and a reliance on rented ground’. It’s a dilemma that needs to be resolved, but it’s also a poor excuse.

It is in the interests of all growers to develop a management plan that protects land for the long term. Save for taking land out of potato production for an indefinite period, there is not one single action that will address the PCN situation.

Instead, growers need to assess the status of their land and develop a suitable plan in response. Depending on the situation, the focus will be on managing the population to ensure it is kept at a level that doesn’t threaten production performance in the long term or bringing populations down to a level that ensures production can continue. In all cases, such a plan will involve a suite of measures built on a zero tolerance approach. This will involve good machinery hygiene to stop the spread of infested soil between fields through to diligent use of nematicides, cover/catch crops and resistant varieties. In cases where infestations are considered to be ‘high’ for that crop situation, the only alternative may be to take the land out of potato production for an extended period.

Implementing a comprehensive management plan will likely come at a cost to the businesses affected. Absorbing the cost may require detailed planning but it is also likely to create savings and other efficiencies through reduced yield losses, a longer working life of the specialist machinery involved and less seasonal labour.

For too long the industry has come to rely on nematicides as a single means of controlling PCN though most growers would concede this was never their intention. The financial pressures of the market may have exacerbated the situation by focussing production on to an ever-decreasing number of growers and reducing area of land, but it also meant the reality was never properly acknowledged or addressed.

An increasing number of growers, advisers and researchers are challenging this mindset. Together, they are showing that where the full gamut of measures is properly integrated, it is possible to protect both crop performance and the viability of the land.

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Crop Science Division
Bayer CropScience Limited
230 Cambridge Science Park
Milton Road
Cambridge
CB4 0WB

cropscience.bayer.co.uk