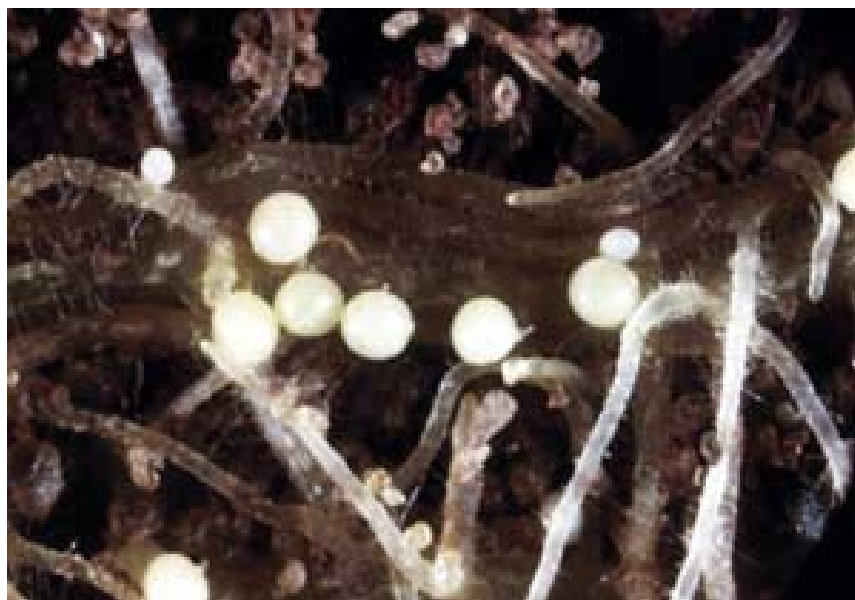


Potato cyst nematodes - a technical overview for Scotland

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(Maturing females and cysts of *Globodera pallida*)



(Maturing females and cysts of *Globodera rostochiensis*)

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Executive Summary

The pests

Potato cyst nematode (PCN) is the name commonly given to two species of cyst nematode that attack potato, namely *Globodera pallida* (Stone) Behrens and *G. rostochiensis* (Wollenweber) Behrens. They are two of the most important pests of potato in the UK, feeding on potato roots, causing losses of yield and costs that vary and are difficult to estimate. Published papers usually quote losses of about 9% of annual yield, estimated at about £43 million for the UK, based on the mean value of the crop from 1990–1995.

Adaptations to a plant-parasitic life

In both species the female forms a hard covering around her eggs when she dies, creating a ‘cyst’ which protects the eggs and developing juveniles from desiccation, predation and chemical control. Only a proportion of the eggs hatch from the cyst each year, and in *G. pallida* this occurs at a slower rate and with a later annual peak of hatching than *G. rostochiensis*. Most eggs have usually hatched after 7–10 years, but hatching can continue for 25–30 years.

Spread and Distribution of PCN in Scotland

PCN cysts are usually spread by contaminated soil, attached to tubers, plants for transplanting or to farm machinery. The introduction of a few PCN cysts will usually go unnoticed until several host crops have been planted and the infestation reaches a level at which it is detected either by pre-cropping sampling and testing, or, more significantly, by the appearance of symptoms such as stunted plants. Thus infested soil can be spread unwittingly within and between farms by normal agricultural practices before the pest is detected. Although PCN in Scotland is widespread, levels are lower than in England and Wales. A survey in England and Wales has shown that *G. pallida* is now the most common species, whereas *G. rostochiensis* predominates in Scotland.

Current statutory measures

As trade in potatoes developed, legislative measures were introduced to reduce the risk of spread of PCN. The most important control measure requires classified seed to be produced on land tested and found free of PCN before planting. Other important measures include reducing the tolerance for soil associated with classified seed to minimal levels; requiring rotations of at least six years (to allow viable egg numbers to fall); the use of buffer zones to isolate areas of PCN infestation within a field; restricting seed production to resistant varieties when non-viable cysts are known to be present; testing of soil where tubers and other plants are for export, and prohibiting the growing of potatoes and plants for transplanting (i.e. nursery stock and bulbs) on land known to be contaminated (‘scheduled’).

Pathotypes and resistant varieties of potato

Many pathotypes (or races) of each species of PCN are known to exist, each originating in South America. In the UK relatively few pathotypes exist. All fully resistant varieties currently grown here incorporate the H_1 (ex *andigena*) gene for resistance. Such varieties work well against PCN populations lacking the gene that confers virulence against this gene, i.e. *G. rostochiensis* Ro1, but have no effect on other pathotype populations of this species, or on *G. pallida*. This explains why *G. pallida* has become predominant in England and Wales when such resistant potatoes have been widely grown.

Control methods

Preventing the introduction of PCN to a clean field requires adherence to a strict management programme and, in the case of land used for seed potato or transplant production, control measures have a statutory basis. Preventing the build-up of PCN on ware land also requires careful management, involving the use of pre-cropping sampling to determine species, viability and level of infestation, the use of resistant varieties if possible, combined with chemical treatment and long rotations, preferably

of at least five years. Hygiene measures to prevent spread between fields and premises are also important.

PCN: species and diagnosis

The present EC Control Directive 69/465 refers to PCN as *Heterodera rostochiensis*. However, in 1973 it was concluded that observed differences in morphology and biology between populations of this species were sufficient to justify the description of two new species. In 1975 these were named *Globodera pallida* (Stone) Behrens and *G. rostochiensis* (Wollenweber) Behrens. As both of the pests in question are still 'PCN', this taxonomic change did not result in any change in policy. However, subsequent research with each species has resulted in a greater understanding of differences in their biology and hence appropriate methods for control.

The first stage in the diagnosis of PCN is to distinguish it from other cyst nematode species which might be found in soil. *Globodera* species have round cysts, whilst all other groups (*Heterodera/Punctodera*) have lemon-shaped cysts. The *Globodera* group also includes other species which are not PCN; *G. achilleae* (Golden & Klindic, 1973) Behrens is occasionally found in the UK and feeds on Yarrow (*Achillea millefolium*). This needs to be distinguished from the PCN species in tests of soil samples to avoid unnecessary scheduling of land or chemical treatments. Such diagnosis still relies on the expertise of nematologists using traditional microscopy techniques, which involve measuring characters found in both juveniles and females (cysts).

Over the last 10-20 years there have been great advances in techniques to diagnose species. The use of molecular techniques have proved to be of great assistance to diagnostic laboratories, but was not appropriate for statutory samples as about 25 cysts need to be collected to provide sufficient material to confirm species. In addition, *G. achilleae* cannot be distinguished from *G. rostochiensis* by this technique, with obvious implications for both advisory and statutory samples.

Biology of PCN species

Nematodes are slender, eel-shaped, unsegmented worms. They are a large and diverse group, many of which are parasitic on or within plant tissues. Cyst nematodes are highly specialised plant-parasites. The free-living, eel-like juveniles migrate to enter plant roots, where young females develop round bodies as eggs develop inside them, and as they die their translucent body becomes a hard, brown protective covering (the 'cyst') to protect the eggs (Fig. 1).

The cyst protects up to 400 eggs, each of which contains a fully-formed juvenile, from extremes of environmental conditions. Most juveniles go into a form of dormancy known as diapause. In this state, most will remain viable for many years, with hatching continuing for 25–30 years and exceptionally instances of infestations over 40 years old being reported. The juveniles are generally stimulated to hatch by exudates produced by actively-growing potato root tips. Under favourable conditions this may stimulate over 80% of the juveniles to hatch. In the absence of a host crop a variable spontaneous hatch occurs, averaging about 30% annually for *G. rostochiensis*, but less (about 20%) for *G. pallida*, depending on soil type and temperature.

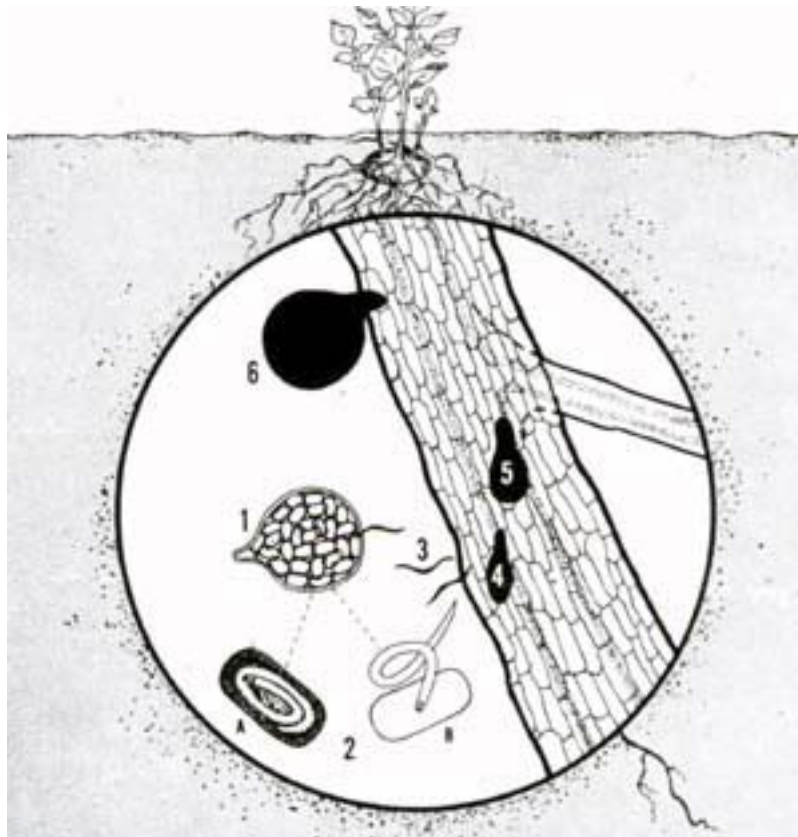


Fig.1. Life cycle of PCN. 1. Juvenile nematode leaving cyst. 2A. Appearance of juvenile in egg. 2B. Juvenile nematode hatching from egg. 3. Juveniles entering potato root. 4 and 5. Immature females inside root. 6. Mature female.

The identification of the two species of PCN in 1973 prompted research which demonstrated that their respective life histories demanded different approaches to control, mainly due to differences in hatching periods and longevity. *G. pallida* has a prolonged hatch with a later annual peak of activity than *G. rostochiensis* during the growing season, which may therefore extend beyond the effectiveness of any chemical treatment. This helps to explain why *G. pallida* is more difficult to control, especially when combined with this species' slower rate of natural decline in all soil types, and the lack of availability of commercial varieties with a high levels of resistance. DNA studies have also shown that races, or pathotypes, of *G. pallida* are much more heterogeneous and variable than *G. rostochiensis*. Thus, although the detection of PCN *per se* might not require detailed diagnosis, laboratory identification to species is necessary to support the most appropriate control methods.

Detection

Soil sampling is necessary to determine the presence or absence of PCN and thus determine which fields can be used for seed potato production. The sampling and extraction systems used by the Scottish Executive Environment and Rural Affairs Department (SEERAD) (based on the European and Mediterranean Plant Protection Organisation [EPPO] Quarantine Procedure for *G. pallida* and *G. rostochiensis*) provide a practical and reliable indicator of the presence of PCN. Soil samples are taken from an area up to 4 hectares, usually by following a 'w'- shaped path and taking regular samples *en route* with a corer. Usually in excess of 70 cores are required to collect a 500ml sample for testing. The combination of producing seed potatoes only on land that has been officially tested and found 'free' from PCN, together with a tight tolerance for the quantity of soil permitted with seed tubers, has greatly reduced the risk of spread through seed potatoes. Soil sampling methods promoted in The Netherlands use larger quantities of soil (6-11 kg of soil), and are often advocated in order to achieve higher levels of statistical confidence, but they are more costly. The EPPO sampling method is currently under review.

For ware growers, soil sampling can provide further information on the number, species and viability of cysts as indicators of likely damage, and is thus an essential part of an integrated control programme management plan. If the grower intends to retain part of a ware crop for planting (i.e. as home-saved seed), it is highly advisable to plant only from a crop which has been grown on land which has been tested and found free from PCN. Otherwise it is highly likely that PCN will be spread if tubers harvested from PCN contaminated land are replanted.

Host plants of PCN

There is potential for PCN to develop on a range of crop and weed hosts in the Solanaceae family (which includes potato, tomato and aubergine), but in practice, potato ground keepers, rather than other hosts, are the main cause for concern between crops. Their elimination is therefore an important part of PCN management. There are very few imports of solanaceous plants, and these are carefully monitored to reduce the risk of importing new strains of PCN.

Symptoms

Typically, PCN damage may appear as signs of mineral deficiency (as roots are unable to absorb sufficient nutrients) or as patches of stunted yellowing plants, or as wilting due to an inefficient root system, but such symptoms usually only appear when infestation levels are already high. From July onwards cysts may be seen on the roots, but PCN may not be the only problem: the fungal diseases *Rhizoctonia* and *Verticillium* wilt are often at least contributory causes of poor growth.

Damage

PCN reduces potato yield and this loss may or may not be accompanied by other obvious symptoms in the haulm as described above. Several factors almost certainly interact either to increase or decrease nematode damage: for example, differences in yield potential between sites, differences between varieties in their tolerance of damage, differences in husbandry, weather, etc.

Pathotypes and Host Plant Resistance

Many pathotypes (or races) of each species of PCN are known to exist, but there is no universally agreed means of describing them. For the sake of consistency, this review will use the terminology of the European International Scheme developed to differentiate between pathotypes on the basis of their multiplication rates on a series of differential potato clones, namely the system devised by Kort *et al.*, but its shortcomings are acknowledged.

In Scotland the Ro1 pathotype of *G. rostochiensis* predominates, with a lower incidence of *G. pallida* populations of Pa1, Pa3, and a mixture of Pa2/Pa3 occurring. In England and Wales the same pathotypes exist, namely Ro1, Pa1, Pa2 and Pa3, but *G. pallida* is now the predominant species and at levels higher than found in Scotland or Northern Ireland.

In Europe, a slightly wider range of pathotypes exists, but it is restricted in comparison with the range found in South America. These differences are assumed to be a direct result of the few introductions that have been made into Europe, but they may also have been determined by the use of different varieties and environments which would all contribute to the eventual expression of virulence. In Western Europe, all countries have reported Ro1, as in the British Isles, but pathotypes from Ro2 to Ro5 have also been reported in Germany, The Netherlands, Norway and Sweden. By contrast, the range of pathotypes of *G. pallida* in Europe is thought to be similar to that in the UK. In Central and Eastern Europe, where the potato crop is also of major significance, less information is available, but the intensive use of varieties resistant only to Ro1 is likely to lead to the prevalence of *G. pallida* pathotypes, as has happened in England and Wales.

Undoubtedly the greatest range of pathotypes is to be found in South America, where potatoes originated and where PCN evolved in conjunction with many other solanaceous plants. DNA-based diagnostic tests on populations from the UK, Europe and South America have shown that genetic differences between these populations can be detected. However, it is not possible to clearly separate all populations according to their current geographical distribution, e.g. to distinguish all South American from all European populations. In addition a build up of different virulence types (reflecting the genetic variability and the potential of different populations to adapt to different environments and overcome resistance) has also led to regional characteristics in populations.

Knowing the characteristics of pathotypes is important to plant breeders trying to develop varieties resistant to PCN (defined simply as those that prevent the development of juveniles to adults). The planting of resistant varieties to control known infestations of PCN has been permitted under a derogation contained within the present PCN Directive (Article 8 (b)). However, the existence of a range of pathotypes, and the ability of different populations of the same pathotype to show a range of virulence on the same variety, can present difficulties in relation to the appropriate use of resistant varieties.

All resistant varieties currently used in the UK incorporate the H₁ (ex *andigena*) gene for resistance. Such varieties work well against PCN populations lacking the gene that confers virulence against this gene, i.e. *G. rostochiensis* Ro1, but have no effect on other pathotypes of this species, or on *G. pallida*. Sustained use of such varieties has selected for *G. pallida*. Unfortunately, because of the inherent genetic variability of *G. pallida*, it is proving very difficult to develop a variety that is resistant to all populations. In the UK and Europe, some varieties claiming partial resistance exist (e.g. cvs. Nadine, Valor, Rocket). These allow a proportion of juveniles to reach maturity, but significantly less than would be the case if a susceptible variety was grown. However, there is little information on their long-term effect in the field – prolonged use may result in virulent pathotypes becoming more common, as has happened at species level in England and Wales.

Pathotypes not yet established in the UK could present a risk if introduced because they (i) might overcome the resistance currently bred into our most commonly used varieties, and (ii) might be more virulent than any of the populations currently found here. The range of pathotypes in prospective members of the EU should be assessed, but the evidence so far suggests that it does not differ significantly from that currently found within the EU. A far wider range of genetic diversity is to be found in South America where some of the most virulent populations are to be found. Hence imports from this part of the world are subject to close scrutiny (including a prohibition on imports of potatoes), not only for PCN, but for a wide range of pests and diseases not found in the UK.

Distribution and spread in Scotland

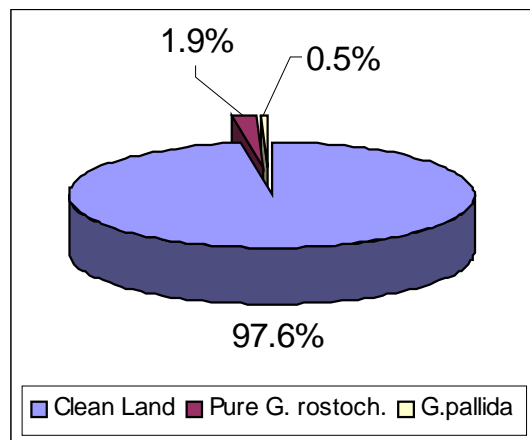
It is most likely that PCN was introduced into mainland Europe during the mid-1880s, when there was an intensive search for, and introduction of, blight-resistant varieties. However, recent evidence suggests that there were few such occasions of import, because the range of pathotypes recorded in the UK is less than that recorded in South America. PCN was first recorded in Scotland in 1913.

PCN can be introduced into clean fields with contaminated planting material. The tiny cysts (about 0.5mm in diameter) can easily escape unnoticed in the tuber eyes, or in soil that may adhere to tubers at harvest. However, this means of spread is most likely to occur with farm-saved seed produced on land that may be contaminated, as the controls in place to prevent infestation of certified seed potatoes will minimise the risk of spread by this means. An alternative route of spread is through soil residues spread on machinery from infested fields, by wind-blown contaminated soil, or by transplanting plants from PCN-infested land.

The incidence of PCN infestations in Scotland from land submitted with the intention of growing a classified crop of seed potatoes has fallen from just over 4% in 1989 to about 2.4% of the land tested.

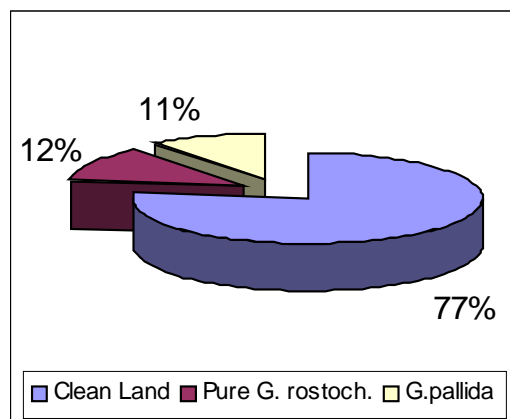
This is illustrated in Figure 1, which presents the proportion of soil samples drawn from land submitted for growing seed potatoes during the years 1998–2000. The results revealed that 97.6% of the 20,535 samples were free of viable PCN, 0.5% contained *G. pallida*, and the remaining 1.9% only contained cysts of *G. rostochiensis*.

Figure 1. Incidence of PCN in Scottish seed potato growing land



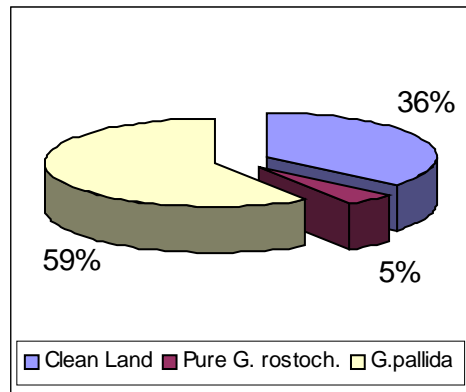
In Scotland, data collected from 397 soil samples submitted by ware potato growers to the Scottish Agricultural College (SAC) during a twelve month period starting in November 1996 revealed 77% of samples to be free of viable PCN infestation (Evans, 1999). *G. pallida* was present in 11% of the remaining samples and 12% only contained cysts of *G. rostochiensis* (Figure 2).

Figure 2. Incidence of PCN in Scottish ware potato growing land



In contrast, a recent structured survey revealed 36% of samples drawn from ware potato growing land in England and Wales were free from viable PCN (Minnis *et al.*, 2000). *G. pallida* was present in 59% of the remaining samples and 5% contained only cysts of *G. rostochiensis* (Figure 3).

Figure 3. Incidence of PCN in ware potato growing land in England and Wales.



Distribution in Europe and elsewhere

In 1913, PCN was found causing damage to potatoes in Germany, and it has subsequently been found throughout Europe. Table 1 presents a selection of first records. The rate of spread, however, cannot be truly measured because such data is usually only indicative of when surveys were done, or when damage was first noticed.

Table 1. First recordings of PCN in west European countries

Year of first recording	Country	Year of first recording	Country
1913	Germany	1952	Spain
1913	Scotland	1953	Iceland
1917	England	1954	Greece
1922	Sweden	1954	Czech Republic
1922	Ireland	1955	Luxembourg
1928	Denmark	1955	Norway
1940	Austria	1956	Portugal
1941	The Netherlands	1958	Switzerland
1946	Finland	1961	Canary Islands
1948	France	1961	Italy
1949	Belgium	1996	Hungary
1951	Faroe Islands	2002	Yugoslavia

Species of PCN have been recorded in most European countries (Table 2). Some countries, such as the Azores, Denmark, Greece and Madeira have only reported interceptions, not field infestations of *G. pallida*.

PCN has been recorded in every continent except Antarctica. In many countries, given the pathotypes recorded, it is likely that PCN has spread from Europe. However some spread of PCN from South America direct to other countries (for example to Japan in sacks of guano used as a fertiliser) has probably also occurred. The range of virulence present in the Andean region (Peru, Bolivia and Argentina) is wider than that known to be present elsewhere and new Andean pathotypes (and even species) are still being discovered in this area. This is one of the reasons why potatoes originating in South America may not be imported.

Table 2. The distribution of *G. pallida* and *G. rostochiensis* in Europe, according to published records

Country	<i>G. pallida</i>	<i>G. rostochiensis</i>
Albania	-	+
Austria	+	+
Belgium	+	+
Belorussia	-	+
Croatia	-	-
Cyprus	+	+
Czech Republic	+	+
Denmark	-	+
Estonia	-	+
Faroe Islands	+	+
Finland	+	+
France	+	+
Germany	+	+
Greece	-	+
Crete	+	+
Hungary	-	+
Iceland	+	+
Ireland	+	+
Italy	+	+
Latvia	-	+
Lithuania	-	+
Luxemburg	+	+
Malta	+	+
The Netherlands	+	+
Norway	+	+
Poland	-	+
Portugal	+	+
Azores	-	-
Madeira	-	+
Romania	+	+
Russia	-	+
Slovak Republic	-	+
Spain	+	+
Canary Islands	+	+
Sweden	+	+
Switzerland	+	+
UK	+	+
Ukraine	-	+
Yugoslavia	-	+

Statutory management of PCN

Implementation

Measures to address the control of PCN were incorporated into European Council Directive 69/465/EEC issued on 8 December 1969. The aim was to protect potato cultivation from the spread of PCN. At that stage, PCN was already known in a few Member States, but it was realised that, without effective international control measures, PCN would pose a permanent risk to potato production.

Further controls are included in the Directives 66/403/EEC (the 'Seed Potatoes Directive') and 2000/29/EC (the 'Plant Health Directive').

Entry into the European Union obliged the U.K. Parliament to accept Directive 69/465/EEC, which is currently implemented through The Plant Health (Great Britain) Order 1993. The Directive sets out minimum provisions to be adopted across the EU and allows Member States to adopt stricter provisions to control PCN or prevent them from spreading (Articles 1 and 9). Seed potatoes intended for marketing may be produced only on land which has been officially recognised as uncontaminated by PCN, i.e. following a pre-crop soil test (Article 2). Where PCN is found, quarantine restrictions should apply to PCN-infested land (i.e. the land should be scheduled) (Article 3). No potatoes, or plants intended for transplanting, may be grown on scheduled land (Article 4). Derogations permit ware potatoes to be grown, provided that the crop is either of a cultivar which is resistant to the PCN pathotypes present, or is harvested before PCN cysts mature, or if the ground has been disinfested by appropriate means (Article 8). Statutory provisions relating to PCN are also contained within The Seed Potatoes (Scotland) Regulations 2000, which establish the minimum rotations acceptable for seed potato crops: since 1966, all land intended for seed production must meet a minimum rotational requirement of six years.

Apart from export testing, restrictions are implemented only when fields have been officially tested and scheduled, and hygiene measures, such as the cleaning of machinery, whilst preferable, are infrequently implemented.

In Scotland, the successful continuation of freedom from PCN for the seed trade can be attributed to the principles used in regulatory controls on seed-growing areas through seed potato classification schemes and, for exports, to the ability to meet the phytosanitary requirements of importing countries. Many growers have become increasingly aware of the latter, as better markets are found outside the EU. The need to control the increasing incidence of *G. pallida* has highlighted the importance of PCN control throughout all stages of potato production. It is in all farmers' interests to consider a long-term strategy for potato cropping, and to exercise prompt management of the first signs of a PCN infestation. The higher incidence of PCN in ware land gives cause for concern, because it must increase the likelihood of spread to seed-growing areas (and uninfested land) unless the fundamental principles are strictly adhered to.

In light of an increasing awareness of the distribution of PCN across Europe, an EC Review of legislative controls is being carried out. Further information is provided in a consultation paper published on 19 July 2002 and available on the Department's web site at <http://www.scotland.gov.uk/consultations/agriculture/pcnconsletter.pdf>.

Scheduling

Land is scheduled if official sampling finds one or more viable cysts of PCN. Thereafter, the land becomes eligible for descheduling after a period of between one and six years, depending upon the species and number of cysts found. Since 1990, an area of 7,180ha has been subjected to new scheduling orders, whereas a total of 5,490ha has had scheduling orders revoked following tests that have been free from PCN, resulting in a nett increase in scheduled land of 1,690 ha. Seed potato production is not permitted until at least six years have passed since the last positive finding of PCN, or twelve years since the last potato crop (or six years since a resistant variety was grown for ware under licence).

Management of PCN in ware potatoes

Preventing the build-up of PCN on ware land requires careful management, but has been exposed to short-term strategies and commercial pressures. It is important that pre-crop sampling is carried out to determine the proportion and numbers of each PCN species present, as well as the viability of eggs in the cysts, to enable control measures, including chemical treatment, to be refined. PCN infestation

levels should be kept low, because chemical treatments are more likely to be effective in such situations. PCN populations can be reduced by long rotational intervals, e.g. at least five years, using only certified seed, alternating resistant or partially resistant varieties with susceptible ones, cleaning footwear and machinery between fields and returning tailings to the field from whence they came. However, in practice, it is likely that only some of these measures will be taken, either for economic or practical reasons, thus allowing PCN infestation levels to build up. For example, if the PCN species is identified as *G. pallida*, there are currently no fully resistant varieties available. It is also doubtful whether adequate cleaning of footwear or machinery often takes place.

Chemical methods

The use of chemicals (nematicides) to control PCN is relatively limited in Scotland, especially when compared to The situation in England and Wales. Chemical control methods can be divided into two types, namely pre-planting fumigation methods, and granular nematicides.

The liquid fumigant Telone II (1,3-dichloropropene) comprises the greatest proportion, by weight, of nematicides applied. Whilst methyl bromide was the most effective fumigant available, the alternatives are not thought to be so effective. This is mainly due to the protection afforded the juveniles by the cyst. Good soil conditions at the time of fumigation treatment, including the appropriate temperature and moisture content, are critical to the success, so timing may mean an application in the rotation a year or two ahead of the prospective potato crop. In addition, there is no point in applying the treatment if a good surface seal cannot be produced.

Both the granular carbamate and organophosphate types are more correctly referred to as nematostats, because their mode of action is to disrupt the metabolism, feeding and movement of the juveniles which does not necessarily result in death. Their effectiveness also depends upon several factors, including the method of application and soil conditions. The problem with such treatments is that the apparently prolonged hatch of *G. pallida* in comparison with *G. rostochiensis* means that the pesticide may have decomposed by the time most of the juveniles become active, and so be ineffective.

Neither method offers complete control of PCN in soil or on potatoes, thus they should be used in conjunction with other methods to improve protection. This includes derogations for potato cultivation on scheduled land.

Non-chemical methods

Resistant and tolerant varieties

The appropriate use of resistant varieties in PCN infested land for ware production is to be encouraged. Varieties with different levels of resistance are available in the UK and in Europe. Table 3 lists those varieties on the UK National List that are resistant varieties to *G. rostochiensis* (Ro1 type). Other varieties that are listed as resistant on the Common Catalogue, a compilation of EU National Lists, may also be grown.

As has been illustrated, repeated use of varieties resistant to *G. rostochiensis* Ro1 in England and Wales has allowed the build up of *G. pallida*.

The term 'tolerance' is often used, and should not be confused with 'resistance' or 'partial resistance'. Tolerance is the ability of a variety to yield well in the presence of a high PCN population. It is expressed in some varieties by vigorous growth, which helps the plant to overcome the effect of damage caused by PCN invasion. Partially-resistant varieties that are of limited use in producing an economic return when grown in PCN-infested soils, unless protected by an appropriate chemical treatment.

Properly managed programmes, which alternate resistant varieties with susceptible ones, manipulate the known biology of the species, and use chemical treatments when necessary, are essential if potato

production is to continue on land that is infested with PCN. The ability of PCN to overcome host plant resistance serves to show the complexity of PCN control, and thus the importance of statutory measures designed to limit the spread of PCN. It also illustrates the limited life of most resistant varieties, unless their use is managed very carefully.

Table 3. PCN Resistant potato varieties on the United Kingdom National List, 2002

Resistant to *Globodera rostochiensis*, pathotype Ro1

Accent	Navan
Admiral	Pentland Javelin
Amour	Pomeroy
Argos	Rathlin
Bimonda	Red Cara
Buchan	Revelino
Cabaret	Riviera
Cara	Rocket
Celine	Roscor
Dundrod	Saxon
Harborough Harvest	Sebastian
Horizon	Spey
Jamila (Atlas)	Stemster
Kingston	Sunbeam
Kirrie	Tay
Maxine	Valor
Maris Piper	White Lady
Midas	Winston
Nadine	

There are no cultivars on the National List with full resistance to *Globodera pallida*, pathotypes Pa1, Pa2, Pa3

Trap cropping

The present Control Directive includes a derogation to allow trap cropping as a method of controlling PCN on infested land. It has long been known that early lifting can limit nematode reproduction by destroying plants before females mature, but the idea of deliberate planting of a trap crop to control *G. pallida* was recently revived. A recent test of the technique in England has revealed the need for very careful timing: the crop must grow long enough for the plants to establish root systems of reasonable size, but not so long that any of the female nematodes mature. Current research work in Northern Ireland is investigating the use of wild, highly resistant but tolerant potato varieties in trap cropping schemes. It is hoped that their ability to stimulate high levels of juvenile hatch and tolerance of high levels of PCN invasion could be utilised in organic potato production.

Biological control

Biological control of PCN has been investigated in England, primarily using the parasitic fungi *Paecilomyces lilacinus* and *Verticillium chlamyosporium*. It may be an appropriate control measure for ware production, where large numbers of PCN would support reproduction of the parasites, but it is currently not acceptable for seed crops, which require total freedom from PCN.

Rotation

The length of rotation has been a consideration in statutory control programmes since legislation was introduced, and should be regarded as a key element in the management of PCN. In the absence of a host crop, the prolonged period of hatching causes PCN populations to decline slowly. The rate of decline is affected by the susceptibility/tolerance of the variety and by environmental factors, such as

the soil type. The barely detectable levels found on scheduled land should therefore decrease to undetectable levels within a few years of the last sampling if no host crops are grown.

Integrated Management Systems

A comprehensive guide to the management of PCN was provided by 'Potato Cyst Nematode: A management guide', produced by MAFF in October 1999. Whilst some details have changed, it remains a useful reference for control strategies, and can be obtained from DEFRA Publications via their web-site <http://www.defra.gov.uk/corporate/publications/default.htm>

Conclusion

Both species of PCN are damaging pests to the potato industry and are difficult to control. This paper provides a technical overview of their biology, distribution and control. It is intended that this information should assist in the review of EC statutory controls against PCN which is taking place from September 2002. For those using it for that purpose, reference should also be made to the consultation paper published on 19 July 2002.

Some preliminary thoughts on the economic consequences of the various options being considered are included in the consultation paper. These will be developed further. If those within industries affected by PCN controls, or others who have an interest in this area can provide further details which will help to refine this document; their contributions will be very much appreciated.

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This review aims to provide basic scientific information on PCN together with an overview of the current situation in Scotland, and has been adapted from the overview for England and Wales compiled by Dr. Sue Hockland. In this she states that she has attempted to summarise the most recent research undertaken in the UK that is relevant to the current consultation process concerning the review of existing EC legislation. She acknowledges the authors of key papers and other published material consulted for this work as follows:

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