Importance of glyphosate use in Scotland

1. The use of glyphosate is an important component of both weed control programmes (in crop production, amenity, forestry and natural environment settings) and in relation to arable crop desiccation. Scottish arable crops, and in particular cereals, are heavily reliant on glyphosate for desiccation, to a much greater extent than in other parts of the UK and Europe.

2. In Scotland, a large proportion of the cereal crop area is treated with glyphosate and pre-harvest applications (which are primarily for crop desiccation) account for around 80% of use. This is a unique use pattern within Europe, and is primarily influenced by the wetter, cooler Scottish climatic conditions and shorter growing season necessitating chemical desiccation to a greater extent than in drier, warmer areas of the UK and Europe. Use of a chemical desiccant ensures even ripening without dependence on optimal weather conditions, and is more cost-effective, and associated with significantly less energy use, than drying grain post-harvest.

3. If authorisations for glyphosate were lost, there would be a major detrimental economic impact on the Scottish rural economy. A recent Scottish Plant Health Centre report estimated that the worst-case scenario impact of glyphosate loss would equate to an annual loss of output value of £51.2 million to the Scottish arable sector. The report also references that loss of glyphosate would be estimated to have an impact on the UK amenity sector of over £200 million per annum.

NFUScotland

Minutes

Date of meeting : 13th December 2021
Time : 09:30-10:30
Venue : Zoom
Committee : Scottish Voluntary Initiative
Present : [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED],
Apologies : [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED], [REDACTED]

ITEMS FOR DISCUSSION

1. Welcome from Chair, [REDACTED]
2. Apologies were received from those noted above. [REDACTED] is retiring from the Scottish Government in February, he has passed on his thanks to the Scottish VI members for the work they have carried out over the years and wishes them all the best for the future.
3. Update on Actions from previous meeting:
   - **Recruitment of Scottish VI Champions:** [REDACTED], a farmer from Strichen, has been recruited as the newest Scottish VI Champion. There was discussion around recruiting a farmer from south-west Scotland/D&G to get better representation from the grassland sector.
     - **Action: [REDACTED] to circulate recruitment advert (included in email attachments) and members to circulate to those they think would be suitable.**
   - **Update on VI website:** [REDACTED] gave a tour of the new VI website, available here: https://voluntaryinitiative.org.uk/. He explained the different sections including news and events, IPM plans and a focus area on grassland, with the aim of improving uptake in this sector. The website is now more colourful, has longer scrolling pages and is mobile friendly.

- While there were plans to have a dedicated Scottish page on the website, it was decided that the Scottish content should be weaved throughout the website instead. [REDACTED] is listed on the contact page so people can get in touch if they have a Scottish-specific query.
- There are plans in the near future to have a bio for each VI Champion on the website and have a table which includes where they are in the country. There are also links to each of the member organisations.
- The VI annual stakeholder meeting took place last week, the recording of which has now been uploaded onto the new website. This is available to view here: https://www.youtube.com/watch?v=kjmglfWrlUA.
- **Update on Plant Health Centre:** [REDACTED] explained the PHC was one of the Government's centres of expertise, and looked at plant health relating to forestry, agriculture and the natural environment. It is four years into its five year term, but hopes to be recommissioned next year.
- Over its lifespan it has commissioned over forty individual projects, including work around knowledge exchange and where people get their information from. The PHC has also undertaken work on the impact of pesticide withdrawals, which has informed the Scottish Government's thinking. The SG will commission work around the impact of the loss of insecticides in the new year. The PHC is also involved in a project looking at solutions to PCN, including potential interventions, IPM measures, and Chitin compost.
- **Update on horticulture IPM plan**: [REDACTED] said the new horticulture IPM plan has been out for consultation over the past couple of months. There is a meeting on Wednesday with representatives of different sectors to decide on the scoring/measurement aspect of the IPM plan. The final plan should be ready to launch early next year. It was noted this plan would have a second section to explore IPM plans going forward and how people can make a commitment to change.
- **Guidance on metaldehyde**: [REDACTED] said draft guidance on metaldehyde had been circulated and following feedback from some members, the final version was ready to be published.

    - **Action: [REDACTED] to circulate metaldehyde guidance (included in email attachments). Scottish VI members to share through their channels.**
- **Guidance on emergency planning:** [REDACTED] was having connection issues but provided an update via email. There is already good information available on emergency spill guidance, such as the materials safety data sheet, the pesticides code of practice and NetRegs. The group agreed that a short one-page guide pulling together the key points from the various sources would be most useful.
    - **Action: [REDACTED] to progress with a one-pager guide on the key points to help minimise risk of spill, how to prepare and what the first steps should be in the event of an accident.**
- **Populating spreadsheet with FAS events and roadshows:** [REDACTED] mentioned that AHDB, FAS and SRUC were hosting three January roadshows. Two events are planned for in person at Carfraemill 18th Jan and Inverurie 20th January (under review with the current Covid concerns so they may move on-line) and a digital on-line event on 26th January. Further details are available here: https://ahdb.org.uk/events. There was a discussion of including some kind of digital calendar on the VI website, although this information is already included through the 'news and events' section.
    - **Action: All members to send through dates and details of future roadshows and events of interest to the Scottish VI.**

4. Plans for Q1 2022 (All)
    - **Training sessions on how to complete IPM plans:** There was a discussion around hosting an online webinar or drop-in for people to be shown how to complete an IPM plan. It was agreed that [REDACTED] and [REDACTED] could get feedback from attendees at the January roadshows as to what exactly would be helpful.
        - **Action: [REDACTED] and [REDACTED] to gauge interest in webinar/drop-in tutorials at the January roadshows and then feed back to the wider group.**

- **Producing guidance on most commonly detected substances:** There was discussion around producing best practice guidance on the most commonly detected substances by Scottish Water. Glyphosate, MCPA, Mecoprop, 2,4-D were suggested, although it was noted by Neal Evans that Scotland has few cases of pesticides exceeding drinking water level standards.

5. AOB

- [REDACTED] will send round a Doodle Poll in February for our next meeting in March 22.

From: [REDACTED]
Sent: 30 June 2021 18:16
To: Minister for Environment, Biodiversity & Land reform; Cabinet Secretary for Rural Affairs and Islands; Cabinet Secretary for Constitution, External Affairs and Culture
Cc: Cabinet Secretary for Net Zero, Energy and Transport; Deputy First Minister and Cabinet Secretary for Covid Recovery; DG Economy; Director of Agriculture and Rural Economy; Director of Environment & Forestry ; Saddler G (SASA) ; [REDACTED]; [REDACTED]; [REDACTED]; [REDACTED]; [REDACTED]; Coull AJ (Alison); [REDACTED]; [REDACTED]; [REDACTED]; Strang F (Frank); [REDACTED]; [REDACTED]; SGEU Obligations; [REDACTED]; [REDACTED]; Communications Net Zero & Rural Affairs; Communications Net Zero & Rural Affairs; [REDACTED]; Crawford E (Ewan); Dobson L (Leanne)
Subject: Pesticides - Ministerial Submission - Routine

Minister for Environment, Biodiversity and Land Reform
Cabinet Secretary for Rural Affairs
Cabinet Secretary for the Constitution, External Affairs and Culture

Please find a routine submission attached for your consideration.

Pesticides - MRL for glyphosate on corn gr

Kind regards
[REDACTED]

[REDACTED] | Agriculture and Rural Economy | Scottish Government | D Spur | Saughton House | Edinburgh EH11 3XD | E: [REDACTED] | T: [REDACTED] | M: [REDACTED]

Name of Project Proposed: Delivering a sustainable potato industry for Scotland through management of Potato cyst nematode (PCN)

Project Reference:

Name of Principal Investigator: Ian Toth

Name of Lead Institute for the Project: The James Hutton Institute

Name(s) of Co-Investigator(s), with Affiliation Included: Hutton: I Toth, I Hein, G Bryan, V Blok, J Jones, P Skelsey; J Price, S Humphris; Hutton/SRUC/SASA: P Burgess; SRUC: S Thomson, F Burnett, A Barnes, Scottish Agronomy: E Anderson; SoilEssentials: J Wilson; SASA: J Pickup; BioSS: K Preedy.

Research aims and key drivers

Research aims: i) prioritise and quantify the main interventions impacting the pest potato cyst nematode (PCN) spread and construct solutions with stakeholders that maximise industry self-management of the problem and inform a national strategy on potential Government actions, ii) develop IPM tools for PCN and integrate them into a fully delivered and validated decision support tool for Scottish growers, iii) develop resistance markers, tolerance tests and pre-breeding methods to provide tools for potato breeders to accelerate the development of suitable varieties.

The potato and flower bulb industries in Scotland are worth £250 million and £4 million, respectively. Scottish seed potatoes supply 70% of a GB potato industry worth £928 million and many billions to the wider potato-based food and drink industries. Scottish seed potato exports are worth £50 million. As potato seed cannot be grown on land infested with the PCN, and flower bulbs from infested fields cannot be exported, PCN has a major impact on the potato and flower bulb industries in Scotland. It has been estimated by SASA that PCN currently costs the Scottish potato and flower bulb industries ca £25 million a year, expected to rise (based on modelling predictions) to £125 million by 2024 and a possible cessation of the seed potato industry by 2050. While one species of PCN (*Globodera rostochiensis*) is currently controlled, mainly using resistant potato varieties, another *G. pallida* is spreading at a rate of 5% per year (doubling every 6-7 years) and has already infested 13% of seed and bulb-growing land.

In 2020, a Ministerial round table meeting took place on PCN, culminating in a request to Scotland's Plant Health Centre (PHC) to hold a working group to identify actions to reduce the spread of *G. pallida*. A report to Scottish Government was submitted with key recommendations including to preserve the land base for future generations, control the epidemic and increase the sector's capability and motivation to implement these changes. However, it was also recognised that investment was needed to address the actions in support of the recommendations. This proposal outlines areas of work aimed specifically at addressing the actions from the working group report and, by bringing them together under a single project, ensures dovetailing of research, delivery of a complete package within the 5 year programme and regular, coordinated and comprehensive engagement with industry to help reset the ongoing losses currently being experienced. The work involves both academia and industry, with expertise in potato genetics and breeding, nematology, integrated pest management, precision agriculture, field trialling and agronomy, spatio-temporal modelling, economics and stakeholder engagement. In a recent survey (July 2021) of the industry by NFUS, soil health / PCN was considered the top priority for potato research and development in the future.

Key outputs: a full economic assessment of PCN in Scotland at the start and end of the programme; a comprehensive decision support system (DSS) for growers; novel markers for use in breeding and development of pre-breeding material; modernisation of breeding methods to ensure rapid progress is achieved in delivering new resistant varieties; new simple and universally acceptable methods of determining varietal tolerance to PCN; improved control of groundkeepers (rogue potatoes that grow in other crops following a potato crop and allow PCN and other pests and diseases to persist through field generations); new IPM methods of PCN control; and a national strategy, time-lined and with key performance indicators to ensure completion of all aspects of the project and provide the basis of a wider programme of knowledge exchange targeted at specific stakeholder groups.

Consultation: the contents of this research programme have been developed with over 50 people from industry (31), government (15) and academia (11) in the working group as well as those engaged by government in the Ministerial round table and associated meeting/workshops, the Plant Health Centre, and two related RISS projects. For a full list of working group members see www.planthealthcentre.scot/publications/pcn-working-group-final-report).

Summary of the proposal

WP1 Economic assessment: Economic losses from PCN of up to £125 million by 2040 are possible and the costs and benefits of interventions are unclear. A detailed economic impact assessment to fully investigate the financial consequences of PCN in Scotland will be carried out in year 1-2, with close involvement of SASA. It will inform and frame research in other work packages, particularly linking to the stakeholder engagement in WP8, including the development of decision support tools for growers and the development of a national strategy in WP8. A key aspect will be potential benefits of farm payments. ***Key milestones***: The economic impact assessment will include a cost

benefit analysis across a number of scenarios (pathways), including the cost of no action versus mitigation, assessment of the most cost-effective mitigations (outlined in these recommendations and weighted by stakeholders in deliverable 'Comparison of datasets into a baseline understanding of the current impact of control measures for PCN' in WP 8 (years 1); an assessment of any specific impact on the seed industry (a higher value product and one of Scotland's premier industries) versus the ware industry (year 1); finally the effect of PCN spread, industry self-management of problem versus legislation and / or incentives and conditional payments and trajectories of overall net costs to industry, and of mitigation costs now versus in 5 years etc. (year 2). The economic impact assessment will be kept linked to findings in years 2-5 and re-modelled in year 5 to integrate the key outcomes from the work with a final output being a concluding policy paper on the value of interventions and value of the national strategy (year 5). ***Key Deliverables*:** (i) an assessment framework for estimating the economic costs and benefits upstream, downstream and on-farm from various PCN control scenarios; (ii) a summary of the farm level, upstream and downstream economic costs and benefits of different PCN pathways (versus the no action baseline); (iv) a summary of the economic costs and benefits of different control options (industry, incentive, regulation) and (v) a recommendation to government on our current statutory regulation of PCN.

WP2 Decision support (DSS): As control options for PCN in Scotland are reducing due to the loss of key nematicides, it is increasingly important to provide growers with ongoing management support. A decision-making tool to help potato growers in Scotland to manage PCN would be extremely valuable and would be in line with the highly successful decision support system (DSS) 'NemaDecide' currently used in the Netherlands. Although NemaDecide is a powerful tool for Dutch growers it may not be well suited for the Scottish industry. We propose instead, while leaving options open, to update the AHDB-hosted PCN Calculator (https://pcncalculator.ahdb.org.uk/) developed as an educational tool but lacks some of the features of NemaDecide that are attractive to growers. The PCN Calculator is built on relevant UK data and a renewed version will offer the opportunity for updates, provide links to other relevant databases (including SPUDS) and will be made freely available to all. ***Key milestones*:** i) through WP8 (KE and Comms) determine what growers need from a DSS and why the current AHDB DSS had a limited impact (year 1); ii) undertake a desk study to determine the most important data available in both models and produced in the intervening 15 years since the AHDB model was created and what further work is needed to fill any evidence gaps (year 1); iii) link the model to relevant available data sets in Scotland and update the model software (years 2-4), iv) develop a user interface and make the software/tool; v) validate the model data using field trials (Years 2-4), vi) make the DSS available to growers (year 5). ***Key Deliverables*:** A readily accessible, relevant, up to date, and easy to use DSS for the Scottish potato industry.

WP3 Resistance marker development and mobilising new resistances: Contamination by PCN is leading to the rapid loss of land suitable for seed production. To address the threat to sustainable potato production, the industry urgently requires improved and new molecular markers associated with existing and new PCN resistance sources for breeding purposes, particularly for the fresh market in Scotland. Previous work in the SRP has enabled the development of a targeted enrichment sequencing technology, RenSeq, that enables the specific re-sequencing of plant disease resistance genes. RenSeq has facilitated the rapid mapping of new resistances against diverse potato pathogens including PCN, the development of highly informative markers that are now used in breeding programs (e.g. late blight resistance genes *R8, R9a, Rpi-blb2*, *Rpi-vnt1*) and the identification of candidate resistance genes. Here, we will build on RenSeq to develop and validate KASP markers for *H1* effective against *G. rostochiensis* and *Gpa5* and *H3* against *G. pallida*. In addition, we will advance the deployment of new resistances in pre-breeding programs with a focus on *H2* and resistances from the wild species *S. spegazzinii* and *S. verrucosum*. ***Key Milestones*:** Development, validation and deployment of molecular markers *for H1, Gpa5* and *H3* (years 1 to 3). Mobilisation of new resistances effective against *G. pallida* such as *H2*, *S. spegazzinii* and *S. verrucosum* in pre-breeding programs (years 1-4). Combining effective resistances with the help of molecular markers in pre-breeding programs (years 3-5). ***Key Deliverables*:** Inform pre-breeding for PCN resistance in Scotland by providing new resistances and molecular markers to rapidly develop and release new cultivars with dual PCN resistance required for sustainable potato production.

WP4 Dihaploid induction for accelerated crop improvement: Potato breeding at the diploid level is currently gaining momentum in Europe and in USA and is likely to become the norm for rapid crop improvement in the future. It is vital that JHI expands its range of diploid adapted potato germplasm to include genes for important breeding targets (especially resistance to pests and diseases such as PCN) that have been previously achieved in tetraploid breeding programmes. We will generate novel dihaploids (diploid lines generated from tetraploids by 'dihaploid induction') that contain genes coding for known PCN resistances (*Gpa5, H3, H2*) against *G. pallida* and *G. rostochiensis* (i.e. *H1*). The availability of these genes in an adapted diploid background will render 'pyramiding' them into the same genotype much faster than in tetraploids. Moreover, the increased agility of working at the diploid level will make it easier to incorporate other important traits from well characterised research material (dormancy, fry colour, heat

tolerance, late blight & PVY resistance etc) in future work. We will 'diploidise' (by dihaploid induction) up to 10 selected potato varieties with known *G. pallida* resistances to produce diploid lines that can be used in both further genetics research, in diploid pre-breeding and in commercial tetraploid breeding via 'interploidy' crosses. This work also allows us to test out the concept of diploid potato breeding via inbred line and F1 hybrid development, ensuring that potato breeding in Scotland keeps pace with similar work being done in Europe and the USA. ***Key Milestones*:** Identify 10 tetraploids with different *G. pallida* resistances (years 1-3); perform pollinations with IVP 'haploid inducer clones, e.g. IVP48 (years 1-3); collect and extract berries produced (years 1-3); and heck ploidy of seed produced (years 1-3). ***Key Deliverables*:** Dihaploid lines containing different PCN resistances and combinations thereof that will serve as a source of material for pyramiding PCN resistances in breeding, both at diploid and tetraploid levels.

WP 5 Mechanistic understanding of tolerance to PCN to aid breeding: Tolerance to PCN infection can be defined as the ability of a cultivar to retain yield when challenged by PCN and is a trait that is highly desired by growers. Tolerance is not related to resistance, as resistant or susceptible varieties can be tolerant or intolerant of PCN infection. Little is known about the genetic control of tolerance and phenotyping of this trait is extremely complex and affected by environmental parameters. However, there is some evidence that tolerance is related to root architecture and that it may also be related to stem determinacy (related to nitrogen management). Control of determinacy is also poorly understood in potato, although it is known to be controlled by a single genetic locus (known as self-pruning gene or SP) in tomato. We will investigate the mechanisms of tolerance to PCN through an analysis of root architecture in tolerant and intolerant lines and in potato lines varying in determinacy and will examine the response of these lines to PCN infection. We will investigate the link between determinacy and tolerance and examine variation in the potato orthologues of the self-pruning (SP) gene, which controls determinacy in tomato. This work area will provide information to allow phenotyping and markers for breeding of tolerance in combination with resistance. ***Key Milestones*:** A desk study to establish what is known about the determinacy and tolerance of a range of potato cultivars, and to assimilate all available data into a short report (year 1). Information on root architecture and its relationship to tolerance and determinacy (year 2). Information on response of tolerant and intolerant lines to PCN infection (year 3). Identification of key potato orthologues of the SP gene (year 2) and variation in these sequences in relation to determinacy and tolerance (year 3). Design and test pot assay for phenotyping tolerance to facilitate incorporation into breeding programmes and compare data to field trials (year 4). Compare histological response of tolerant and intolerant lines to PCN infection (Year 4). Analyse data from genetic analysis of SP gene and field/pot trials to determine whether markers that are linked to tolerance can be developed (year 5). ***Key deliverables*:** Understanding of the mechanistic basis for tolerance. Information on whether it is possible to generate markers linked to this trait. Methods for phenotyping tolerance that can be used in breeding programmes.

WP6 Groundkeeper control: Poor control of groundkeepers enables PCN populations, along with other pests and pathogens, to increase between potato rotations. This greatly undermines the usefulness of rotations in reducing PCN in the soil. Addressing this problem requires the cooperation of farmers, including those who rent their land for growing potatoes. A reduction in groundkeeper occurrence, through better control, would have a major impact on the presence of PCN. However, the potential loss of the herbicide glyphosate to control groundkeepers, especially alongside other herbicide withdrawals, will make control more difficult and costly. To control groundkeepers, it is first necessary to know where they are, what factors lead to increased incidence, how to detect them and how effective different control options are. ***Key milestones*:** i) Develop image-based technologies for automated groundkeeper identification and counting; ii) determine the extent of groundkeepers in Scotland; iii) understand the factors that lead to increased incidence and retention of groundkeepers; iv) undertake a desk study to determine the consequences of loss of glyphosate and determine alternate methods of control and their associated costs; and v) demonstrate the impact of groundkeepers on PCN populations and link to stakeholder engagement (WP8). ***Key Deliverables*:** Readily deployable groundkeeper identification and counting technology; improved management of groundkeepers; policy recommendations on glyphosate regulation.

WP7 Novel IPM tools: After resistant varieties, chitin and trap crops are two other potential non-chemical control options for PCN as part of a sustainable management strategy for Scottish growers. However, more work is required to determine their efficacy particularly in Scottish conditions. There are several published examples of the successful use of chitin and wood-based composts that have shown reductions in PCN numbers, and recent unpublished data in Scotland suggests a similar efficacy. Chitin may increase the presence of microbes in the soil which break down chitin and, in theory, may also target the chitinous compounds in PCN eggshells. Solanceous trap crops, which are close relatives of domestic potato (*Solanum tuberosum*) induce PCN hatching but do not allow the juveniles to develop or multiply due to an inability to feed on the roots. In an IPM context, this will contribute to a reduction of the PCN field population over time. The three most promising trap crops for potato are *Solanum sisymbriifolium* (sticky nightshade), *Solanum scabrum* (African nightshade/broad-leaved nightshade) and *Solanum chenopidoides*

(Chinese variant), all of which grow well in warmer climates but their ability to grow efficiently, and therefore be used as trap crops in Scotland, remains to be determined. ***Key Milestones*:** Determine the efficacy of chitinous compounds and trap crops under Scottish conditions to reduce PCN numbers on soil (years 1 and 4). ***Key Deliverables*:** New IPM tools to manage PCN in soil as part of a wider management system.

WP8 National knowledge exchange and communications programme: A national programme addressing the future threat of PCN in Scotland will be developed and delivered to stakeholders within relevant supply chains aimed at sustainably protecting the land base for future generations. The WP will underpin and form an integral part of other areas of activity to ensure programme outputs are delivered effectively to stakeholders (linkages to all WP's will be developed but especially WP1, WP2, WP6 and WP7). ***Key Milestones*:** We will integrate findings from existing data sets into a coherent baseline understanding of the current impact of control measures for PCN (year 1). Following dialogue with stakeholders, the information generated will be used to produce a National Strategy in consultation with SASA, and key performance indicators will be identified for different stakeholder groups, alongside a mechanism for measuring delivery (year 1). Multiple communication channels, including grower events, website posts, social media and stakeholder-relevant publications will be used to deliver messaging on the National Strategy and to set the groundwork for a wider programme of KE targeted to specific regional or interest stakeholder groups around the activity areas of (a) protecting the land base, (b) controlling the epidemic and (c) utilising existing and introduction of new varieties to form the basis of targeted messaging around the National Strategy (years 2-3). Outputs from other WPs will be incorporated into messaging using a variety of KE methodology throughout the programme and especially in years 4 and 5. Assessment of programme delivery and achievements will be measured against the national strategy (reviewed yearly and final assessment year 5). ***Key Deliverables*:** (1) Integrated datasets to establish baseline understanding of current situation; (2) national strategy with measurable KPI's requiring KE delivery to achieve targets; (3) programme of communication with industry delivering focused and consistent messages to all stakeholder groups; (4) annual review of progress against National Strategy KPI's; and (5) integration of programme outputs into developing Knowledge exchange programme.

Technical Approach

WP1: Economics

Activity 1.1, Economic contribution of seed: This activity will gather data to develop a robust economic profile of the Scottish seed potato sector. This will require analysis of secondary data analysis (e.g. MySpuds seed area, HMRC export statistics, SASA export data, June Census / Single Application Form areas) to assess the production area and markets for Scottish seed. As seed is a vital input into the ware sector we will also undertake an economic profile of the Scottish ware sector, particularly as the ware sector creates competition for clean ground, and has less regulation regarding PCN. We will assess available published economic data with industry intelligence (WP8) and, if necessary, we will collect primary information from growers and packers in the sector (a short, anonymous, cost survey) that can identify upstream and labour expenditure (year 1).

Activity 1.2, Model economic impacts of PCN scenarios. Using data on potential PCN spread and control pathways a model to estimate the economic costs (loss of yield, control costs, rents, loss of markets) and benefits (yields, marketability) of different PCN assumptions on the Scottish potato sector will be developed. This will include an assessment of potential upstream and downstream impacts and will involve an estimation of baseline (current) and future costs of different PCN prevalence scenarios, including estimates of the effects on sector size and associated employment and economic impacts. We will work with sector experts (WP8) to assess the costs and benefits from each of the different mitigation options (identified by existing and future decision support systems – WP2), and their probability of success in effectively mitigating the spread of PCN and resulting consequences (year 1).

Activity 1.3, Interventions. Working with sector experts (WP8) we will provide an assessment of how PCN control may best be affected (i.e. regulation, industry led initiatives, policy incentives). We aim to speak to industry and Government officials through a Delphi method to elicit independent views on the most appropriate methods of engendering PCN control (year 2).

Activity 1.4, Model updates. Updates based on other WPs, in particular WP2 (year 5).

WP2: Decision support (DSS)

Activity 2.1, Gathering requirements. Undertake a desk study to determine i) which data built into the AHDB tool remains relevant for use in the new system, ii) what new data has become available in the intervening 15 year period since the model was developed, iii) which specific environmental factors and management options have the biggest impact on PCN population levels and yield parameters (from PHC2020/08) and, as a consequence, iv) what further work is needed to fill any evidence gaps (year 1). Specific requirements for the development of the DSS will be re-examined at intervals throughout the project (years 1-5). Through WP8 (KE) workshops will be arranged to determine the key attributes that growers require from a DSS.

Activity 2.2, Field validation. Based on the outcomes of Activity 1, field experiments will be undertaken to provide missing data, specifically under Scottish conditions, for the model (years 2-5). Experiments are expected to cover one or more of the following areas: Decline rates in different soils under Scottish conditions; spatial distribution of PCN within fields; efficiency of nematode reproduction, varietal resistance; potato yields under different PCN levels.
Activity 2.3, Model implementation. Initial implementation of the AHDB PCN model will take place before being updated with key parameters identified in Activity 1 and 2 (year 2). The DSS will be set up to run efficiently using available criteria, a report generation function will be enabled (years 3-5), and the full release made available (year 5). A user-friendly interface will be developed for the model and the model integrated into the Plant Health Centre website for stakeholder access (year 5). Towards the end of the project, future options for improving the DSS will be identified and examined for inclusion in the model (year 4-5). We will implement a feedback mechanism to incorporate DSS user PCN results over the project duration to improve the DSS model using machine learning where appropriate.There will also be feedback to the machine learning in WP6 and PHC 2020_08 where useful PCN risk factors may be identified.
Activity 2.4, Integration with SASA's SPUDs and other databases. The possibility of linking the model to existing datasets (*e.g* SPUDS at SASA, GPS coordinates of samples and Hutton hosted soils database) will be examined and those found to add suitable information to the model will be integrated (year 5).
Activity 2.5, DSS delivery. The updated DSS will be hosted on the PHC web site alongside the groundkeeper tool and other established tools such as the IPM tool and, through WP8 (KE), a series of workshops will take place with growers to demonstrate the new DSS to help with uptake (year 5).

WP3: Resistance marker development and mobilising new resistances:
Activity 3.1, Develop robust and informative KASP markers for *H1, Gpa5* and *H3*. We will use RenSeq-based technologies to first identify disease resistance genes linked to the resistance phenotypes provided by *H1, Gpa5* and *H3*, and then develop KASP markers to track these resistances (years 1-3). Specifically, we will extract DNA from potato cultivars known to contain the resistance(s) and conduct Illumina and PacBio-based RenSeq on samples. The RenSeq-derived reads will be used in an AgRenSeq analysis to identify candidates that are then independently validated through dRenSeq. We will identify highly informative and diagnostic single nucleotide polymorphisms (SNPs) in linked resistance genes using a computational pipeline established in the previous SRP. These SNPs will be used for the development of KASP assays that enable the tracking of functional resistances in pre-breeding programs.
Activity 3.2, Mobilise new resistances *H2, S. spegazzinii* and *S. verrucosum* in pre-breeding programs. Work in a previous SRP has identified new *G. pallida* resistances in the clone P55-7 (*H2*) and the wild species *S. spegazzinii* and *S. verrucosum*. We will develop dual-purpose segregating populations to advance these resistances in pre-breeding programs, including those developed at James Hutton Limited (JHL), and to characterise the resistances on a molecular level with the aim to develop markers (years 1-4). To mobilise these novel resistances, we will set up crosses with diploid potatoes cultivars (e.g. Mayan Gold), diploid SLI lines (e.g. M6 or dihaploid lines) and/or established cultivars. We will take advantage of established winter crossing facilities (speed breeding) at the Hutton to expedite the process of generating segregating populations. Following genotypic (RenSeq and/or GBS) analysis and phenotypic assessment, we will develop markers following the approach outlined in Objective 1.
Activity 3.3, To combine effective resistances against PCN. We will set up crosses to combine *H1, Gpa5* and/or *H3* with new resistances *H2*, *S. spegazzinii* and/or *S. verrucosum* in collaboration with JHL and, where appropriate, other breeding companies. We will also setup crosses with cultivars and/or pre-breeding clones characterised in Objective 1 and the mobilised resistances in Objective 2. Using the developed markers, we will identify and characterise advanced pre-breeding clones that contain combinations of these different sources of resistance (years 3-5). This is a pre-requisite for the development and release of durable PCN resistant potato cultivars in Scotland.

WP4: Dihaploid induction for accelerated crop improvement
Activity 4.1, Develop dihaploid lines from tetraploid varieties carrying PCN resistance and other genes. We will use standard approaches for generating dihaploid clones from tetraploid starting material selected to contain the targeted resistances and other traits (years 1-3). This entails performing pollinations of the tetraploid parent with pollen from a 'dihaploid inducer' clone (e.g. IVP48). When successful, such crosses lead to the generation of berries containing small numbers of diploid and more rarely, triploid seed. Ploidy can be checked by various means (cytological examination, markers, loss of purple embryo spot marker etc). When a tetraploid by diploid cross is performed the expected ploidy level of progeny is triploid, but such seeds are rare due to the well documented 'triploid block' in potato. A small panel of 10-12 tetraploid varieties has been selected for this work and will be selected from: 10.Z.41 A 1, King Russet, Gemson, Melody, GL 78/97, Ivory Russet, Athlete, Alverstone Russet, Royal, Taurus, as well as four selected breeding clones from JHL carrying the target genes.

WP5: Mechanistic understanding of tolerance to PCN to aid breeding

Activity 5.1, A desk study will be undertaken to establish what is known about determinacy and tolerance of a range of potato cultivars, and to assimilate all available data into a short report (year 1). This will bring together all available data (SASA, AHDB etc.) and will inform future field studies to demonstrate whether there is a causative link between determinacy and tolerance to PCN.

Activity 5.2, A series of potato lines varying in their tolerance and determinacy will be grown in pots, with or without PCN infection. The structure of the root systems will be monitored during each set of experiments and the structure and size of the root system will be examined at the end of the assay. This will provide information on whether tolerance is related to root biomass and structure or whether there are differences in the way roots respond to PCN infection and will also provide information on root structure in potato lines that vary in determinacy (years 2-4).

Activity 5.3, A series of potential orthologues of the tomato SP gene are present in the potato genome. We will identify the genes most closely related to SP and analyse variation in the sequences and expression profiles of these genes in a small number of potato genotypes that show wide variation in determinacy and tolerance (years 2-3). This will provide information on the potential role of SP in control of both determinacy and tolerance and potentially allow markers linked to these traits to be developed (year 5). We already have a small amount of data that suggests that a potato gene related to SP on chromosome 6 is involved in the determinacy trait.

Activity 5.4, Assessing tolerance in pots has been reported in the past as a means of determining the ranking of relative tolerances of a group of potato genotypes. A glasshouse assay comparing tolerance in clay pots versus smaller plastic pots will be carried out. The results will be compared to data from a series of field trials examining tolerance and to tolerance levels previously established in various cultivars (year 4).

Activity 5.5, The response of tolerant and intolerant roots to high levels of PCN infection will be investigated to determine whether differences in response to the damage caused by PCN infection underpin tolerance. Roots with and without PCN infection from tolerant and intolerant potato genotypes will be compared after histological staining to assess damage and cell death to examine the response associated with infection and to examine whether the roots from different lines show different abilities in terms of the ability to recover from infection (year 4).

WP6: Groundkeeper control

Activity 6.1, Glyphosate loss: A desk study will be undertaken to determine the consequences of loss of glyphosate on groundkeeper control in Scotland and other potential control options considered and valued (year 1).

Activity 6.2, Population effects: Fields containing high numbers of groundkeepers will be identified and, using GPS technologies to monitor precise locations, experiments will be conducted in those fields to determine the effect of groundkeeper presence on PCN populations (years 1-2).

Activity 6.3, Precision methods: Groundkeeper field data gathering will take place to allow the full specification and outputs of the project to be defined. This will involve selecting crops (peas, carrots, arable) and potential groundkeeper sites. The project duration is designed to include three growing seasons allowing for a robust data set to be obtained. An RTK drone with high resolution camera will be purchased and used to obtain field images. Images will be annotated using specialist SE software and stored within SE cloud repository. The software platform will be developed to cover all elements of model generation and outputs. This will use the data obtained above to generate Artificial Intelligence (AI) models. A 'model factory' will be developed to allow a selection of models to be selected linked to image quality, image size and target type. When trained, models will be used on field imagery in a cloud-based inference server. The output will be available for presentation in various ways, including via the PHC web site for use by growers, and will include a targeted spray map to be used with a precision spray system and/or to monitor soil sample locations and results close to detected groundkeepers. Technology advancements will be monitored throughout the period of work to enable those emerging to be adopted to the workflow. Monitoring and adopting this technology will allow for the successes of the work to be transferred into the working environment (years 1-3).

Activity 6.4, Extent of groundkeepers: Machine learning will be used to relate the extent of groundkeepers in Scottish potato growing areas to factors identified in the SPUDs database (year 2).

Activity 6.5, Incidence of groundkeepers: Analysis of results from Activity 2 combined with variety and field rotation data in the SPUDS database (SASA), together with factors such as soil type, variety etc affecting increased groundkeeper incidence, will be identified and fed into the DSS in WP 5 (years 2-4).

WP7: Novel IPM tools

Activity 7.1, Chitinous compounds and trap crops: Two field treatments, together and independently, will be used in commercial field trials to determine their effects on reducing PCN populations (years 2-4). Treatments will include chitin-based compost and the three solanaceous trap crop species *S. sisymbriifolium*, *S. scabrum* and *S. chenopidoides*. The chitin trial will include 70 defined plot areas (35 treated and 35 untreated) in a known PCN-infested field location. 400ml soil samples will be taken from each of these plots for PCN testing, and high precision GPS will be used to geo-locate the corners of the trial to permit future soil testing to evaluate the reduction in PCN

viability over time. The trap crop trial will include a single plot area of 1.83 x 3 x 12 m for each trap crop plus an untreated plot (no trap crop), each with a surrounding 2m buffer zone to mitigate against soil cultivation equipment horizontally dragging cysts. There will be up to 6 replicates per treatment (trap crop). Approximately 1.0 Ha strips each of *S. sisymbriifolium*, *S. sisymbriifolium* and *S. chenopidoides* will be sown commercially to evaluate growth and management of the crops from a practical perspective under typical soil and climatic constraints. Prior to planting, PCN distribution, egg count and viability will be carefully monitored within the field area to ensure an even distribution across the experimental plots. Extensive sampling, decline rates (Pi & Pf), egg count and viability will be monitored on completion of the trial (year 1) and again later in the project (year 4) to determine changes in PCN infestation rates over time.

WP8: National knowledge exchange and communications programme

Activity 8.1, Integrating datasets: Work with stakeholders will be undertaken to integrate information on the economic impact of PCN (WP 1), the implementation of IPM strategies for PCN control, and output from 'Modelling the spread of PCN' (PHC 2020/08) alongside other information sources from Scottish Government (SASA SPUDS database) to produce a baseline understanding of the current impact and control measures for PCN (year 1).

Activity 8.2, National Strategy: Use the established PHC PCN Working Group to develop the baseline output into a published and sector owned national strategy for the control of PCN in Scotland. Long term (5 years) industry, academic and policy KPI's will be identified for all groups alongside a mechanism for measurement of delivery (year 1).

Activity 8.3, Communication with industry: Use multiple channels of communication to co-construct and deliver focused initial messages from the national strategy to specific stakeholder groups. Stakeholder workshops will include, grower events and meetings, website posts and social media. Establish a 'PCN local management group' to test the concept and provide feedback on current and future activity (years 1-5).

Activity 8.4, Annual review of progress against National Strategy. Stakeholder grouping will provide a forum to review progress on an annual basis (year 2 and 5).

Activity 8.5, Integration of programme outputs into developing Knowledge exchange programme. Engagement with all WPs will take place to ensure KE elements are delivered to the sector in a format that has maximum impact (years 1, 3, 4, 5).

Detailed Work Plan

WP1: Economics

Activity 1.1: Economic contribution of seed

Y1: (M1.1/D1.1) Baseline information gathering and model economic contribution

Activity 1.2: Model economic impacts of PCN scenarios

Y1: (M1.2/D1.2/D1.3) Costs and benefits of PCN control pathways

Activity 1.3: Interventions

Y2: (M1.3/D1.4) Mitigation costs and options including Delphi study

Activity 1.4: Model updates

Y5: (M1.4/D1.5) Updates and policy paper

WP2: Decision support system (DSS)

Activity 2.1: Gathering requirements

Y1: (M2.1) Desktop study to gather data and identify evidence gaps. (D2.1) Report

Y1: Workshops to gather industry needs - see WP8

Activity 2.2: Field validation (based on outcomes of Activities 1 and 2)

Y2-4: (M2.2/M2.3/M2.4) Field validation of model data

Activity 2.3: Model implementation

Y2: (M2.5) Define requirements for DSS model and initial implementation

Y2-5: (M2.6/7/8/9) Re-examine requirements for DSS model yearly

Y3: (M2.10) Model update

Y5: (M2.11) Model report generation

Y5: (M2.12) Full model release. (D2.2) Model release.

Y5: (M2.13) Embed model into PHC website (D2.3) Model to PHC web site

Activity 2.4: Integrate model with SASA's SPUDs and other databases

Y3: (M2.14) Implement SPUDS integration

Y3: (M2.15) Develop grid function

Y5: (M2.16) Release integration as part of model

Activity 2.5: DSS delivery

Y5: (M2.17) Presenting demos at the workshops to industry with WP8. (D2.4) Demo workshops

WP3: Resistance marker development and mobilising new resistances
Activity 3.1: Develop robust and informative KASP markers for *H1, Gpa5* and *H3*
Y1: (M3.1) DNA extraction, AgRenSeq and KASP marker for *H1*
Y2: (M3.2) DNA extraction, AgRenSeq and KASP marker for *Gpa5*
Y2: (M3.3) Validation of *Hi1* and *Gpa5* KASP marker and utilisation in pre-breeding
Y3: (M3.4) DNA extraction, AgRenSeq and KASP marker for *H3*
Y3: (M3.5) Validation of *H3* KASP marker and utilisation in pre-breeding. (D3.1) Report marker results
Activity 3.2: Mobilise new resistances *H2, S. spegazzinii* and *S. verrucosum* in pre-breeding programs
Y1: (M3.6) *H2* dual-purpose population generation
Y2: (M3.7) *S. spegazzinii* and *S. verrucosum* dual-purpose populations generation
Y2: (M3.8) Assessment of *H2* population
Y3: (M3.9) Refinement of *H2* KASP marker
Y3: (M3.10) Assessment of *S. spegazzinii* and *S. verrucosum* populations
Y4: (M3.11) Development of *S. spegazzinii* and *S. verrucosum* markers. (D3.2) Report on new resistances / markers
Activity 3.3: To combine effective resistances against PCN
Y3: (M3.12 Combining *H2* with *H1, Gpa5* and/or *H3*
Y4: (M3.13) Using markers identify and assess phenotypically pre-breeding progenies that contain H2 with *H1, Gpa5* and/or *H3*
Y4: (M3.14) Combining *S. spegazzinii* and/or *S. verrucosum* with *H1, Gpa5* and/or *H3*
Y5: (M3.15) Using markers, identify pre-breeding progenies that contain *S. spegazzini* and/or *S. verrucosum* with *H1, Gpa5* and/or *H3*
Y5: (M3.16) Assess phenotypically pre-breeding progenies that contain *S. spegazzini* and/or *S. verrucosum* with *H1, Gpa5* and/or *H3*. (D3.3) Report on combined resistances, markers and results

WP4: <u>Dihaploid induction for accelerated crop improvement</u>
Activity 4.1: Develop dihaploid lines from tetraploid varieties carrying PCN resistance and other genes
Y1: (M4.1) Establish panel of 10-12 tetraploids targeted for dihaploid induction and inducer clones (IVP35, IVP48) in pollination wings of JHI glasshouses.
Y1: (M4.2) Perform pollinations of each tetraploid with inducer clones
Y1: (M4.3) Harvest berries from plants and extract seed
Y2: (M4.4) Germinate seeds from Year 1 and establish ploidy of seedlings. (D4.1) Report results
Y2: (M4.5) Establish panel of 10-12 tetraploids targeted for dihaploid induction and inducer clones (IVP35, IVP48) in pollination wings of JHI glasshouses
Y2: (M4.6) Perform pollinations of each tetraploid with inducer clones
Y2: (M4.7) Harvest berries from plants and extract seed
Y3: (M4.8) Germinate seeds from Year 2 and establish ploidy of seedlings. (D4.2) Report results
Y3: (M4.9) Establish panel of 10-12 tetraploids targeted for dihaploid induction and inducer clones (IVP35, IVP48) in pollination wings of JHI glasshouses
Y3: (M4.10) Perform pollinations of each tetraploid with inducer clones
Y3: (M4.11) Harvest berries from plants and extract seed. (D4.3) Report results

WP5: Mechanistic understanding of tolerance to PCN to aid breeding
Activity 5.1: Desk study to establish what is known about the determinacy and tolerance
Y1: (M5.1) Desk study on determinacy versus tolerance
Activity 5.2: Root biomass and structure in relation to tolerance
Y2: (M5.2) Comparison of root architecture of tolerant and intolerant lines
Y3: (M5.3) Comparison of changes to root structure in response to PCN infection
Y4: (M5.4) Comparison of root architecture and response to infection in lines showing varying levels of determinacy (D5.1) Report on mechanistic basis for tolerance
Activity 5.3: The role of the SP gene in determinacy and tolerance
Y2: (M5.5) Identification of potato genes most similar to SP
Y3: (M5.6) Comparison of sequences and expression profiles of SP orthologues in potato lines varying in tolerance and determinacy
Y5: (M7) Integration of sequence data with information on relationship between tolerance and determinacy to determine whether markers can be developed. (D5.2) Report on availability of markers
Activity 5.4: Developing pot assays for phenotyping tolerance

Y4: (M5.8) Perform pot assay for tolerance using lines that have large differences in tolerance
Y4: (M5.9) Compare data with that obtained from field trials for the same lines (Scottish Agronomy). (D5.3) Report on phenotyping methods for tolerance
Activity 5.5: Histological analysis of the response to infection
Y4: (M5.10) Comparison of cell death and recovery from damage in tolerant and intolerant lines

WP6: Groundkeeper control
Activity 6.1: Glyphosate loss
Y1: (M6.1) Desk study on effect of Glyphosate loss on groundkeeper control and cost and effectiveness of alternatives; (D6.1) Policy report
Activity 6.2: Population effects
Y1: (M6.2) Effect of groundkeepers on retention of PCN populations (year 1). (D6.2) Publication / report
Activity 6.3: Precision methods
Y1-3: (M6.3/M6.4/M6.5) Image 10-30 fields containing groundkeepers in Scotland to obtain model training data
Y4 (M6.6) Horizon scanning to adapt emerging technologies into software development
Y4: (M6.7) Completion of software development and optimisation of methodology. (D6.3) New groundkeeper detection methodology; (D6.4) Demonstration report
Activity 6.4: Factors affecting groundkeepers
Y2: (M6.8) Modelling using SPUDS database to capture key factors influencing groundkeeper incidence. (D6.5) Information fed into DSS (WP5)
Activity 6.5: Incidence of groundkeepers
Y2: (M6.9) Initial testing of new precision method for capturing groundkeeper presence and number
Y3: (M6.10) Survey of groundkeepers in Scotland year 1
Y4: (M6.11) Survey of groundkeepers in Scotland year 2. (D6.6) Policy report on extent and location of groundkeepers in Scotland

WP7: Novel IPM tools
Activity 7.1: Trap crops and chitin trials
Y1: (M7.1) Select suitable PCN infested land for trial and determine PCN distribution, egg count and viability
Y1: (M7.2) Field trial to determine effect of chitin and trap crops on PCN populations in soil
Y1: (M7.3) Decline rate (Pi & Pf), egg count and viability testing post trial
Y4: (M7.4) Repeat of decline rate (Pi & Pf), egg count and viability testing post trial. (D7.1) Publication
Y4: (M7.5) Interpretation of data and transfer to DSS. (D7.2) Transfer of information to the DSS (WP2)

WP8: National knowledge exchange and communications programme
Activity 8.1: Integrating datasets
Y1: (M8.1) Work with stakeholders to integrate information on the economic impact of PCN (SRP deliverable, Thomson) into National Strategy
Y1: (M8.2) Baseline document outlining current impact and control measures for PCN. (D8.1) Baseline document
Activity 8.2: National Strategy
Y1: (M8.3) Engagement with key stakeholders
Y1: (M8.4) Establishment of industry ownership of the national strategy
Y1: (M8.5) Production of an agreed national strategy. (D8.2) National Strategy
Activity 8.3: Communication with industry:
Y1: (M8.6) Establish of channels of communication with stakeholders
Y1: (M8.7) Establish pilot local grouping
Y2: (M8.8) Establish further local / specific target groups to engage in best practice PCN control and deliver the national strategy in local situations. Support these groups to deliver change
Y2-4: (M8.9/M8.10/M8.11) Conduct best practice demonstrations of PCN IPM, based on current knowledge. Engage with industry to deliver changes in practice. (D8.3/D8.4/D8.5) Best practice demonstrations
Y2-5: (M8.12/M8.13/M8.14/M8.15) Engage with all stakeholders using appropriate messaging for different groups from the full range of available platforms
Y3-5: (M8.16/M8.17/M8.18) Continue to support local and specific target groups to deliver change and establish a legacy of knowledge and engagement beyond the end of this WP
Y5 (M8.19) Produce sector focused document outlining best practice informed by all work packages. (D8.6) Best practice grower document.
Activity 8.4: Annual review of progress against National Strategy.
Y2/3/4: (M8.20/M8.21/M8.22) Annual review of progress against KPI's agreed in national strategy

Y5: (M8.23) Final review of progress against KPI's agreed in national strategy. Publication of assessment of delivery
Activity 8.5: Integration of programme outputs into developing Knowledge exchange programme.
Y1: (M8.24) Embedding of knowledge exchange element within all work packages
Y1: (M8.25) Integration of programme outputs into Knowledge exchange programme (WP1)
Y3/4: (M8.26/M8.27) Integration of programme outputs into Knowledge exchange programme (WP2/3/6/7)
Y5: (M8.28) Integration of programme outputs into Knowledge exchange programme (WP2/3/4/5/6/7)

Expertise

BioSS are one of the UK's leading groups of statisticians and mathematicians applied to agriculture, environment, food and health. They have extensive experience of experimental design for agriculture, potato genomics and PCN and in the translation of complex data sets for stakeholder KE. Long-standing collaborations with JHI, JHL and SRUC include close cooperation on potato and PCN work as part of the Scottish Government SRP aligned with funding from the BBSRC, Innovate UK and AHDB.

Hutton is a world-leader in the genetics of potato and PCN biology and has produced many publications and led strategic and applied research projects in these areas, including as part of multinational consortia. The molecular and phenotypic work described in this proposal builds on investments in MRPs over the previous two SRPs as well as aligned external funding. The Potato@Hutton group is experienced in the maintenance and generation of new potato material for research and breeding and maintains the Commonwealth Potato Collection, which is a key component of this work. To expedite the rapid uptake of our research and to develop new varieties, we will take advantage of the existing interactions between JHI, JHL potato pre-breeding and other breeding companies.

SRUC has a long-standing reputation for applied potato research, advice and consultancy, supported by its extensive potato field trials programme. SRUC's agricultural economic leads work closely with SG to help frame policy interventions. SRUC undertakes extensive KE with growers and industry stakeholders, including as part of its SACAPP potato producer subscription service with associated grower groups, newsletters and annual conference. It also leads on skills and training in Scotland, including industry CPD. The KE teams at SRUC are experienced in running stakeholder workshops and running attitudinal studies to identify barriers and accelerate uptake.

SASA is a Division of the Agriculture and Rural Economy Directorate of the Scottish Government providing scientific advice and services in the fields of arable agriculture, plant health and food safety, including the statutory and regulatory control of pests and diseases such as PCN. SASA carries out the statutory PCN testing of all land intended for seed potato production in Scotland and carries out VCU testing of all potato varieties added onto the UK National List, including testing for resistance against both species of PCN.

Scottishpotatoes.org is a partnership of JHI, SRUC and SASA which provides the bridge between research being conducted at the partner organisations with growers and the wider supply chain. The leader of this partnership is embedded in activities at all three organisations and has experience in knowledge exchange and implementation of innovation on farm in a wide range of settings.

Scottish Agronomy Ltd Eric Anderson, Director and Senior Agronomist, provides strategic consultancy and applied research to a large UK-wide and international client base, and has over thirty-four years of experience in potato. He is a speaker and authority on agronomic advice on farm and to support consultancy on Integrated Crop Management he regularly conducts seminars and training courses on the transfer and application of science into practical solutions. He is/was part of the operational group for the current AHDB Scottish Strategic Seed Potato Farm and the National Potato Virus Forum, and has been involved in consultancy Western Europe, North Africa, Asia and North America.

SoilEssentials exists to combine precision agronomy, cutting-edge technology and innovative engineering to increase agricultural efficiency and deliver a practical, innovative tool set to companies, growers and agronomists. They have over 20 years' experience with software as a service platform, using the latest crop and soil modelling and software development technologies to produce a complete product tailored specifically of the agricultural industry. They have in-house expertise to undertake GIS mapping, spatial crop and soil modelling integrated with web and mobile application development. SoilEssentials have led or participated in ten Innovate UK proposals and European Space Agency projects since 2014.

Key linkages, interdisciplinarity & collaboration

SRP/PHC: This project links to several aspects of PCN-related research in the current and future SRP, including the exploitation of resources developed over many years on potato genetics and genomics and on plant nematology, and will complement externally funded research projects. The research will use resources maintained in the RESAS-funded Underpinning Capacity including potato germplasm (Commonwealth Potato Collection) and PCN collections. Year 6 deliverables from the current SRP include the development of a microfluidics system for rapid counting of PCN, which could be used by SASA in statutory testing or as part of future commercial diagnostic services (relevant to WP2). Metagenomics-based diagnostics are also being used to identify differences in virulence between PCN

pathotypes to help understand the spread of PCN and to assist in its management (relevant to WP2). The new SRP topics A1 and B1 (2022 – 2026) include work on PCN resistance (WP3/4/5), and the refinement of AgRenSeq in B1 will inform the identification of *H1*, *Gpa5* and *H3* candidates that will, in turn, inform the KASP design. Similarly, the new SRP includes aspects of diploid breeding (relevant to WP4) further development of metagenomics and climate-related decline rates (relevant to WP2). Two PHC projects have been commissioned to investigate PCN in Scotland. The first relates to the future threat of PCN in Scotland (PHC2018/16), which ultimately led to the working group and this project proposal and is relevant to many areas of this bid. The second relates to the use of machine learning to model the spread of PCN in Scotland (PHC2020/08), results of which are intended to dovetail with this project to identify key factors in the spread of PCN for factoring into the development of DSS (relevant to WP2).
RISS: Two recent Rural Innovation Support Service (RISS) projects on PCN have involved SRUC and Scottish Agronomy. The first of these, led by SRUC, helped to kick start conversations with industry on the next steps to tackle PCN, with these existing groups being an important place to start further conversations as part of WP8. The second project was to investigate the concept of using chitin to control PCN, which will now be investigated in field trials as part of WP7.
Make Innovation Happen: A Highlands and Islands Enterprise grant is funding a current precision sampling feasibility study to support integrated pest management of PCN for Scottish potato growers. The partners in this proposal come from an existing, multi-disciplinary RISS consortium of farmers, agri-cooperatives, agronomists, land managers, potato processors and RTOs to address the challenge of PCN in the Scottish potato growing sector through proving and commercialising an integrated pest management concept.
Innovate UK: A number of projects have taken place to develop tools to better manage potato and other crops, including TuberZone (No. 102125 - potato yield size, distribution and starch content), KORE (working with the European Space Agency), BlightRisk (No. 131553 - to predict late blight outbreaks and done in conjunction with the Hutton) and SKAI (No. 105154 - building machine vision models). All of these projects will provide knowledge and tools for use in the DSS and groundkeeper models being developed as part of this project.
Collaborative Training Partnership: PCN disease resistance is relevant to a recent CTP2 application (pending) in sustainable crop production that will potentially fund several joint PhD students with a range of industry partners (Sainsbury, G's, PepsiCo and Solynta), and provide a direct route for impact for this work. Established partnerships are already in place with industry partners including James Hutton Limited (JHL), Simplot, Agrico, Greenvale, McCain and Solynta on disease resistance projects in potato, and with further breeding companies including McCain, Cygnet, and others. This project also links to three PhD projects (related to AgRenSeq) that commenced in 2020 and supported by seedcorn PhD funding to the JHI postgraduate school and that draw on external funds from several sources.

Added Scientific Value

The marker and tolerance work will benefit from internationally aligned projects including BBSRC and GCRF awards aimed at establishing the disease resistance potential of potato varieties at CIP South America, China, Columbia, and Russia, and projects closer to home including AHDB. This work is also aligned with numerous PhD student projects funded via EASTBIO and the China Scholarship Council. We work closely with colleagues at The Sainsbury laboratory, and at the Universities of Cambridge, Cornell and Wageningen on all aspects related to potato disease resistance. Tolerance work will complement existing and recent externally funded research projects on natural resistance to PCN (BBSRC, AHDB) and is related to recent work funded by AHDB on determinacy. Dihaploid work will complement that being done elsewhere, e.g. JHL and Solynta who are interested in using DH lines in diploid breeding. The outputs of this work allow diploid genotypes to be used for further characterisation of important PCN resistances by creating further genetic crosses to be exploited within other projects. The new populations will also allow more detailed genetic analysis of other important potato traits, and some material will feed directly into commercial breeding programmes. The DSS will be based on the code used to develop the PCN Calculator, which has been developed over 2 decades through AHDB funding and contains much of the data required for this project. Updating this already familiar tool will allow considerable savings in terms of software development and data gathering while, at the same time, allowing new data and capabilities to be added to the available source code. We have also been given free access to the commercial Dutch DSS NemaDecide for testing and comparison to the PCN Calculator.

KE Audiences and Impact

Over 30 industry representatives took part in the PCN working group and agreed the contents of the final report (available at www.planthealthcentre.scot/publications/pcn-working-group-final-report). As well as growers and individual companies, the following organisations took part: BPTA, AHDB, FPSA, SAOS, NFUS, PBGA, SSCR and STET. In addition, there were 15 Scottish Government representatives, including the Chief Plant Health Officer for Scotland's (CPHOS) Office, SASA and plant health policy, plus 11 academics. The above audiences will be engaged in all aspects of the work, with others across the potato and flower bulb industry production chains also engaged throughout the programme. These groups will include those we have already engaged with through the RISS projects (see Key linkages section) and at our regular events including Potatoes in Practice and the Scottish Society for Crop

Research (SSCR) potato sub-committee and their stakeholder Winter meeting. This project aims to address all actions in the working group report over the suggested 5 year time scale to protect the future of the potato and ornamental industries. Major impacts are expected from this project including i) a reduction or cessation in the contamination of seed land by PCN in Scotland, ii) industry-applied methods for the clean-up and better management of contaminated land, and iii) an increased industry awareness of the PCN issue to allow different parts of the industry to work together to achieve i) and ii). Other major impacts will include a new PCN decision support system (DSS) for growers, a new method to identify groundkeepers for treatment, new resistance markers for breeding companies, application of an accelerated breeding technology, a new method to test varieties for PCN tolerance, and new IPM methods to control PCN. Overall, the work will have a major impact on sustainable potato and bulb production in Scotland. In terms of breeding for new varieties, we have links with relevant industry partners (including Agrico, McCain, Greenvale, Solynta, Simplot, JHL and Simplot) to ensure incorporation of developed markers into their breeding programmes. This aspect of the project has been developed in discussion with partners to ensure that our PCN marker research is focused on key resistances of relevance both to Scotland and beyond.

PCN also causes significant disease burdens to growers in developing nations and has recently been described in several countries in East Africa including Kenya, Uganda and Rwanda where potato is a staple crop. Our work on PCN in this project is relevant to several current and proposed global challenges research fund (GCRF) projects that are undertaken with NGO partners such as CIP in these regions. These include projects aimed at incorporating disease resistance into locally preferred cultivars. Resistance and other information from this project therefore have a direct route to development in these countries.

Work Planning and Timetable for Year 1: *Please include major milestones, (key research activities, deliverables, KE/impact events) and their timing. Please identify one member of staff responsible for delivery of each item.*

Year 1: 2021/22	Lead Responsibility	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Activity: O1.1	Thomson											M1.1 D1.1	
Activity: O1.2	Thomson											D1.2	M1.2 D1.3
Activity: O2.1	Blok									M2.1 D2.1			
Activity: O2.3	Wilson												
Activity: O3.1	Hein										M3.1		
Activity: O3.2	Chen											M3.6	
Activity: O4.1	Bryan		M4.1			M4.2					M4.3		
Activity: O5.1	Blok									M5.1			
Activity: O6.1	Wilson										M6.1 D6.1		
Activity: O6.2	Wilson												M6.2 D6.2
Activity: O6.3	Wilson								M6.3				
Activity: O7.1	Anderson			M7.1						M7.2 M7.3			
Activity: O8.1	Burgess												M8.1 M8.2 D8.1
Activity: O8.2	Burgess										M8.3		M8.4 M8.5 D8.2
Activity: O8.3	Burgess										M8.6		M8.7
Activity: O8.5	Burgess												M8.24

Work Planning and Timetable for Year 2:

Year 2: 2022/23	Lead Responsibility	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Activity: O1.3	Thomson			M1.3 D1.4									
Activity: O2.2	Anderson								M2.2				
Activity: O2.3	Wilson				M2.5					M2.6			
Activity: O2.4	Wilson												

Activity: O3.1	Hein			M3.2								M3.3	
Activity: O3.2	Chen					M3.7			M3.8				
Activity: O4.1	Bryan	M4.4 D4.1	M4.5			M4.6					M4.7		
Activity: O5.2	Jones												M5.2
Activity: O5.3	Bryan						M5.5						
Activity: O6.3	Wilson								M6.4				
Activity: O6.4	Wilson						M6.8			D6.5			
Activity: O6.5	Wilson									M6.9			
Activity: O7.1	Anderson									M7.2			
Activity: O8.3	Burgess						M8.9 D8.3						M8.8 M8.12
Activity: O8.4	Burgess												M8.12

Work Planning and Timetable for Year 3:

Year 3: 2023/24	**Lead Responsibility**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Activity: O2.2	Anderson								M2.3				
Activity: O2.3	Wilson									M2.7 M2.10			
Activity: O2.4	Wilson					M2.15							M2.14
Activity: O3.1	Hein		M3.4				M3.5					D2.1	
Activity: O3.2	Chen					M3.9			M3.10				
Activity: O3.3	Chen							M3.12					
Activity: O4.1	Bryan	M4.8 D4.2	M4.9			M4.10					M4.11 D4.3		
Activity: O5.2	Jones							M5.4					
Activity: O5.3	Bryan												M5.6

Activity: O6.3	Wilson								M6.5				
Activity: O6.5	Wilson								M6.10				
Activity: O7.1	Anderson									M7.3 D7.1 D7.2			
Activity: O8.3	Burgess												M8.16 M8.13
Activity: O8.4	Burgess												M8.21
Activity: O8.5	Burgess												M8.26

Work Planning and Timetable for Year 4:

Year 4: 2024/25	**Lead Responsibility**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Activity: O2.2	Anderson								M2.4				
Activity: O2.3	Wilson												M2.8
Activity: O2.4	Wilson												
Activity: O3.2	Chen				M3.11							D3.2	
Activity: O3.3	Chen			M3.13					M3.14				
Activity: O5.2	Jones						M5.4	D5.1					
Activity: O5.4	Jones						M5.8		M5.9	D5.3			
Activity: O5.5	Jones												M5.10
Activity: O6.3	Wilson							M6.6					
Activity: O6.4	Wilson							M6.7 D6.3 D6.4					
Activity: O6.5	Wilson								M6.11				D6.6
Activity: O7.1	Anderson								M7.4		M7.5		
Activity: O8.3	Burgess												M8.17 M8.14
Activity: O8.4	Burgess												M8.22

Activity: O8.5	Burgess												M8.27

Work Planning and Timetable for Year 5:

Year 5: 2025/26	**Lead Responsibility**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Activity: O1.4	Thomson										M1.4 D1.5		
Activity: O2.3	Wilson				M2.11				M2.13 D2.3		M2.12 D2.2		M2.9
Activity: O2.4	Wilson					M2.16							
Activity: O2.5	Wilson												M2.17 D2.4
Activity: O3.3	Chen		M3.15						M3.16			D3.3	
Activity: O5.3	Bryan										M5.7		D5.3
Activity: O8.3	Burgess												M8.18 M8.15 M8.19 D8.6
Activity: O8.4	Burgess												M8.23
Activity: O8.5	Burgess												M8.28

From: [REDACTED]
Sent: 17 August 2021 13:59
Subject: PCN working group recommendations funded!

Dear all,

You may have seen at Potatoes in Practice last week or in the media that Scottish Government has agreed to fund in full the actions arising from the recommendations in the PCN working group report that you all played such an important part in. The government asked that we write a more detailed proposal (attached), which has now been sent to them and we are awaiting a response, although the money seems to be assured. We will continue to update you as the project continues but a very important aspect, as you will remember, is the knowledge exchange part so we will certainly be in touch as the project unfolds to gather your views and knowledge as well as updating you on the project's progress.

Thanks again for all your help in making this possible and most of all for your willingness to work together to change the current PCN situation.

Regards

[REDACTED]

PCN Working Group project proposal - fina

Ps see Scottish Government press:

https://www.gov.scot/news/safeguarding-scotlands-bulb-and-potato-sector/