Plant Health Centre
Scotland's Centre of Expertise

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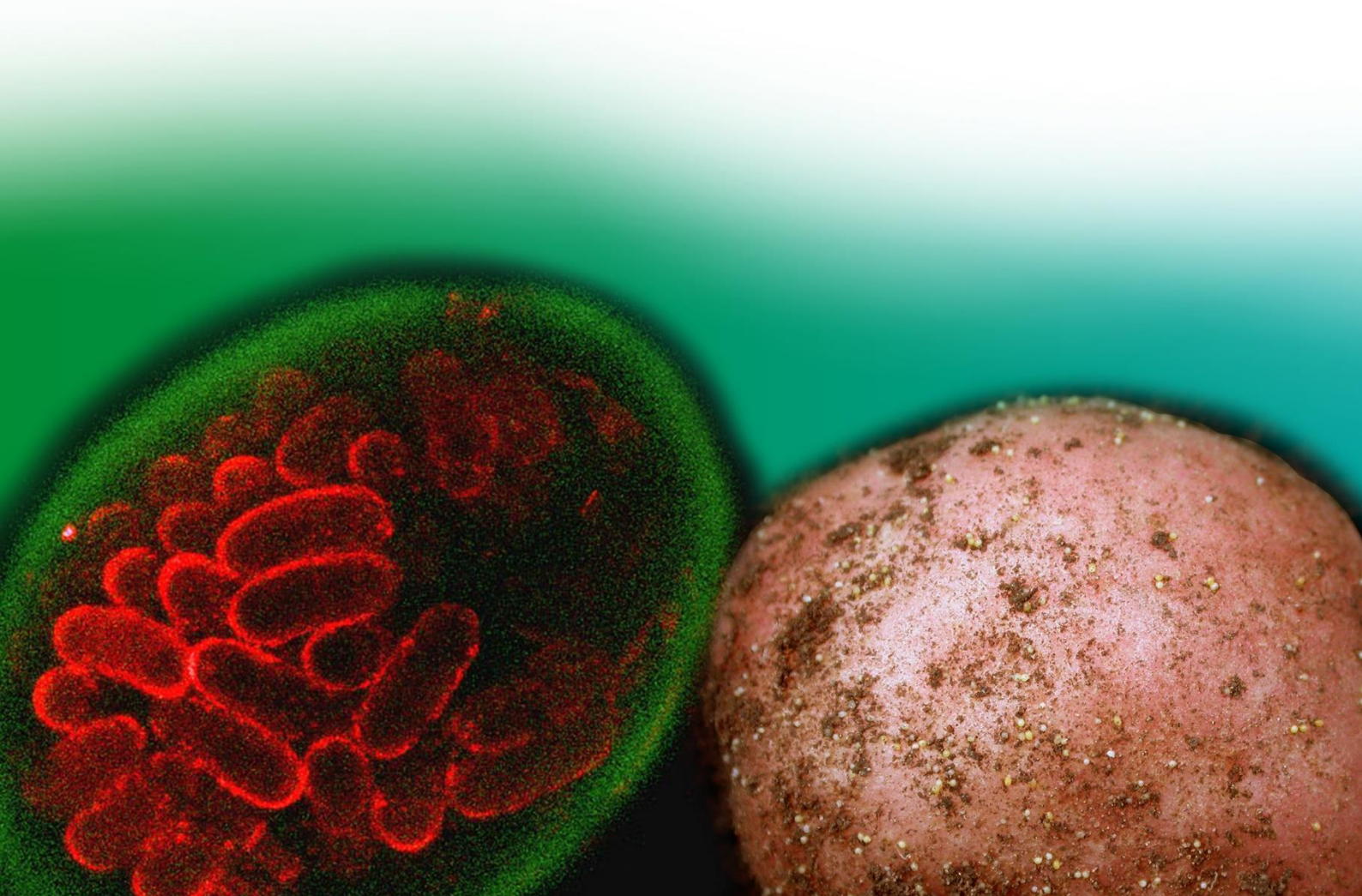
Potato Cyst Nematode (PCN) and the future of potato production in Scotland

Report of the Scottish PCN Working Group

November 2020



Contents

This report is standalone but the reader may benefit from reading the Plant Health Centre's report 'The future Threat of PCN in Scotland' (www.planthealthcentre.scot/publications)

1. Executive summary

'Pause and ask yourself what a world without potatoes would look like? The plant pest threat (potato cyst nematode) highlighted in this report has been insidiously eroding the certified seed potato supply chain for the past two decades which, if left unchecked, will see the demise of the seed industry and our country's ability to be self-sufficient in the production of this most vital food crop. The work of the plant Health Centre of Expertise has brought together scientific, industry and civil service expertise to focus minds on how to tackle this pest and thereby safeguard the future of our industry. If acted upon without delay or procrastination the recommendations herein could safeguard the future resilience and sustainability of the industry.' - Archie Gibson, Executive Director, Agrico UK Ltd

1.1 The case for action

The potato industry in Scotland **employs over 2000 people** and is worth **£250 million to the economy**. It has a worldwide reputation for seed health and quality, supplying 77% of the seed for a **£928 million GB potato industry** and **exports worth £55 million**. Potato is the most **economically sustainable** main food crop in terms of water usage and greenhouse gas emissions, an important point when considering that 85 kg are consumed by each person each year in the UK. However, the industry is under serious threat from a pest - potato cyst nematode (PCN) – which has **infested over 13% of land** for growing potatoes and bulbs and is doubling every 7-8 years; an increase in **spread of 5% per year**. This is already having a major impact on farm businesses and is particularly hitting the potato seed and flower bulb sectors, which require certified PCN-free land to grow their crop. **Current losses are estimated at £25 million** but if allowed to continue under current regulations and conditions, **potential losses of £125 million** farm gate value by 2040 are predicted (excluding job losses and upstream impacts on exports and the wider GB food industry), and the **possible end of future seed potato and bulb production across the whole of Scotland by 2050**.

1.2 Key Recommendations

Following a Ministerial round table meeting on PCN in June 2020, a working group of over 50 potato industry, government and academic partners was set up (from both Scotland and the wider UK) to identify a clear strategy for dealing with the PCN crisis. Following over 320 person hours of scheduled meetings, plus many days of personal discussions, **four recommendations have been proposed (below).**

A. Increase the potato sector's capability and motivation to implement change

Provide a clear plan and ongoing education to ensure that change occurs, including i) a **national (evidence based) strategy** and ii) a dedicated **KE and communication support package**, which underpins all approaches outlined in the report.

B. Preserve the land base for future generations

Instigate clear key actions to ensure that the spread of PCN into new areas of land is halted, including i) **special status for land** found free from PCN, ii) new incentives or the conditional use of existing **incentives** for keeping soil free from PCN, iii) **land retesting** to free up land for (PCN resistant) seed production and iv) the extended use of **diagnostics** for PCN management.

C. Control the epidemic

Where PCN has been identified, make available a range of tools and actions for land managers for the long-term sustainable control and management of PCN in soils, aligned with the **government's IPM ambitions**, including i) improved acceptance of currently available **resistant / tolerant varieties**, and the development and commercialisation of new varieties, ii) improved use of **decision**

support systems (DSS) to maximise the use of these varieties, iii) expanded use of **commercial diagnostics** to better manage infested land, and iv) development and testing of **integrated pest management (IPM) tools**.

D. Recognise the investment needed to tackle the PCN problem

Invest in the tools to tackle PCN in Scotland and protect against the downstream income losses, with **priorities for financing** being i) Action 3 - an extensive **programme of knowledge exchange**; ii) Action 6 and 7 - the purchase of **GPS equipment** for potato inspectors; and iii) Action 9 - the employment of a dedicated **full-time research technician** to accelerate the ongoing resistance marker development work.

To ensure success, the above recommendations have **associated 'Actions' with clear timelines, responsibilities and estimated costs** (where possible) (see Table of Actions).

Short-term actions (within the next year) include a detailed economic assessment comparing a 'do nothing' approach against interventions outlined in the report, together with a better understanding of future PCN spread. This will help to develop a national strategy for PCN, with changes in legislation, financial incentives and an extensive programme of knowledge exchange helping to protect PCN-free land and increase grower and land-owner awareness of the issues.

Medium term actions (within 2-3 years) will see improved management of groundkeepers (rogue potatoes that grow in a field following a potato crop) while fighting to retain essential herbicides (including glyphosate) to enable this to take place. To allow this management to happen, and enable more accurate PCN soil sampling, both statutory and commercial diagnostics will be ramped up and inspectors given the GPS tools to more precisely map the coordinates of land where further actions are required. Existing resistance markers will be improved for use in

breeding programmes, better methods will be developed to assess tolerance, and decision support systems and existing IPM strategies will be tested.

Longer term actions (beyond 3 years) will see a coordinated breeding programme introduced as well as new resistance markers and IPM tools developed.

2. The current situation in Scotland

2.1 ***Potato production in Scotland***

Potato is the fourth major food crop worldwide and the UK is the **fifth biggest potato producer and seed exporter in Europe**, with Scotland making up most of the latter. **Scotland is the tenth highest consumer per capita of potatoes worldwide** and the sixth in Europe at ca 85 kg per year, down by ca 15% over the last decade largely due to an increase in consumption of rice and pasta. However, potato is the **highest yielding** of the main food crops and is more **environmentally sustainable** than pasta and rice in terms of both water usage and greenhouse gas emissions.

Potatoes make up ca 6% of total farm area in Scotland, and **18% of the cropping area** (28,000 ha - three times that of the potato cropping area in GB as a whole and six times that of Europe). There are 2600 main or minor holdings in Scotland that grow potatoes; down 22% over the last decade although with yields remaining stable at ca 1-1.3 million tonnes). Scottish potato production represents 23% of the GB industry, which has a **farm gate value of £928 million** and supports an agri-food sector in the GB worth £120 billion. In 2020, 28,400 ha of potatoes were produced in **Scotland with a farm gate value of £250 million**: 12K ha certified seed potatoes (ca 42% of total production) worth £105 million and 16,300 ha ware potatoes (58%) worth £145 million. Certified Scottish seed represents 77% of all seed grown in GB, with 21% of this **seed being exported (worth £58 million)** and the remainder underpinning >70% of all potato production in England and Wales, which in 2020 was ca 90,100 ha (data from Scottish Government Agricultural survey) (Fig. 1). There are ca 650 ha of flower bulbs grown in Scotland and, taking an average year, the **flower industry's sales are ca £4 million**. Potato and bulb production therefore have a major impact on the Scottish economy, employment and, in the case of potato, on food security.

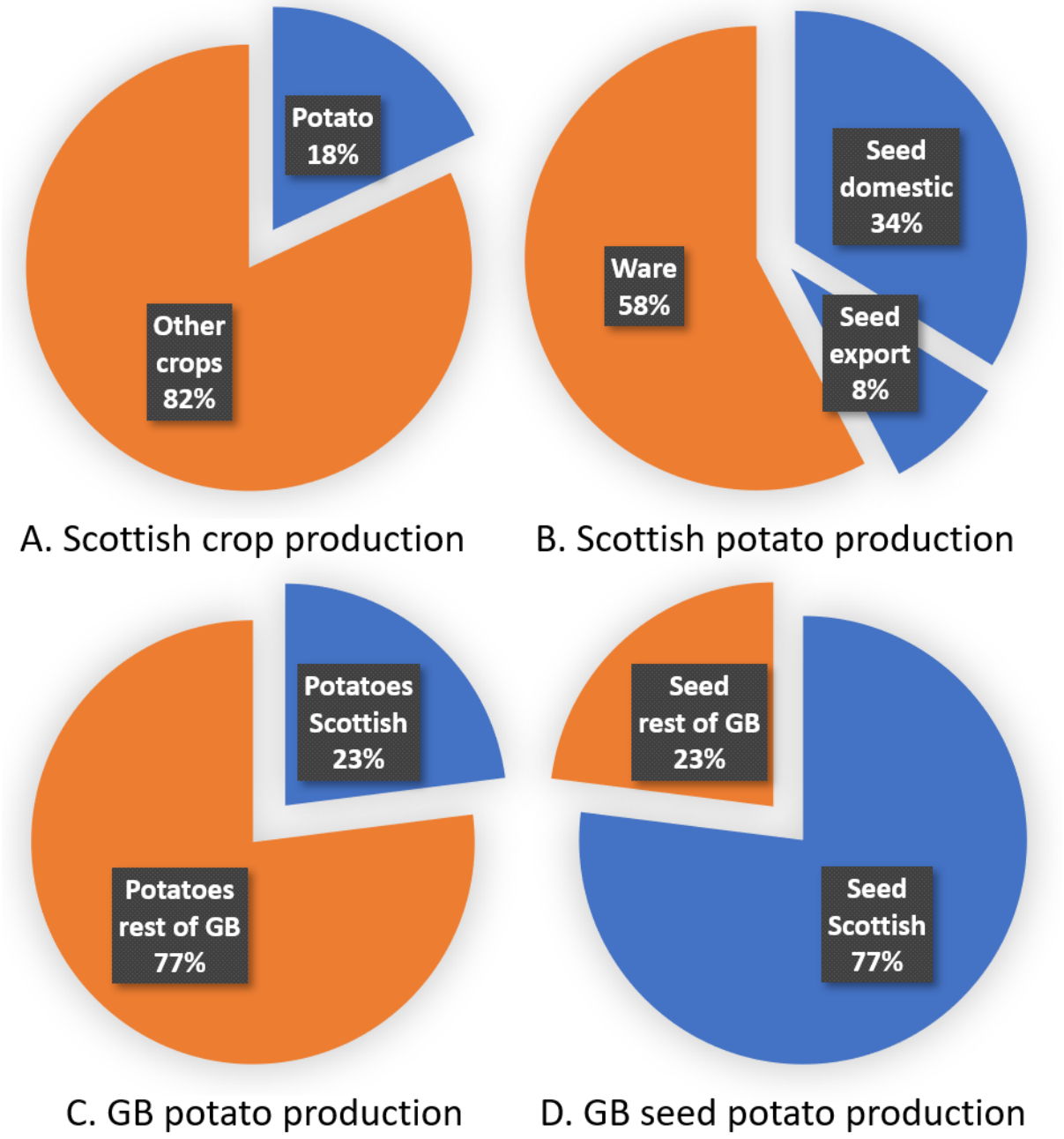


Figure 1. Potato production in Scotland (ha): Cropping area (A), seed versus ware production in Scotland (A, B) and the proportion of Scottish production in GB (B, C).

2.2 Potato Cyst Nematode (PCN) in Scotland

Potato cyst nematodes (PCN) are the most damaging nematodes to affect potato crops, capable of causing over 70% yield loss in susceptible varieties. Cysts, resulting from dead female nematodes, contain approximately 400 live eggs and so have massive potential for reproduction (see front cover image). These cysts are spread by adhering to potatoes which are then planted or through movement of soil (either attached to potatoes used as farm-saved seed or on machinery) and potentially by water and wind. **Nematode eggs can survive inside cysts for up to 40 years**, thereby effectively taking out seed potato and bulb production land for a significant time once identified as infested if no mitigation is undertaken.

Two species of PCN are present in Scotland: *Globodera rostochiensis* - the golden cyst nematode and *Globodera pallida* - the white cyst nematode. In the 1970s, G. *pallida* represented 2–3% of PCN findings with *G. rostochiensis* representing the rest. In recent years, however, the **incidence of *G. pallida* has increased** markedly, with Angus (the biggest producer of potatoes in Scotland) being the most affected county. While there are currently commercial varieties with resistance to G. *rostochiensis* suitable for the Scottish fresh market (e.g. those carrying the H1 resistance gene), this is not the case for *G. pallida*. However, resistance is available in processing varieties and, therefore, is having a significant impact on controlling PCN in countries where these varieties are grown (which does not include Scotland). To add to the difficulties with *G. pallida*, it has a slower decline rate than *G. rostochiensis* in soil in the absence of a host crop and its prolonged hatching period renders nematicide control less efficient.

Statutory testing data collected by SASA shows that the area of land recorded as infested with *G. pallida*, currently 6,200 ha, is doubling every 7–8 years and now accounts for nearly 70% of findings (Fig. 2), while the area of land infested with *G. rostochiensis* is relatively static at c. 14,500 ha. SASA estimates that over **13% of the area regularly planted with potatoes in Scotland is now infested with PCN**, with an estimated increase in spread of 5% per year. The widespread presence of *G. pallida*, and its spread into land historically used for seed production, is a particularly acute problem since land infested with PCN, by statute for sound

biological reasons, cannot be used to grow seed. This spread, therefore, is currently impacting on potato seed and flower bulb production businesses, especially in Angus (see case study #1) and if allowed to continue under current regulations **PCN spread could end future production across the whole of Scotland in as little as 30 years** (Fig. 3). This would have a major impact on both the important potato seed export sector and the downstream sustainability of the ware sector throughout GB. Moreover, if PCN infestation was to reach a level that impacted significantly on high grade seed growing areas in Scotland, which are managed by the only 22 remaining high grade seed growers in Scotland, this would have a major knock-on effect to the rest of the industry and accelerate its demise.

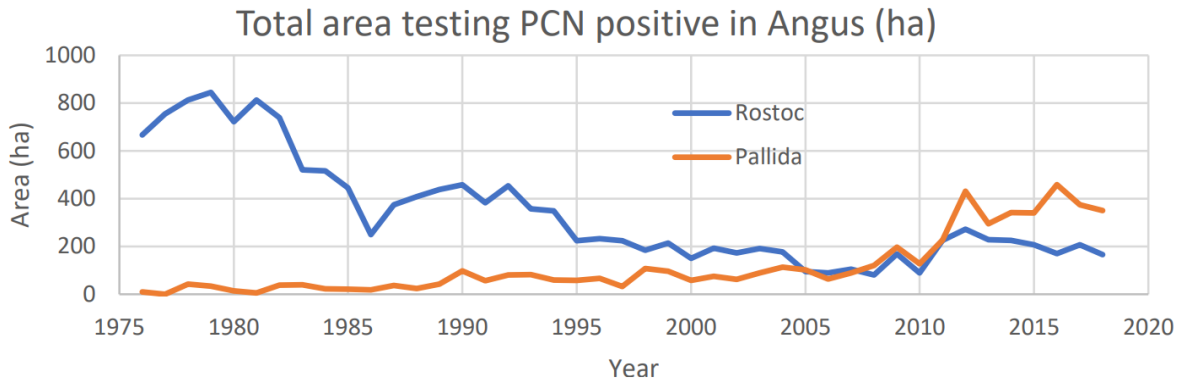


Figure 2. Total area testing positive for G. rostochiensis (Rostoc) and G. pallida (Pallida) between 1976 and 2018 in Angus (taken from the Plant Health Centre's report 'The future threat of PCN in Scotland').

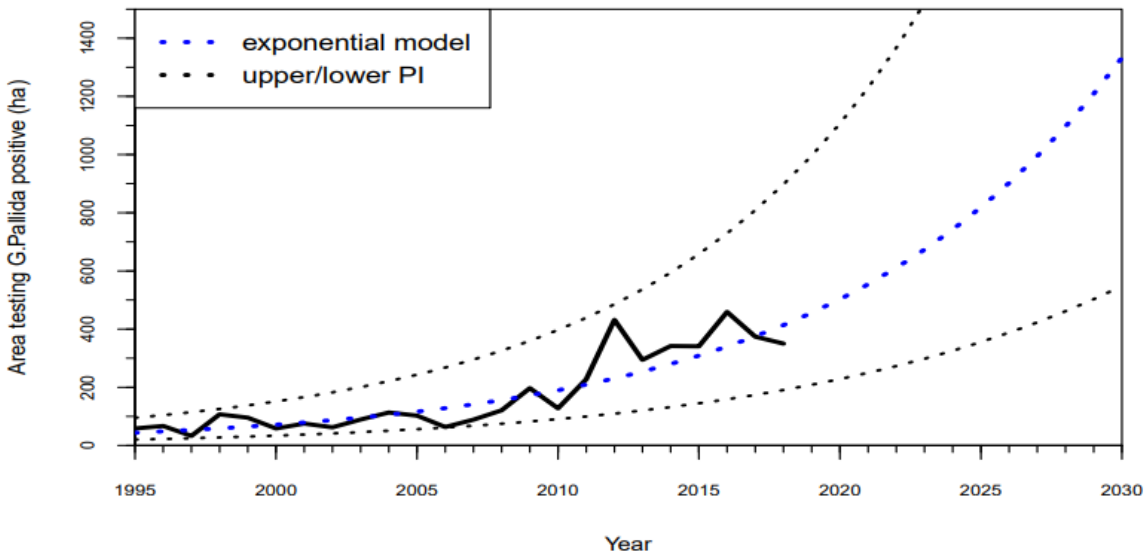


Figure 3. Increase in area testing positive for G. pallida (solid line) compared with the model prediction (blue dotted line) and the upper and lower predictive 95% confidence intervals (taken from the Plant Health Centre's report 'The future threat of PCN in Scotland').

2.3 Current control of PCN in Scotland

Scotland is recognised by the EU and internationally as a high-grade region with low pest and disease levels, largely due to its cooler climate. The two species of PCN are the only global quarantine pests of potatoes affecting Scottish potato production. To meet international standards, **seed potatoes cannot be grown on land recorded as infested with PCN**. This is determined by a Scottish Government programme of PCN testing, which is undertaken prior to land being passed for seed planting. Where PCN infestation is found, European legislation permits only the production of ware potatoes on such land, if produced under officially approved control programmes that suppress PCN populations. Where landowners/agents are looking to rent land for potato production, they may prefer renting for ware, thus avoiding the risk of losing income should a positive PCN test be returned, prohibiting seed production and placing constraints on future ware production through the SG PCN control programme. If the land is not subject to any official (SG) testing, then

income can be protected until the point when PCN starts to cause crop failure/severe yield loss. However, many custodians of this land (which is often rented to growers) have **limited knowledge of issues relating to PCN and few incentives** to keep the land PCN-free, thereby retaining it for seed production.

Despite the extra restrictions relating to the control of PCN placed upon the ware sector within Scotland, the area of **land testing positive for PCN continues to increase** thereby reducing the area of land available for long term sustainable potato production. While ware potatoes are an important crop in Scotland and a major contributor to the Scottish economy, it is vitally important to ensure that the seed sector is maintained due to its strategic importance for the whole of the sector. However, Scottish Government estimates suggest that the overall **seed area has shrunk by 14.6% during the last decade** - from a peak of 11,637 hectares in 2010 to 10,153 hectares in 2019.

2.4 The economic consequences of PCN in Scotland

A recent report by Scotland's Plant Health Centre ('The future threat of PCN in Scotland') estimates that PCN infestation currently causes losses of ca £5000/ha, equivalent to an **estimated loss to Scottish potato production of £25 m in 2019 rising to £125 m by 2040** if this issue is not addressed (opportunity loss not actual loss, i.e. the value of potatoes that could have been grown had the land not been infested by PCN).

Fig. 4 highlights that the values of the seed potato sector grew steadily from £45.5 million in 2005 to £75.4 million 2013, before falling back to £65.1 million in 2017. Despite the area under potatoes continuing to fall in 2019 the estimated **value of**

> *'With the predicted exponential increase in G. pallida and already high levels of G. rostochiensis, within 20 years the UK's leading exporter of daffodil bulbs and one of the top 5 exporters of seed potatoes will cease to exist.'* Mark Clark, Managing Director, Grampian Growers Ltd.

the seed crop rose dramatically to £90 million in 2019 due to substantial increases in the average market price received for Scottish seed potatoes.

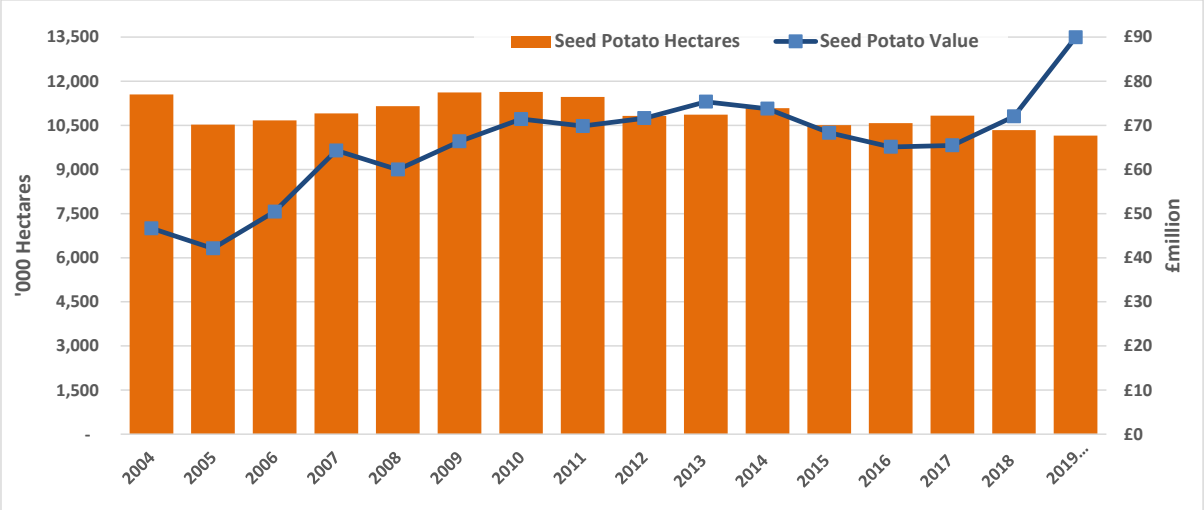


Figure 4. Estimated area of seed potato production and economic value between 2004 and 2019. Data extracted from the Economic Report on Scottish Agriculture 2020 Edition.

When examining value, area and yield charts it is important to consider the crop growing year that farmers had to endure both in Scotland and further afield. Weather can significantly impact on crop yield – particularly in harvesting – as illustrated in Fig. 5 where the impacts of the very wet summer and autumn harvesting periods in 2012 were apparent. Growing conditions amongst Scotland's seed growing competitors can impact on the market price for seed – meaning Scottish growers can best influence their returns from maximising output from the area grown.

There are ca 280 registered seed growers in Scotland of which <25 are high grade Pre Basic producers. Of the 255 commercial seed growers in Scotland, which represents **70% of all UK seed growers**, ca 50% are located in the East of Scotland region. Using the Scottish Government's coefficients for Standard Labour Requirements[1] it is estimated that the Scottish seed potato sector directly employed 1,068 full-time

[1] SLR for maincrop potatoes is 110 hours per hectare and for early potatoes 200 hours per hectare – with 1 Full-time Equivalent 1,900 hours

equivalents (compared to 1,062 in the ware sector). Conservatively, using the minimum wage of £8.72 per hour, this suggests that the **seed potato sector contribute at least £17.7 million to local economies** through direct on-farm wage costs.[2]. As potato and vegetable operations are more labour intensive than cereals or grass production, many of these jobs and associated wages will most likely be lost if effective management strategies are not introduced promptly.

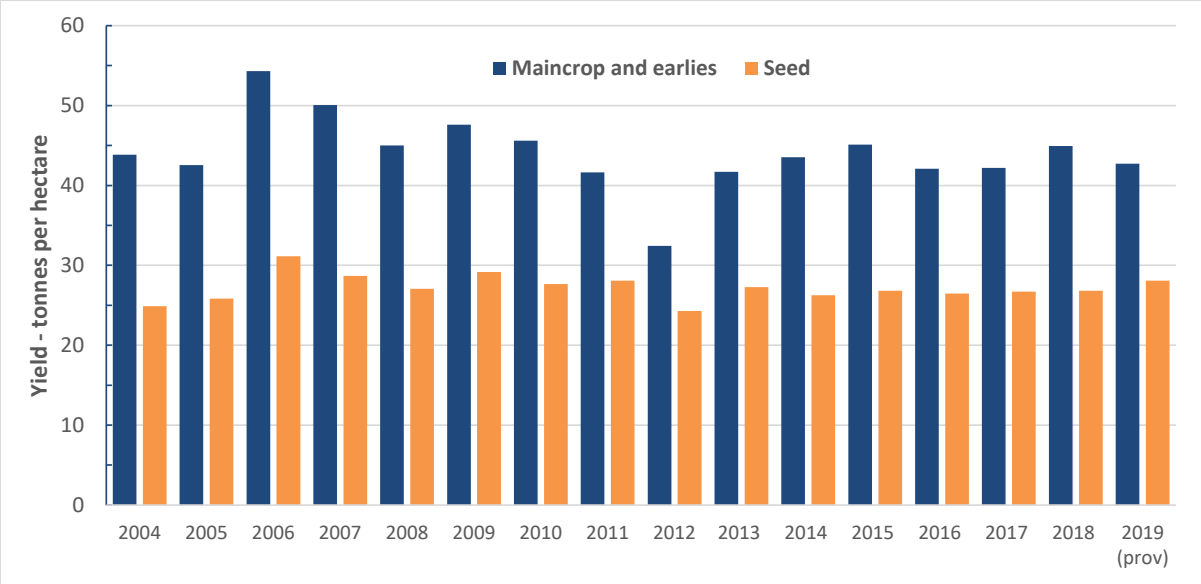


Figure 5. Estimated yields of seed and ware potatoes between 2004 and 2019. Data extracted from the Economic Report on Scottish Agriculture 2020 Edition.

The loss of seed production would also have economic impacts to both upstream suppliers and downstream to merchants and exporters, regulators, etc. For example, SRUC's 2020-21 Farm Management Handbook suggests that for every hectare of seed potato grown, variable costs on-average amount to £5,527 (30% on seed, 3% on fertiliser, 12% on chemicals 55% on other expenses[3]). This suggests that ca **£56 million was spent on direct production costs** before any account is taken of

[2] This does not account for farm family labour
[3] Other crop costs include: AHDB levy costs, SPCS field inspection fees, roguing and labels, positive ventilation and cold storage, bags, chemical treatment at storage time and royalties (which will depend on variety).

the high capital value equipment that is required. When labour and direct input costs are combined it suggests that ca **£74 million in regular expenditure is made by the potato seed sector each year**. Unpublished research by Thomson and Bell (2019) for the Scottish Government[4] suggests that seed potato exports were estimated to have total value of £58 million (including merchant's margins and costs) with growers receiving about £25 million. These export revenues are at risk in the long run if no action is taken on PCN.

3. The need for change

To avoid the potential loss of the seed potato and bulb industries in Scotland within the next 30 years, and the slow decline of these sectors in general, impacting the economy, employment and wider food and drink sector much sooner, concerted action needs to be taken now. The original Plant Health Centre report outlines several key recommendations and future work, which coincided with a Ministerial round table in June 2020 to discuss the impact of PCN and the way forward for Scotland. Based on outputs from that report and the round table meeting, a working group was set up to report back to the Minister with a national strategy for dealing with PCN. This working group consists of industry, Scottish Government and academics (Appendix I), and it responsible for producing this report.

3.1 Learning from how others manage PCN

A first step to this process is to better understand how other nations have dealt with PCN infestation.

The Netherlands has a major problem with PCN infestation but has largely learned to manage the pest through the implementation of different key strategies:

a. *Commercial diagnostic testing*

[4] Scottish Seed Potato Sector- Potential Impacts from Brexit

Testing of a field/area is carried out up to several years prior to its use as seed land, and often immediately after harvest of the previous potato crop. Where a positive PCN result is obtained, control strategies are put in place to clean up that land often using resistant varieties. This allows several years to manage the infestation and make ready the land for official government testing prior to planting. Commercial testing at high volume provides this advance warning and identifies land parcels with very early infestations (five times below the detectable limit for statutory testing). This high resolution PCN analysis encourages proactive management of the land parcel and minimises land being placed under a PCN control order.

b. Retesting of scheduled land

Where government testing identifies a PCN infestation prior to seed planting, the land will undergo increased levels of testing in strips across the infested area to better identify infested and non-infested areas of that land. Where strips are found to be below the detection limit for PCN, seed planting is permitted using resistant varieties only.

c. Use of resistant varieties

Unlike Scotland, the Netherlands is a major grower of processing varieties and has been successful in breeding PCN (both *G. rostochiensis* and *G. pallida*) resistant varieties for this market. These have been used highly effectively to reduce PCN populations in infested land in conjunction with (a) and (b) above. Unfortunately, many of these varieties are unsuitable in Scottish conditions, which are not conducive to the production of potatoes for processing. In addition, in The Netherlands more growers own their land making it easier to manage PCN, and grow on shorter rotations, typically every 3 years. In comparison, Scotland has adopted longer rotations, and a high proportion of the crop is grown on land rented specifically for potato cropping typically at 5 to 6 year intervals (6 year rotations are obligatory for seed production). Therefore, while better access to diagnostics and retesting of land could be introduced into Scotland, the availability of suitably resistant varieties for the Scottish market is still restricted, as is the ability to coordinate PCN control/management activities amongst the growers and the land

agents who rent the land. However, in Scotland there is currently a project led by SoilEssentials that is helping to target the limited pool of resistant varieties to the land parcels of greatest need or benefit, such as those blocks adjacent to a positive PCN finding.

d. Decision support system (DSS)

The Dutch governmental program, "Het Meerjarenplan Gewasbescherming", was initiated in the 1990s and continues to develop methods and decision support tools to reduce the use of pesticides. The principle behind this program is the management of PCN at densities that cause no yield loss, as opposed to an eradication plan. The DSS NemaDecide, which cost many € millions to develop, co-ordinates the intensive sampling required, the use of resistant varieties in production, species determination and the cost/benefit calculations of the different management options.

e. Groundkeeper control

The Dutch have strict requirements for groundkeeper control.

f. Use of non-chemical controls as nematicides are withdrawn

The trap crop *Solanum sisymbriifolium* has shown considerable promise in the reduction of PCN populations in The Netherlands and surrounding countries but due to its requirement for a reasonably high soil temperature, to enable germination, its use is limited in more northerly climates, including the UK and Scandinavia.

In the USA G. *rostochiensis* was identified in a potato field in New York in 1941 but over the years has not spread to the extent it has in Europe and so is of less relevance than the situation in the Netherlands. However, in the USA two main strategies have been used to control PCN including i) regulation to achieve containment and ii) eradication. Initially, the growth of host crops was prohibited on infested land and only allowed if authorised by the authorities. Once resistant potatoes became available these were approved for use. Strict restrictions on the movement of all materials, including soil and any plant material from the field, have been implemented and only allowed under permit, while equipment is required to be

washed and steam sterilized before leaving infested fields or those associated with an infested field. Vegetable root crops are washed in approved facilities according to approved methods. These strict measures have successfully allowed land over time to be deregulated.

In Idaho *G. pallida* was found in 2006 but was contained to <10 fields. Again, following extensive sampling (more testing in the last decade than has ever been undertaken in Scotland), land was regulated, nematicide was used, growth of host crops was not allowed and access to the land was restricted. Following intensive eradication efforts, some potato crops were grown but PCN has been found again recently. Resistant varieties for *G. pallida* suitable for the US market are not yet available to replace the dominant variety grown in Idaho, Russet Burbank.

In Norway *G. rostochiensis* is managed by crop rotation with resistant varieties. Infestations of *G. pallida* or virulent *G. rostochiensis* (not managed by H1) found on land results in a 40-year ban on growing potatoes on that land.

In Northern Ireland land for seed production, if tested positive for PCN, cannot be resampled for at least 15 years and, if still infested after this time, is eligible to be retested every 5 years.

These examples provide an insight into the potential for official control programmes where the pest is present both in wide and more isolated areas. In Scotland, PCN has been present for many decades and can be found in all areas of the country, which is a similar situation to that found on The Netherlands. Therefore, **while regulation has an important role to play, the eradication of PCN in Scotland is not a realistic option in the foreseeable future**.

Following over 320 person hours of meetings by over 50 members of the PCN working group, together with information from the original PCN report and Ministerial round table, the following Key Challenges, Key Recommendations, Knowledge gaps and specific short-, medium- and long-term Actions have been identified and agreed by the working group.

3.2 ***Key Challenges***

PCN spread: PCN is already spreading and reducing land availability for seed and bulb production at a rate of ca 5% per year and the rate of spread needs to reduce drastically.

Industry knowledge: There is a general lack of grower / landowner knowledge and coordination related to the management and control of PCN on land for growing potatoes. There is also a lack of an underpinning knowledge exchange programme and few accessible decision support tools to help improve this knowledge.

Policy knowledge: There is no national strategy on PCN that uses available testing and other data and coordinates policies in this area.

Accountability on rented land: Much of the land for seed and ware production is rented, and there is currently a lack of awareness, coordination and accountability between growers (those that rent) and land owners or their agents in terms of PCN status and maintenance of PCN-free land.

Ware vs seed: The current differentials in the 'Risk vs Reward' equation between seed and ware production, in part due to existing PCN regulations, is incentivising growers away from seed production and towards ware production.

Groundkeeper control: Poor groundkeeper (rogue potatoes that grow in a field following a potato crop) control is enabling PCN populations, along with other pests and pathogens, to remain and even increase between potato rotations. This greatly affects the usefulness of rotations in reducing pests and pathogens in the soil. Addressing this problem requires the cooperation of farmers who may not grow potatoes.

Pesticide losses: The herbicide glyphosate is critical for groundkeeper control and, if removed through legislation, the control of groundkeepers will be made much more

> *'Should the current system continue there is a real risk Scotland will not be exporting Seed Potatoes in future years.'* - Mike Cummings, Estate Manager, Lour Farms

difficult and costly in crops where remaining effective herbicides cannot be used. There would be significant knock-on impacts to other crops in rotations to employ the cultural methods that might offer partial control. Nematicides, currently used on a significant area of Scotland against other soil-borne nematodes as well as PCN, are at high risk of withdrawal. Their loss will impact on potatoes as well as other crops, where they are also used to control free-living nematodes.

Lack of IPM tools: There is currently only a limited number of alternative IPM tools to replace or reduce existing reliance on pesticides (herbicides and nematicides) to control PCN and to aid decision support systems (DSS). Resistant varieties and DSS are also a key part of IPM (as is the targeted use of pesticides) but have been discussed separately in the report for clarity.

Lack of commercially grown resistant varieties: The number of commercially grown PCN resistant varieties (dual resistance to both species of PCN) suitable for production within the Scottish climate is currently limited and insufficient to enable the widespread adoption of control/management of PCN through the use of such varieties.

3.3 ***Four Key Recommendations***

Four key recommendations are described below with information expanded in Appendix II ('Detailed text on recommendations and actions') and summarised in Fig. 6).

A. *Increase the sector's capability and motivation to implement change*: Provide a clear plan for industry with clearly outlined options and framework, incentives and ongoing education to ensure that change occurs.

    a. *National (evidence based) strategy*: Implement a strategy to encourage a robust PCN management plan and monitor its progress.

b. *Dedicated KE and communication support package*: Develop a complete KE / communications package for the sector to facilitate change and skill development aimed at delivering for all supply chain stakeholders.

B. *Preserve the land base for future generations*: Take actions that ensure the spread of PCN into new areas is halted or reduced.

a. *Special status to PCN-free land*: Give PCN-free land special status and protect this status through effective management and the use of incentives.
b. *Grower/land-owner incentives*: Link the preservation of PCN-free land / soil to new industry incentives or conditional for receipt of existing incentives, e.g. by expanding the current list of Good Agricultural and Environmental Conditions to include PCN reduction / control. This could form part of the Scottish Government pilots of what is to replace the current CAP.
c. *Groundkeeper control*: Improve groundkeeper control through a combination of KE, effective tools and incentives.
d. *Land retesting*: Where statutory PCN testing leads to a positive result, retest in smaller defined units of land and, if below PCN detection limits, allow planting of PCN-resistant seed to produce a seed crop and to assist with the management of the problem.
e. *Commercial diagnostics*: Increase commercial diagnostic testing to ensure freedom of PCN in the years leading up to potato planting or to allow better management of PCN on infested land.

C. *Manage the epidemic*: Where the pest has been identified, a range of tools and actions need to be available to land managers (growers and/or landowners) to control and reduce PCN to manageable levels within in their soils.

a. *Introduce new dual resistant / tolerant varieties*: Evaluate recent *G. pallida* resistant varieties for suitability of production in typical Scottish soils. While new varieties could take many years to produce, those that currently exist or are close to market should be incorporated into an efficient control programme wherever possible. Such a programme may include some form of incentive related to improved land management, for example if there is lower marketable yield, and engagement and education with the supply chain as to the importance of using these varieties. For environmental and sustainable reasons, the inclusion of new plant breeding technologies, including genetic engineering, should also be considered to allow the introduction of new resistant varieties at the earliest opportunity.
b. *Decision support tools*: Test and implement existing decision support systems (DSS), e.g. NemaDecide, make then suitable for Scottish conditions and, if necessary, develop new ones.
c. *IPM tools*: Develop and test further integrated pest management (IPM) tools for PCN control with particular emphasis on trap/cover crops and soil amendments.

D. Recognise the investment needed to tackle the PCN problem

Investment will be needed to tackle the PCN problem in Scotland and protect against the downstream income losses (predicted to be £125 million farm gate value by 2040; excluding job losses and the upstream impacts on exports and the wider GB food industry), with **priorities for financing** being i) Action 3 - an extensive **programme of knowledge exchange**; ii) Action 6 and 7 - the purchase of **GPS capabilities** for potato inspectors; and iii) Action 9 - the employment of a dedicated **full-time research technician** to help accelerate the ongoing marker development work.

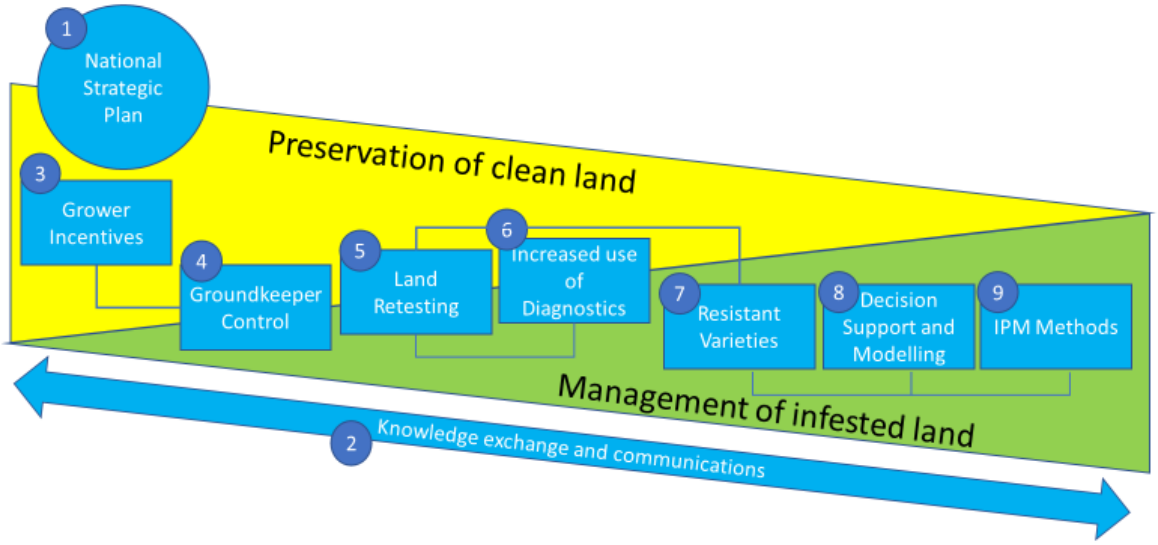


Figure 6. Diagram showing the different aspects of the three key recommendations, their linkages to each other and to the overarching aims: 'Preservation of clean land' and 'Management of infested land'.

3.4 ***Knowledge gaps***

a. *Economic benefits*: Economic benefits and consequences of implementing the different management options outlined in Actions (below) within the short, medium and longer terms.
b. *Groundkeepers*: Extent of groundkeepers in Scotland, how best to monitor their incidence, and how to control them in future, especially with the threat of the loss of herbicides such as glyphosate.
c. *Resistance markers*: The need for improved and additional molecular markers associated with multiple resistance sources (which cannot be differentiated in the field), which can be incorporated into more efficient and cost-effective formats for breeding programmes.
d. *Tolerance*: Standard and comparable methods of assessing tolerance are required to support decision making by growers.

e. *Decision Support Systems (DSS)*: Suitability of DSS NemaDecide developed in the Netherlands for use in Scotland and the availability of suitable Scottish data to validate and improve these systems or to develop new ones.
f. *Alternative IPM methods*: Application of existing IPM tools for PCN control under Scottish conditions and the development of new tools for integration into potato and wider cropping systems.
g. *Underlying causes of PCN spread*: Identification of underlying causes responsible for PCN spread in Scottish potato growing regions and the key areas for targeted intervention, e.g. farmers' knowledge, farming strategies, field hygiene, organisation at the level of the supply chain etc.
h. *Coordinated strategy*: What mechanisms are in place to coordinate PCN control across the whole of the supply chain and what needs to be put in place to support this?

'There is a lot of thought going into how PCN can be managed. This is simply not good enough for early generation seed growers. Complete freedom from PCN is the only acceptable goal for us.' - Jim Cruickshank, JS Cruickshank Farmers Ltd.

3.5 *Actions*

No.	Action	Target delivery date
Recommendation 1 – Increase the sector's capability to implement change		
Action 1	*National evidence-based strategy*: Develop a PCN Strategic National Plan for Scotland.	Apr 2022
Action 2	*Economic analysis*: Undertake an economic assessment to determine the cost to industry of no further actions being taken again PCN (current status) versus the introduction of key control options being taken, and determine the economic value of these different options being put into place.	Apr 2022
Action 3	*KE and comms programme*: Develop a 2.5 year programme of extensive knowledge exchange and communications to underpin all approaches centred around three main areas (below).	Apr 2024
Action 3a	*KE on preservation of clean land*	
Action 3b	*KE on managing infested land*	

Action 3c	*KE on introduction and commercial use of resistant varieties*	
Recommendation 2 - Preserve the land base for future generations		
Action 4	*Special status*: Introduce special status for PCN free land used in the potato rotation to allow its protection and management.	Apr 2022
Action 5	***Grower incentives***: Design appropriate (financial) incentives (or make it conditional for existing incentives) for landowners / growers to retain PCN-free land for seed production, to help manage groundkeeper control, to encourage farmers to declare when land is infested and to make use of an available DSS, improved hygiene, diagnostics and /or other control options.	Apr 2022
Action 6	*Control groundkeepers*	
Action 6a	*Groundkeeper survey*: Determine the extent of groundkeepers in Scotland using existing data at SASA and / or a farm survey.	Apr 2022
Action 6b	*Groundkeeper surveillance*: Develop protocols and better enable surveillance through purchase of improved GPS positioning	Equipment purchase by Apr 2022 with improved protocols by Apr 2024

	equipment for use by crop inspectors or use commercial suppliers (as with sampling precision – Action 7c).	
Action 6c	*Glyphosate retention*: Determine the consequences of losing glyphosate and assess the alternatives for the effective treatment of groundkeepers.	Apr 2022
Action 6d	*Groundkeeper impact*: Demonstrate the impact of groundkeepers on PCN populations to feed into a DSS and forecasting work in Actions 12 and 13.	Apr 2024
Action 7	*Retest land following a positive statutory PCN test*	
Action 7a	*Policy rule change*: Change policy rules around official PCN testing of seed land to enable retesting to free up more land for planting of dual resistant potato seed.	Apr 2022
Action 7b	*Increase statutory sampling provision*: Increase Scottish Government PCN testing provision to allow land retesting.	Apr 2022
Action 7c	*Increase sampling precision*: Increase sampling precision through purchase of improved GPS positioning equipment for use by crop	Apr 2022

	inspectors or use commercial suppliers (as with groundkeepers – Action 6b).	
Recommendation 3 – Manage the epidemic		
Action 8	*Commercial diagnostics*: Expand the provision of commercial diagnostics (with possible government-subsidy) through improved coordination of existing suppliers (e.g. SASA, SRUC, JHL) to allow PCN status to be determined (independently of statutory testing) to enable better land management, ie to determine status for incentives (and time to clean up infested land – see manage epidemic below).	Apr 2022
Action 9	*Resistance marker development*: Markers for multiple resistance sources against *G. pallida* need to be identified and converted into formats compatible with breeding programmes.	Apr 2026
Action 10	*Enhanced breeding programme*: Development of a pre-breeding programme using genomic selection between scientists and breeding companies for improved PCN resistance marker development leading to new Scottish-relevant varieties. Also consider the inclusion of new plant breeding technologies,	Apr 2026

	including genetic engineering, to make existing widely grown PCN susceptible varieties resistant. Evaluate new PCN *G. Pallida* resistant varieties for key growing crop characteristics in typical Scottish soils.	
Action 11	*Standardise tolerance testing*: Develop robust methods for comparative testing of variety tolerance possibly based on determinacy testing and determine the potential to include tolerance testing in National List tests.	Apr 2023
Action 12	*Decision support systems (DSS)*: Test existing DSS tools and their appropriateness for Scottish conditions to allow growers to integrate IPM tools, resistant varieties, pesticides and wider crop management strategies and inform their decision making (NemaDecide forms an obvious framework and could be validated with Scottish varieties, soils and climate parameters).	Apr 2024 and ongoing
Action 13	*Model PCN spread*: Determine the factors responsible for the spread of PCN using existing data sets and use outcomes to help inform the use of DSS and the development of a national strategy for PCN management.	Initial assessment by Apr 2022 with academic research on PCN biology ongoing

Action 14	*Other IPM tools*	
Action 14a	*Soil amendments*: Investigate the use of different soil amendments, e.g. chitin, and the regulations around their application to agricultural land. Undertake laboratory and field experiments to determine their efficacy for PCN control.	Apr 2024 and ongoing
Action 14b	*Cover crops / biofumigants*: As above, investigate the efficacy of these treatments as part of a sustainable farm management system.	Apr 2024 and ongoing

The diagram below (Fig. 7) gives a summary of all Key Challenges, Key Recommendations, Knowledge Gaps and Actions. Appendix III contains case studies on the current situation and future outlook related to PCN by representatives of the potato and flower bulb industries.

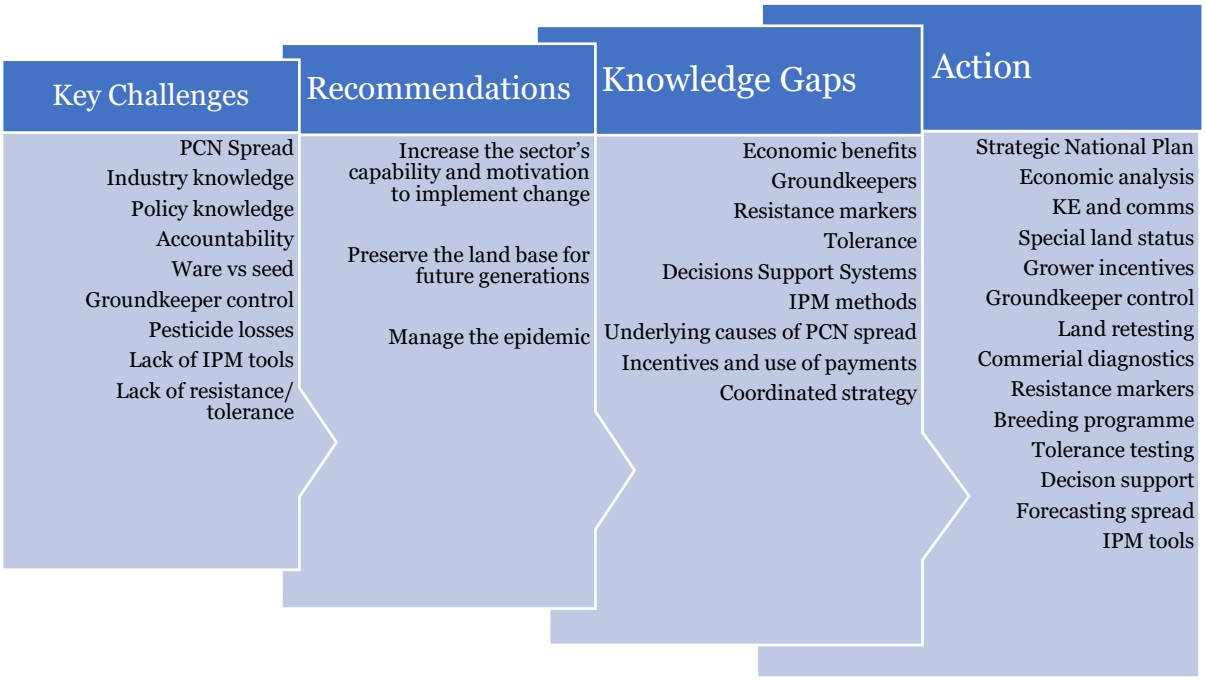


Figure 7. Summary of highlights. Diagram showing the three key recommendations to address the challenges identified in the report, together with knowledge gaps and suggested actions.

4. Appendix I: Working group participants

4.1 ***Main working group***

Lead partner Ian Toth (Plant Health Centre); Gerry Saddler, Denise A'Hara (SASA, CPHOS Office); David Kenyon (SASA); Gerard Croft (British Potato Trade Association [BPTA]), Archie Gibson (Agrico UK Ltd); Eric Anderson (Scottish Agronomy Ltd); Phil Burgess (Scottishpotatoes.org); Sue Cowgill (AHDB); Peter Grewar (A&P Grewar / NFUS); Drummond Todd (James Hutton Limited); Colin Herron (McCain Foods GB Ltd); Mark Clark (Grampian Growers Ltd); Andy Evans, Steven Thomson (SRUC); Kenneth Loads (Sefari Gateway); Yvonne Hay, John Speirs (SG Plant health policy); Mark Taylor (Fresh Potato Suppliers Association [FPSA]); Helen Glass (Scottish Agricultural Organisation Society [SAOS]); Vivian Blok, Alison Lees (James Hutton Institute).

4.2 ***Subgroup 1 – Policy and economics***

Lead partner Jon Pickup (SASA); Triona Davey (SASA); John Speirs, Debbie Kessell (SG Plant health policy); Gerard Croft (BPTA); Archie Gibson (Agrico UK Ltd); Peter Grewar (A&P Grewar / NFUS); Peter Loggie (NFUS); Mark Taylor (FPSA); Niall Arbuckle (Greenvale AP Ltd); Jim Cruickshank (JS Cruickshank Farmers Ltd); Steven Thomson (SRUC); Callum McIver (Drumderfit Farm); Carla Barlagne (James Hutton Institute).

4.3 ***Subgroup 2 – IPM and diagnostics***

Lead partner Fiona Burnett (SRUC); David Kenyon (SASA); Willie Campbell (Ferryton Farm, PBGA); Colin Herron (McCain Foods GB Ltd); Martin Cessford (Angus horticulture); Jim Aitken (Branston Ltd); Eric Anderson (Scottish Agronomy Ltd); Mike Cumming (Lour farms); Peter Shiells (Mertoun Estate Farms Ltd); Andy

Steven (Agrovista UK Ltd); Alison Lees, Peter Skelsey (James Hutton Institute), Phil Burgess (Scottishpotatoes.org); Henry Creissen, Andy Evans (SRUC); Morven Anderson (HL Hutchinson Ltd); Jim Wilson (SoilEssentials).

4.4 ***Subgroup 3 – Resistance and breeding***

Lead partner Colin Herron (McCain Foods GB Ltd); Jon Pickup (SASA); Archie Gibson (Agrico UK Ltd); Sue Cowgill (AHDB); Drummond Todd (James Hutton Limited); Vivian Blok, Glenn Bryan, Ingo Hein (James Hutton Institute), Peter Hewett (Stet Potato Ltd), Doug Harley (Cygnet PB); Mark Clark (Grampian Growers Ltd).

4.5 ***Subgroup 4 – Knowledge exchange and communications***

Lead partner Phil Burgess (Scottishpotatoes.org); Eric Anderson (Scottish Agronomy); Claire Hodge (AHDB); Helen Glass (SAOS); Paddy Graham-Jones (Albert Bartlett and Sons Ltd); Gerard Croft (BPTA); John Gordon (Rose Farm); Vivian Blok (James Hutton Institute); Kenneth Loads (Sefari Gateway).

5. Appendix II: Detailed text on recommendations and actions

5.1 ***Key recommendation A: Increase the sector's capability to implement change***

Action 1

Develop a national (evidence based) strategy

A national strategy should be developed to implement a sustainable PCN management plan for Scotland and monitor progress. While individual growers can act to reduce the risk of yield losses arising from PCN on their own land, the many interdependencies with other actors make the need for a national strategy that informs policy requirements an imperative. A national strategy should be developed using available evidence to inform on key statutory requirements, such as compulsory testing requirements, and drive to best practice behaviours through incentive schemes. A national PCN strategy for Scotland could also address the acceptability or otherwise of key PCN management interventions (minimum rotation lengths; approvals and registrations for pesticides; the place for genetic engineering in varietal resistance breeding programmes) and integrate with an ongoing knowledge exchange programme, e.g. as *G. pallida* has a longer decline rate in soil than *G. rostochiensis*, the minimum seed rotation could be lengthened in the presence of *G. pallida* from the current 1 in 6 to 1 in 10 years. There are rich data sources available from long running PCN testing programmes at SASA and other laboratory providers which can be used to evidence the relative impacts of these strategies. The national strategy should be kept under review and modified regularly, including stakeholder input and new data as it arises.

Action 2

Undertake an economic analysis

Many factors are likely to be impacted by doing nothing about PCN in Scotland, from national scale employment and economic losses to more local consequences such as land price changes and collapse of individual businesses. The PCN crisis may also adversely affect export to 3rd countries and the EU, especially following a no deal BREXIT, due to the actual or perceived threat to the quality of our seed health. Critically, the loss of just a small number of the 22 high-grade seed growers in Scotland could have a disproportionate impact on the overall viability of the industry. This could ultimately lead to major losses not just at the farm gate but to the food and drink industries in Scotland and the rest of the UK.

A preliminary economic assessment has recently been undertaken on this issue and is outlined in the Plant Health Centre's report 'The Future Threat of PCN in Scotland – PHC2018_16', where economic losses amounting to £125 m by 2040 have been predicted. However, a more detailed **economic impact assessment** is required to determine the financial consequences of PCN in Scotland on both the potato and bulb industries. This will include a cost benefit analysis across a number of factors including the **cost of no action versus mitigation**, assessment of the most cost-effective mitigations (outlined in these recommendations), the disproportionate impact on the seed industry (a higher value product and one of Scotland's premier industries) versus the ware industry, the effect of PCN spread, industry self-management of problem versus legislation and / or incentives and conditional payments, trajectory of overall net costs to industry, and cost of mitigations now versus in 5 years etc.

Action 3

Develop a knowledge exchange and communications programme

A national programme with local delivery addressing the future threat of PCN in Scotland.

Knowledge exchange (KE) aims to deliver the change that is required by the potato sector to ensure that the future threat of PCN in Scotland is addressed; sustainably protecting the land base for future generations and all sector stakeholders**. KE needs to both underpin and form an integral part of other areas of activity to ensure effective IPM tool development and implementation to benefit the sector**. A programme of knowledge exchange will be undertaken to incorporate organisations such as Scottishpotatoes.org, Scottish Agronomy Ltd., AHDB etc., where applicable. Consistent messaging that delivers targeted information to differentiated stakeholders will deliver the change in behaviours required. For example, the process will include areas such as:

- Identify what will be improved
- Present a solid case to stakeholders
- Plan for change
- Provide resources and data for evaluation
- Communication
- Monitor and manage resistance to change
- Review and revise
- Celebrate achievement

An active pipeline of tools and policy activity over a significant period will be required to support this change. The activity needs to be supported by an active and consistent communications programme that strengthens the message and ensures continued engagement, as outlined in Fig.8.

The longevity of PCN and the apparently 'slow' epidemic combined with the requirement of businesses to deliver short term financial returns provides a unique challenge for KE practitioners. However, with an honest recognition of these challenges and the importance of getting this right for future generations, a holistic and focussed programme can deliver change. The fact that this sector needs to co-exist with a domestic ware production sector is providing further challenges to sustainable delivery.

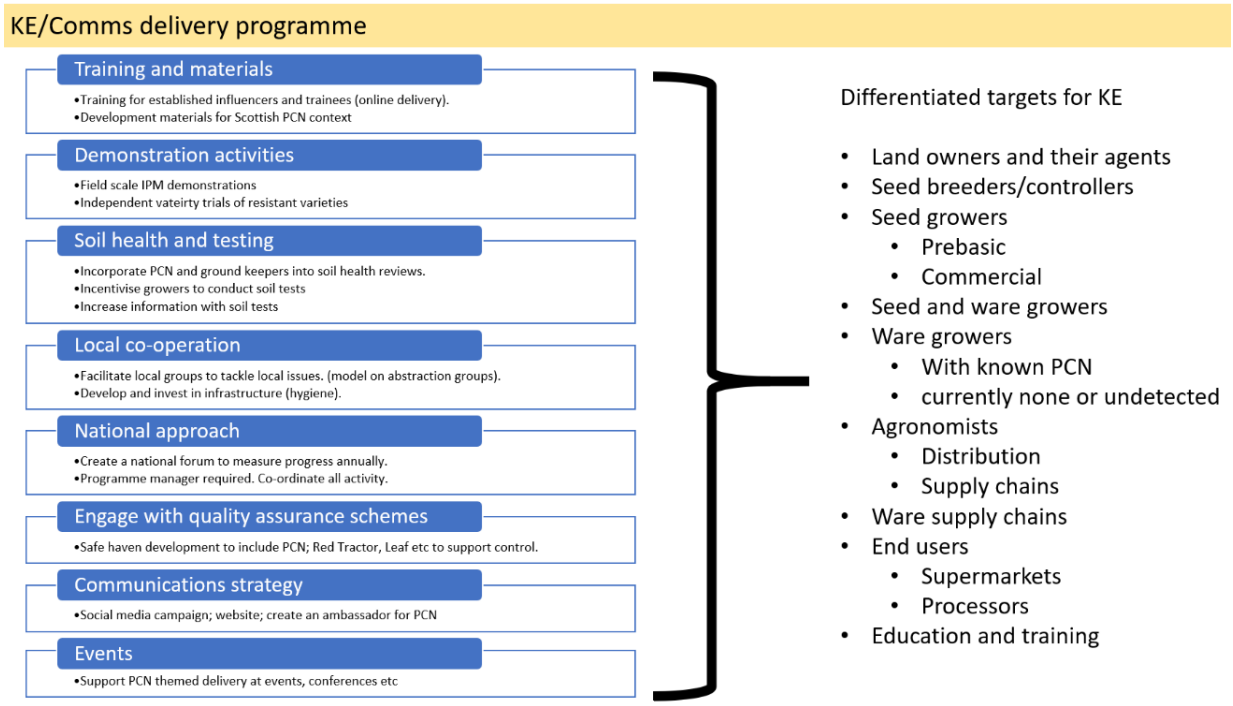


Figure 8. A national KE and communications programme with local delivery addressing the future threat of PCN in Scotland.

Three priorities areas for Knowledge exchange

There are three interlinked priority areas for KE that are recommended for action. The main areas of activity within each priority area are listed and will form the focus of activities. Each will draw upon actions and activity taking place within other sections of the KE plan. The areas of activity within each priority area should not be considered exclusive, with overlap between priorities, and the necessity to use 'all tools in the tool-box' to drive activity.

Priority 1: Protecting the land base

Main KPI: Preventing the erosion of, and over time increasing, the land base available for seed production. NB Opportunities for reducing PCN populations mostly occur when potatoes are grown so, with a 5-6 year rotation, there is an inevitable time lag before this KPI can be applied.

Groundkeeper control (Policy and IPM dependencies): Provide technical solutions to groundkeeper control to enable growers to follow policy guidelines/requirements and best practice. Currently there are few new solutions or incentives.

Soil sampling: Detection (Policy, IPM). Identify fields at risk before statutory testing. Incentivise and encourage commercial high volume PCN soil testing. Testing capacity, capability, cost and policy driven consequences all require addressing to delivery improvements.

Decision support: Modelling spread of the pest (IPM, Policy). Use of databases and models can be used to identify at risk areas. These models require embedded KE objectives during development to ensure maximum value and incorporation into grower action plans.

Hygiene: Theory and practice (IPM). Identify high risk practices and provide practical solutions.

Priority 2: Controlling the epidemic

Main KPI: Recording a reduction in the number of eggs per gram in contaminated soils.

IPM control strategies (Chitin, bio-fumigation and trap crops) (IPM dependency): Providing best practice guidance on implementing strategies within a full crop rotation, helping to retrain growers in the use of foundation strategies including agronomy, rotations, resistant varieties and DSS before last resort solutions such as nematicides.

Modelling epidemic development (IPM): Using newly developed modelling information to develop appropriate control strategies and assist with KE. Development of these models requires embedded KE objectives to ensure maximum value and acceptability.

Soil sampling – quantification: Ensuring all growers test for PCN following standard protocols and act appropriately upon the information received.

Priority 3: Introducing new resistant varieties

Main KPI: Varieties resistant to PCN, particularly *G. pallida*, accounting for significantly increased proportion of both seed and ware production.

New varieties: Introducing new varieties for (a) Seed and (b) Prepack ware and salads (IPM, Research and Policy), requiring the provision of information supporting the introduction of new 'resistant' varieties to supply chains, which goes beyond PCN issues and to their suitability for Scottish production conditions. Working with all stakeholders to ensure uptake and market/consumer acceptance of such improved varieties.

Resistance and tolerance characteristics: Understanding these characteristics in varieties (IPM, Research).

Understanding resistance and tolerance: Providing the knowledge for growers and advisors to understand the differences between resistance and tolerance and to ensure appropriate use within a complex IPM landscape.

Delivery model for knowledge exchange and communications

The proposed model aims to deliver on a well understood, long term integrated national strategy for the future control of PCN. This national approach would be combined with locally focused and appropriate delivery, which recognises that the management of PCN is a complex subject for individual stakeholders active within potato supply chains. Targeted delivery solutions would be developed for different groups, specifically aimed at their particular situations and based on the best available evidence. Over time the messaging would develop as new tools become available through the concerted research and IPM efforts proposed for PCN. As new tools and developments become available, the messaging would be refreshed and renewed.

Blending the three priority areas, the delivery model seeks to engage with the entire supply chain to understand and react to the drivers that impede change. It is

understood that circular engagement with all stakeholders is required. Landowners, colleagues and professional trainers, agronomists and supermarket supply chains all play a significant part in the development of a sustainable future and will be included in the KE programme alongside the differentiated grower base. Interactions between the different groups will be necessary as management solutions are developed.

Local management groups will be formed and supported to deliver sustainable PCN management solutions locally. This will ensure that the strategies developed in different areas are appropriate for each local situation, enabling different strategic themes to develop as appropriate in different areas. Some local areas would concentrate on 'protecting the land base' (e.g. Inverness-shire) while others would work to 'control the epidemic' (e.g. Angus or areas within Angus). These local groups would be supported by other engagement and communications activities with variety demonstrations, events attendance, social media presence and other activities.

Alongside this local engagement, end user stakeholders (variety breeders and maintainers, prepack suppliers, supermarkets) would be actively engaged to bring about change from the 'top down' complementing local groups making changes from the 'bottom up'.

Management of KE delivery programme

It is proposed that to bring the full programme together, combining the national strategy with local engagement and delivery, **a full time "Knowledge exchange manager" or "PCN Programme ambassador" is required**. Over a period of several years this post would develop and deliver the strategic management plan for addressing the future threat of PCN in Scotland.

The postholder would need to be supported from the policy, research and advisory organisations directly involved in the delivery of this programme. SASA, Scottish Agronomy Ltd., SRUC and JHI being the most significant although engagement with other bodies such as AHDB would be essential. Several options could exist as to how the post would be managed, including the use of PHC and scottishpotatoes.org (an existing partnership between SASA, SRUC and JHI).

5.2 Key recommendation B: Preserve the land base for future generations

Action 4

Afford special status to PCN-free land

Scotland is internationally renowned for its high health seed potato production and consequently has vibrant GB and international markets. To expand these markets and maintain our high health status, it is vital that PCN-free land remains available. However, currently it is being lost at ca 5% a year, which is already having a negative impact upon seed producers (see case study #1). By recognising PCN-free land that is used to grow potatoes, for example through the use of incentives, the decline rate of suitable seed land can be slowed or stopped to ensure a vibrant future for our seed industry.

Action 5

Tie PCN-free land status to grower incentives

There are currently few incentives to prioritise the use of land for growing seed over ware. Indeed, the statutory requirement to test land for PCN prior to seed production could arguably be a disincentive to the use of land for seed production. Consequently, land that is free from PCN, including land that has been without potato production for 10-20 years, is currently not prioritised for seed production. To address this situation, a change in legislation is required to utilise farm support to reward growers/land-owners with suitable PCN free seed land and/or penalise those growers/land-owners with PCN infested land that fail to implement a recognised PCN management program. It is hoped that by introducing such an incentive landowners and growers will make better use of available decision support tools, improved hygiene (especially when moving soil and large machinery between sites), expanded diagnostic testing and other control options.

Action 6

Control groundkeepers

Groundkeepers are responsible for helping to maintain PCN populations, as well as providing an inoculum source for other potato pests and pathogens. Groundkeeper control is an ongoing issue for potato growers, compromising the health and quality of crops. A reduction in groundkeeper occurrence, through support for better control, would have a major impact on the presence of PCN (and other pests and pathogens). We also recognise the need for retaining the tools to control groundkeepers, for which continued access to the herbicide glyphosate is a very high priority. Legislation could be changed to utilise farm support to reward growers for groundkeeper control or aim to with-hold support for non-compliance. To enable inspectors to be able to accurately locate groundkeepers, improved GPS technologies are needed, as well as the software to allow transfer of data from GPS devices onto the SPUDS database (or to provide support for this to be undertaken by commercial suppliers).

Action 7

Retest and expand the use of PCN infested land for seed production

Current EU legislation dictates that land for planting seed is pre-tested for the presence of PCN. This is currently done on a ca 4.5 ha basis. If PCN is detected on any of this 4.5 ha the whole area is removed from seed production. If the spatial distribution of those PCN-positive samples within the 4.5 ha could be more precisely determined, more land could be freed up for seed production, although this would be limited to the cultivation of resistant varieties only, thus improving PCN control. This would move Scottish policy closer to that adopted in The Netherlands, where such land retesting is a cornerstone of their PCN control strategy (see section 2.1). This cost would also support the requirement for GPS testing in Action 6 (Groundkeeper control).

A consultation would take place with the industry to agree such a change. Following a standard statutory test on a 4.5 ha area (400 ml soil/ha), on finding a positive result the soil would be resampled 1 ha units (1500 ml soil /ha - equivalent to 400ml / 0.25 ha) to identify infested / non-infested units, i.e. ca 4 x more intensive sampling. This testing would be a part of SASA's statutory testing (in that results generated would be tied to legislation) but carried out following voluntary agreement and would be paid for at commercial rates with/without subsidy.
Infested units – seed production remains prohibited (and preferably a dual resistant ware crop is grown).

Uninfested units – seed production is permitted but only for varieties with dual resistance to both species of PCN.

Where a grower is confident that infested land (positive test) has been cleared due to control measures being undertaken, there is also the possibility of withdrawing the statutory interval for a retest on PCN positive land down from 6 years.

As with groundkeeper control, the introduction of improved GPS technologies (hardware) to field inspectors would allow them to accurately monitor field locations. In this case, to divide land found to be infested down from 4.5 ha block to 1 ha strips and further to 0.25 ha blocks and even 10m x 10 m areas for accurate sampling. There would also be a requirement to ensure that data from GPS equipment was able to feed into the SPUDS database (either remotely or back at base). While such field locations for sampling can currently be assessed accurately through limited commercial collaboration, e.g. SoilEssentials Ltd., SG inspectors do not have these capabilities.

A current collaboration with commercial partners, SoilEssentials Ltd., Scottish Agronomy Ltd. and SASA is looking at the effect of using *G. pallida* resistant varieties on soil test results and trialling the proposed sampling and testing aspects of this proposal. The changes in available land for seed production following retesting would be modelled as part of the economic assessment for different PCN mitigation measures.

*5.3 **Key recommendations C: Control the epidemic***

Action 8

Set up an improved and cost-effective commercial diagnostics service

SASA currently undertakes statutory PCN testing of fields immediately prior to seed planting, the latter of which is prohibited following a positive result. This pre-planting testing removes the possibility for the grower/ landowner of cleaning up infested land in preparation for seed planting. The use of earlier testing, possibly even as potato is lifted from the ground a rotation earlier, would allow potential mitigation strategies to be implemented in the intervening years.

To determine the PCN status of such land, further diagnostics are required in addition to statutory testing. While these **diagnostics are likely to be commercial, there may also be a case for some government financial support** for tests undertaken. Commercial diagnostics for PCN are currently available in Scotland but are limited and a higher throughput and more coordinated approach across providers is required.

This action looks to set up a PCN testing service across providers, e.g. SASA, SRUC, JHL etc., who are in principle willing to cooperate. Other commercial labs exist and may provide additional local or GB capacity. These tests would be undertaken at the discretion of the grower / landowner and may be linked to special status / incentives / groundkeeper control / land retesting and knowledge exchange (Actions 3-7).

Action 9

Development resistance markers for G. pallida

The long-term sustainability of the sector is primarily dependent upon the availability, introduction and market acceptance of new varieties that combine resistance sources (against both species of PCN) that are also tolerant to PCN.

Although some *G. pallida* resistant varieties are available, many of these are not suited to Scottish growing conditions and few combine dual PCN resistance (against both species of PCN) with other desirable traits. However, some initial evaluation is currently being undertaken by Scottish Agronomy Ltd., and it is important that such trials continue and expand.

G. pallida present in GB is more genetically complex than *G. rostochiensis*, which may determine the effectiveness of this resistance. It will therefore be important to combine multiple sources of *G. pallida* resistance with the existing *G. rostochiensis* resistance (provided by the H1 gene) for PCN resistance to be durable.

Molecular markers associated with resistance are of critical importance for breeding PCN resistant varieties. While it is possible to use PCN resistance screening in a glasshouse / field when breeding for a single resistance source, it is not possible to use such screens when combining multiple sources of *G. pallida* resistance, as the resistance observed is the same whether an individual source or both sources are present. Robust markers are available for H1 (against *G. rostochiensis*) but markers for *G. pallida* resistance sources have proven more elusive, although two markers for resistance to *G. pallida* are available. However, development of such markers in a form suitable for incorporation into commercial breeding programmes remains a priority.

The industry also requires "future proofing" through the identification of further resistance sources against PCN from the Commonwealth Potato Collection (CPC). Modern mapping techniques, pioneered at the James Hutton Institute, allow new resistance sources to be mapped rapidly and the genes underlying that resistance to be identified, greatly facilitating their introduction into breeding germplasm. Continued investment in identification of new PCN resistance sources within the CPC is therefore required.

Action 10

Enhanced breeding programmes for dual species resistance / tolerance

PCN resistance alone will not ensure that a cultivar is taken up by the industry. There is therefore an important market opportunity for varieties that combine durable PCN resistance with other desired traits, including tolerance to PCN infection. Tolerance is a genetically complex trait and one that is influenced heavily by environmental factors. A lack of tolerance within a variety, in the absence of effective nematicides, could therefore be a barrier to the future uptake of new resistant varieties. However, tolerance is of greater concern for ware than seed production as it protects crop yields in soils heavily infested with PCN. It is therefore likely to be suited for incorporation into a genomic selection programme along with other complex traits (requiring more than one gene / marker), e.g. yield. There is an opportunity for an academic/commercial partnership to form a pre-breeding consortium in the area of genomic selection that can be combined with other efforts, ongoing in the SRP and through external funding, to develop molecular markers for PCN resistance sources. The inclusion of new plant breeding technologies, including genetic engineering, could also be considered to enable widely grown but *G. pallida* susceptible varieties to be made resistant.

Action 11

Standardised tolerance testing and investigate national listing

Recent data from AHDB has shown a link between the determinacy of a variety (N determinacy group - to determine N fertilizer recommendations) and the number of leaves on the main axis of the potato plant (AHDB project 11140044). More recently, this measure of determinacy has also shown a possible link to PCN tolerance. Traditionally, tolerance has been very difficult to assess with any accuracy often relying on observations in fields with PCN infestation (which remains an important part of tolerance testing). It is also carried out by individual breeders, which means that there are no national standards or universally accepted methods of testing for

tolerance. There is thus a need to extend the previous study comparing tolerance with the relatively straight forward and largely reproducible determinacy score to evaluate options for developing a rapid, reliable test of variety tolerance. In addition, it is also important to investigate the barriers to including tolerance on the UK National List (a database on GB-certified potato varieties that have undergone independent resistance testing for key pests and diseases) in order to standardise methods and provide an independent view on variety tolerance to PCN.

Action 12

Test and roll out decision support systems

Decision support systems (DSS) provide growers / landowners with the means to determine the most appropriate actions to take for any given situation. A DSS for PCN, previously developed at JHI, and for many years hosted on the AHDB Potatoes web site, has been a useful education tool but lacks updated information. Developing a model based on available data to inform and improve a DSS at a national level is an important next step. It is therefore necessary to use existing Scottish data, e.g. in the SPUDS database and elsewhere, to model the spread of PCN in Scotland and determine its use for a DSS.

There is also a need for DSS which allow growers to integrate sustainable management / IPM options on farm. A second tool called NemaDecide, developed by the Dutch and based on their nematodes, soils, environments and varieties etc., is available commercially but has been used little in Scotland due to its Dutch focus. The use of Scottish data and its modelling to help predict future spread, should be exploited to validate NemaDecide or to develop an additional DSS for Scottish conditions. This would ensure accuracy of the DSS for Scottish varieties, rotations, agronomic practices, geographical information and climates. This could be linked to a range of parameters including soil type, biofumigant crops or trap crops, nematicide application, integrated pest management, satellite and drone imagery and ultimately yield and tuber size distribution information.

An ongoing trial will be extended by Soil Essentials Ltd. and Scottish Agronomy Ltd. with an increased number of growers / landowners. The focus is on addressing the challenge of PCN in the Scottish potato growing sector by facilitating an operational group to evaluate the potential of NemaDecide for the management of PCN to help facilitate decisions in reducing the PCN population within the seed potato crop rotational cycle. The program enables advisors to prepare advisory reports with tables, graphs and comparisons for practical use by the grower. NemaDecide has been used in The Netherlands since 2006. It can make calculations for mixed infestations of the two PCN species. It also supports the management of root-knot nematodes and root-lesion nematodes. The effect of decisions regarding crop rotation on control measures, nematode development and yield loss are presented in a user-friendly manner. This activity would be fully integrated into the knowledge exchange programme (Action 3).

Action 13

Forecast PCN spread

As part of the research undertaken for the Plant Health Centre's report 'The future threat of PCN in Scotland' it was possible to determine how PCN has spread in different regions of Scotland to this point, and how future increases may affect the economics of potato production (Fig. 3). However, it is also important to determine how, when and where PCN will spread in the future to determine the risk of spread between different regions, as well as the factors most responsible for that spread.

Cost: Initial study funded by the PHC at a cost of ca £50K, with further work being carried out on the SRP and through external funding.

Action 14

Develop and test integrated pest management (IPM) tools

While the most common treatment against PCN has been the use of control chemicals (nematicides), many of these are in the process of being withdrawn following EU legislation, to the point where few products are now available. Without these products it is essential that other effective solutions are identified as part of an IPM approach. Diagnostics, resistant varieties, DSS, PCN spread forecasts (Actions 8-12) and the strategic use of any available pesticides play a vital role in IPM. However, other alternative methods may also be of use and some of these will be investigated further, with potential for enhanced / accelerated studies through the use of the Advanced Plant Growth Centre (APGC) at the James Hutton institute.

Replicated commercial field trials using **chitin compost** will investigate its role in reducing PCN populations in the soil. This work will be done in light of an ongoing PhD studentship at SASA/ University of Edinburgh investigating the role of chitin metabolising microbes on PCN viability, and an imminent review on chitin treatment being undertaken at Harper Adams.

Cover crop / biofumigant studies will also be carried out including i) Biofumigant work currently taking place at SRUC, ii) An evaluation of glucosinolate and isothiocyanate profiles of commercially available biofumigant crops and an impartial database of biocidal isothiocyanate profiles from commercial varieties marketed as biofumigants, iii) Cover crop trials within ongoing sustainable crop management research at the Centre for Sustainable Cropping (CSC) at JHI, iv) Testing of new and novel solanaceous trap crops such as *Solanum chenodioides*, which is currently being evaluated by Scottish Agronomy Ltd., Harper Adams and H.L. Hutchinsons, and v) Testing the efficacy of waste brassica extracts for chemicals that could target PCN, and therefore act as biofumigants, for potential commercial field treatment as part of a circular economy approach.

Ongoing commercial studies using other treatments have shown some promise in controlling pests and pathogens both through their direct action and by strengthening the plants defence system and overall vigour. Funding is currently

being sought at the Hutton to determine the efficacy of other soil treatments against PCN both in the laboratory and through field trials.

5.4 Key recommendation D: Recognise the investment needed to tackle the PCN problem

The damage that PCN is causing the potato and bulb industries is already impacting production and economic prosperity in Scotland but over the next 20-30 years this problem is predicted to grow at an alarming rate to the point where it is estimated to result in the **loss of half of the current value of the Scottish potato industry by 2040** (a loss of £125 million farm gate value - excluding job losses and upstream impacts on exports and the wider GB food industry), and the possible **end of future seed potato and bulb production across the whole of Scotland by 2050**.

The participants in this working group have recognised the need to act now to prevent these losses by industry, government and science coming together to identify and implement solutions. The actions within the report highlight possible solutions from the working group but all have an associated cost. Some actions are currently unfunded, while others are fully or partially funded and are ongoing. **The most pressing action that requires funding is a comprehensive Knowledge Exchange and communications programme**, which is vital to deliver change required by the potato sector to ensure that the future threat of PCN in Scotland is addressed. Potential new legislation (e.g. to better management of groundkeepers and land retesting) will mean that inspectors require **funding for GPS equipment** to identify and track field locations. This may also be achieved using commercial services, which would also require funding.

The SRP will play an important role in providing funds to continue research on IPM methods and PCN resistance markers but the resistance aspects would be significantly accelerated by the involvement of a dedicated **research technician**. A request has also been made to RESAS for work within the SRP to undertake an

economic evaluation of the 'do nothing' approach versus specific actions. Other costs will come from small projects through the Plant Health Centre, which has already committed funds to both the role of the soil amendment chitin in PCN suppression and a modelling exercise to predict future spread of PCN in Scotland. External funding will also be sought for other areas of research including other amendment trials.

We would ask Scottish Government to consider whether incentives for the preservation of PCN-free land can be built into new or existing legislation, e.g. forming part of the Scottish Government pilots of what is to replace the current CAP.

Finally, there is a need for commercial diagnostic laboratories to work together and fund a joint initiative to develop a fit for purpose, high capacity diagnostic service for PCN in Scotland (for which the Scottish Government could provide subsidy to encourage testing). The bringing together of commercial breeding companies and academics to initiate a joint breeding programme will help to develop a pre-breeding programme for the accelerated roll out of new Scottish-focussed resistant varieties.

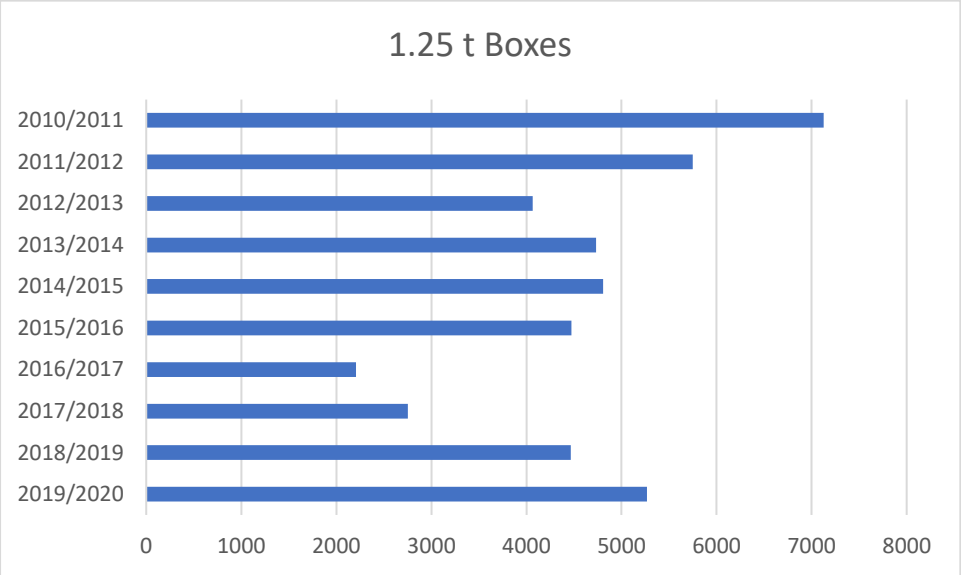
6. Appendix III: Case studies

6.1 ***Case Study 1 – Archie Gibson, Executive Director, Agrico UK Ltd***

Agrico UK Ltd are a wholly owned subsidiary of Agrico BV a Dutch owned farmers' cooperative. Our Mission is to understand our customers and consumers thus ensuring we are a reliable partner in the supply of high-quality seed potatoes of varieties optimised for the UK domestic and international markets. Agrico first opened an office in Ely, Cambridgeshire before relocating to Castleton of Eassie, near Glamis, Forfar, Angus in the 1990's. Our vision is to deliver the highest quality certified seed potatoes to our customers. There are various determinants that help deliver this Vision, including Scotland's status as a protected region, the internationally recognised reputation of growers who are known for their expertise and the tradition of producing high quality certified seed. These elements are complimented by healthy soils and the highly respected management of the seed potato classification scheme (SPCS) run by SASA.

Agrico service ca 7% of the UK demand from crops grown in Scotland in addition to production in England and imported seed from the near continent. We have an 8000-box store at Castleton of Eassie, Glamis. Our storage facility is available to growers in West Perthshire, Angus and Kincardine, to store certified Safe Haven accredited seed crops prior to grading and despatch.

In April 2010 a new EU protocol for soil sampling to test for PCN was adopted. In the years following the introduction of the new testing regime we noticed the effect of positive PCN tests on availability of clean land suitable for seed crops. The graph below illustrates the initial downturn in the availability of clean land expressed in numbers of boxes coming into our store. In Angus alone over 11.5% of schedule seed land is adversely affected by low levels of PCN contamination. As a notifiable pest this disqualifies the field from being used for certified seed production but, critically, still allows ware crops to be grow providing control measures are agreed with SPCS.



After analysis of our production area and discussion with our growers it was apparent that the main reason for the decline in the volume of crop being stored was as a result of fields being de-scheduled, PCN (G. *pallida*) having been detected. This decline is further influenced by a number of additional factors including; crop rotations, size / availability of fields, ware growers taking on de-scheduled land, the activity of agricultural contractors and flooding, all contributing to the spread of PCN, hence its increased level of detection.

Our experience reflects the 4% decline in seed production over the last decade in Scotland. This being a national average it does not reflect regional variances as illustrated by the situation in East Perthshire, Angus & Kincardine. The projection is that unless proactive measures are taken to manage the risks from the PCN pest then it will become a threat to future livelihoods and potentially farming businesses. If the local situation continues to decline and the volume of certified seed crops coming through our premises continues to fall then the storage element of the business becomes economically unsustainable, which will likely lead to restructuring and reductions in the numbers of employees.

6.2 Case Study 2 – Mark Clark, Managing Director, Grampian Growers Limited

Grampian Growers (GG) is a farmer owned cooperative established in 1968 and is based in Angus. GG specialises in the production, packing and marketing of seed potatoes, daffodil bulbs and daffodil flowers. The £13 million T/O business relies on 100% of seed potatoes and 90% of bulbs being grown on PCN free land. As yet to be agreed, SASA/Scottish Government are interpreting the rules post 31st December that 100% of bulbs grown in the UK destined for the EU will be required to be grown on PCN free land. With the predicted exponential increase in G. *pallida* and already high levels of G. *rostochiensis*, within 20 years the UK's leading exporter of daffodil bulbs and one of the top 5 exporters of seed potatoes will cease to exist. GG employs 30 fulltime staff and a further 30 to 50 seasonal staff depending on the product season.

6.3 Case study 3 - Mike Cummings, Estate Manager, Lour Farms

A business either goes backwards or forwards, it never stands still. The same is true of the Scottish Seed Potato industry. To advance & develop, it is essential that the industry has the ability to invest in new technologies & capital infrastructure to maintain its renowned high regard both within the UK sector & foreign markets. In the face of increasingly disproportionate capital costs, such investment is becoming ever more challenging as the industries lifeblood, PCN free land, is restricted. At Lour I am acutely aware we need to expand our seed production area in order to maintain our status within the industry. In growers' eyes, the move away from physical PCN counts to DNA testing in recent years may have contributed to a well-documented severe effect on land availability.

At Lour, we have ongoing access to rented land containing occasional blocks scheduled as "low incidence/localised" for *Pallida* that upon independent old-school physical count testing has proved entirely clear. We have been growing *Pallida* resistant varieties for years. Given the forecast impact of PCN of the Scottish Seed

industry, surely there could be a way to utilise these varieties combined with an alternative sampling approach on such land parcels to allow seed production? We need our Scottish statutory bodies to firstly be more commercially aware, accept the current system is not fit for purpose, stop the endless talking & adopt a new strategy incorporating *Pallida* resistant varieties and other evolving technologies. Should the current system continue there is a real risk Scotland will not be exporting Seed Potatoes in future years.

6.4 ***Case study 4 -Jim Cruickshank, JS Cruickshank Ltd.***

To be honest PCN is well down the list of challenges that threaten my potato growing business – TODAY. We grow early generation seed on long rotation intervals in an area which historically has been recognised as a seed area, and where most potato production has been subject to PCN control over the years through the seed certification system. We are in the fortunate situation where our test results show we do not have a PCN problem – so why should I worry about PCN?

In the short term - what remains of my lifetime - I do not foresee a problem locally, but we are producing seed from mini tubers which will be multiplied up for many years to come so we have a responsibility to ensure that this input seed carries as little disease as possible. There is a lot of thought going into how PCN can be managed. This is simply not good enough for early generation seed growers. Complete freedom from PCN is the only acceptable goal for us.

We know that the area of PCN contaminated land in Scotland is rising each year, and as demand for clean land increases so does the disease pressure on it. Both seed and ware industries are dominated by large growers travelling unprecedented distances to rent land. The potential to spread PCN throughout the country has never been greater.

In our own growing operation, we have a fundamental rule. We only buy in seed in the form of mini tubers, which we are satisfied to be PCN free. We then have a closed multiplication system so the threat from seed should be zero. The only threat is from

field contamination and we rely heavily on the SASA sampling for reassurance. After all is said and done the test only guarantees that nothing was found in the sample, not the whole field, so we all need to do what we can to make sure that any undetectable infection stays that way. Movement of soil on machinery between fields and groundkeeper control are only two examples of opportunities for the spread of PCN. There are many more which will hopefully be highlighted in this PCN report and the actions that follow from it.

If we as an industry continue to ignore the warning signs, we will land in a real PCN mess, and our short-term gains will result in long term pain. On a more optimistic note, as our grandmothers used to say, if we put in the effort now “a stitch in time saves nine”.

7. Glossary

Biofumigant: Use of a plant to release chemicals into the soil which suppresses soil-borne pests and pathogens. See glucosinolate, isothiocyanate and cover crops below.

Cover crop: A non-commercial crop that covers the soil to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife.

CPC: Commonwealth Potato Collection housed at the James Hutton Institute – a collection of 1500 accessions of 80 wild and cultivated potato species.

Cyst: The swollen, chitin-strengthened body wall of a female nematode that contains and protects around 400 eggs for up to 40 years (see front over image).

Decision Support System: A tool used to support management decisions, e.g. PCN decline rates in soil, agronomy practices etc. This can range from a simple in-field tool to a sophisticated computer model.

Determinacy: A test to determine nitrogen (fertilizer) application based on the number of leaves on the main axis of a potato plant.

Diagnostic: A test to determine the level and species of PCN in a sample.

DSS: Decisions Support System.

Farm gate value: The value of a product leaving the farm.

Farm-saved seed: Seed retained by the grower to plant on farm.

Genomic Selection: A method of breeding that associates a desired property with a genetic fingerprint for rapid analysis.

Genetic engineering: Modification of an organism's characteristics by manipulating its genetic material in this case to develop a PCN resistant potato plant.

Globodera pallida: The white potato cyst nematode.

Globodera rostochiensis: The golden potato cyst nematode.

Glucosinolate: Produced by biofumigant plants to suppress soil-borne pests and pathogens in the soil.

Glyphosate: A herbicide used to treat groundkeepers and other unwanted plants (weeds) in agriculture and other sectors.

GPS: Global positioning system.

Groundkeeper: Rogue potatoes that grow in a field following a potato crop, also known as volunteers.

H1 gene: A gene in potato conferring resistance to PCN species *G. rostochiensis*.

ha: Hectare – a metric unit of area equivalent to 2.47 acres.

High grade seed: Potato seed produced during the early stages of the SPCS.

IPM: Integrated Pest Management.

Isothiocyanate: Produced by biofumigant plants to suppress soil-borne pests and pathogens in the soil.

KE: Knowledge Exchange.

National List: A database on GB-certified potato varieties that have undergone independent resistance testing for key pests and diseases.

NemaDecide: A decision support system for PCN developed and used in The Netherlands.

Nematicide: A pesticide active against nematodes.

New plant breeding technologies: Methods allowing the development of new plant varieties with desired traits by modifying the DNA of the seeds and plant cells.

PCN: Potato Cyst Nematode

Pre basic: High grade seed potatoes that appear in the early stages of the SPCS.

Resistance: For PCN, this is the ability of a potato variety to limit the reproduction of the pest.

Resistance marker: A piece of DNA associated with a particular property, such as disease resistance, allowing a rapid assessment of whether a plant has that property based on the presence of the DNA (marker).

Soil amendment: The treatment of soil with a substance to improve or change its properties, in this case to reduce the presence of PCN.

Solanum chenopodioides: A plant that is being tested as a trap crop to attract PCN and therefore remove it from the soil.

Solanum sisymbriifolium: A plant that is resistant to PCN and used as a trap crop to attract PCN and therefore remove it from the soil.

SPCS: Seed Potato Classification Scheme

SPUDS: Database of Scottish seed and ware crops held at SASA as part of the SPCS.

SRP: RESAS Science Research Programme by which Scottish Government funds its agricultural research institutes.

Tolerance: The ability of a plant to prevent or recover from damage caused by pests and to produce a yield. For PCN, it can be affected by the population level of the pest as well as the availability of water and nutrients in the soil.

Trap crop: A plant that attracts agricultural pests, usually insects, away from nearby crops and/or helps to remove them from the soil.

Potato Cyst Nematode (PCN) and the future of potato production in Scotland
Report of the Scottish PCN working group November 2020

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Images on Front Cover: Female potato cyst nematode containing eggs courtesy of Vivian Blok (James Hutton Institute); Desiree tuber with both *G. rostochiensis* and *G. pallida* females courtesy of Eric Anderson (Scottish Agronomy Ltd.).