PFR SPTS No. 16363

P15-01: Increasing potato yield through understanding the impacts of crop rotations and soil compaction – Year 3

Sinton S, Dellow S, Shah F, Richards K, Michel A, Linton J

June 2018

Confidential report for:

Foundation for Arable Research
P15-01

PUBLICATION DATA

Sinton S, Dellow S, Shah F, Richards K, Michel A, Linton J. June 2018. P15-01: Increasing potato yield through understanding the impacts of crop rotations and soil compaction – Year 3. A Plant & Food Research report prepared for: Foundation for Arable Research. Milestone No. 75153. Contract No. 35052. Job code: P/411040/03. SPTS No. 16363.

Report approved by:

Sarah Sinton
Research Technologist, Field Crops
June 2018

Paul Johnstone
Science Group Leader, Field Crops – Sustainable Production
June 2018

CONTENTS

EXECUTIVE SUMMARY

P15-01: Increasing potato yield through understanding the impacts of crop rotations and soil compaction – Year 3

Sinton S[1], Dellow S[1], Shah F[1], Richards K[2], Michel A[1], Linton J[3]
Plant & Food Research: [1]Lincoln, [2]Auckland; [3]Foundation for Arable Research

June 2018

Investigations from Year One and Two of the FAR Sustainable Farming Fund project (P15-01) have shown that potato crop performance can be negatively affected by poor soil structural conditions and the presence of seed- and soil-borne diseases, and that these two yield limiting factors are often inextricably linked. The severity of these factors is in turn influenced by the cropping history of a field (crop type and associated cultivation practices), along with disease management of preceding seed generations (including during crop growth, winter storage and handling).

All 35 crops monitored in the first 2 years of this study exhibited *Rhizoctonia* stem canker symptoms with potential to limit growth during the tuber bulking phase. This was especially true for the crops grown in poorly structured soils (19 fields) that also harboured other pathogens, particularly *Spongospora* (21 fields). The work showed that yield was maximised by using whole seed (more vigorous than cut seed) and choosing fields with enhanced soil structure resulting from 7+ years of uninterrupted restorative crop growth (for example, grass). This was despite the continued presence of soil- and seed-borne disease and the fact that pre-plant potato cultivation negatively impacted some of the soil structural gains from the restorative grass phase.

Further work is needed to quantify the effect of crop type and cultivation history on soil physical quality, especially the cultivation undertaken immediately pre-potato planting, but is beyond the scope of the final year in this project. Instead, the team concentrated on measuring the contribution of seed-borne diseases on crop health.

The third year had three research components:

Firstly, a line of ‘Russet Burbank’ whole seed tubers was graded for visible *Rhizoctonia* black scurf (the resting structure or sclerotia, which can later cause stem canker) severity, using a standardised scale of 0%, 5%, 20%, 46%, 60% black scurf coverage. The tubers were either dipped or not dipped in formalin solution, and then planted in pathogen-free growing medium in planter bags (10 replicates). The resulting *Rhizoctonia* stem canker on the growing plants was just as severe for the 0% black scurf coverage (treated and untreated with formalin) as it was for the other four severity categories (formalin treatment average), with formalin treatment reducing overall severity by only 30% compared with the untreated controls. Implications are that an unknown proportion of commercial seed could be infected with *Rhizoctonia*, but without visible symptoms, and that formalin seed treatment may be only partially effective at controlling this disease. This warrants further investigation.

Secondly, a second planter bag experiment (10 replicates) used a random sample of commercially cut and Mancozeb-treated 'Russet Burbank' seed, arranged into categories relating to the number of cut sides (zero to three), half of which were also dipped in formalin to control surface diseases. Nine out of ten tubers with three cut sides and untreated with formalin failed to emerge, compared with only one out of ten tubers with three cut sides and treated with formalin. This reflects the amount of disease possibly present on cut seed. Increasing numbers of cut sides equated to increased variability in emergence rate and stem number, as well as reduced yields. In a field situation this could translate into a crop with a lowered yield potential and an unfavourable tuber size class distribution.

Thirdly, the health of seven commercial 'Agria' crops (harvested as G5, 2017–18) was monitored and compared with in-season health of the preceding seed lines (harvested as G4, 2016–17). A selected sample of the same G5 seed was grown in a controlled environment to estimate the potential incidence and severity of any seed-borne pathogens. For this study, all seed was planted whole. Amounts of *Rhizoctonia* stem canker were low in the G4 seed crops, G5 glasshouse plants and in all but one daughter crop, the latter of which was subjected to drought and flood conditions (Manawatu) during growth. *Spongospora* disease was scarce in the G4 seed crops and G5 daughter crops (some were grown in 'supressive' Pukekohe soils), but severe in the G5 glasshouse plants (this polycylic pathogen multiplies rapidly in optimum conditions). These results show that the presence of seed-borne inoculum is often highly likely, but if amounts are minimised through the supply chain, the impact on well-managed crops can also be minimal.

For further information please contact:

Sarah Sinton
Plant & Food Research Lincoln
Private Bag 4704
Christchurch Mail Centre
Christchurch 8140
NEW ZEALAND

Tel: +64 3 977 7340
DDI: +64 3 325 9607
Fax: +64 3 325 2074
Email: Sarah.Sinton@plantandfood.co.nz

1 INTRODUCTION

Intrinsic environmental conditions (climate and soil) in New Zealand give the opportunity for potato crops to regularly yield around 85 t/ha (Jamieson et al. 2006, 2009). Seed- and soil-borne disease and degraded soil structure are two main factors that are reducing this potential by 20–40% (Sinton et al. 2013, 2014, 2015, 2016, 2017).

Eighteen crops surveyed (located in both the North and South Islands) in Year 1 of this project (2015–16 season) followed this yield trend, with grower-measured yields ranging from 45 to 73 t/ha (14–47% yield loss, compared with a modelled potential yield from an average season). While multiple factors probably influenced yield, all crops developed the seed- and soil-borne disease *Rhizoctonia* stem canker and 10 of the 18 crops had *Spongospora* root gall infestation, the latter linked with previous potato cropping history. A concurrent glasshouse trial, using soil collected from the monitored fields and the same seed lines (treated with formalin, a surface sterilant), showed that some of the disease inoculum was also being transferred to the field by the seed.

In Year 1, 14 of the survey fields had soil aggregate stability values of around 1.5 mm mean weight diameter (MWD) or less, a key benchmark below which gives an increased risk of reducing crop yields below the regional average. Eight of these fields also had soil structural condition scores (a measure of root hospitality) of 5 or less (10 being highly conducive to root growth), where soils are increasingly resistant to root penetration. Ten fields had at least 10 years of arable or vegetable crops with no significant pasture restorative phases. Long-term arable cropping is known to reduce soil physical quality, making essential resources (water, air and nutrients) less available and thus reducing yield.

In Year 2, a four-plot experiment was set up in 15 commercial potato crops with four replicated treatment combinations. The fields covered a range of cropping history, including previous potato crops in the last 10 years (seven fields) or excluding them (eight fields), and either a predominant history of annual crops in the last 10 years (ten fields) or grass (five fields). The four plots were set up with two cultivars ('Russet Burbank' and 'Innovator') and two seed 'sterilisation' treatments (dipped and not dipped in a formalin solution). The same seed was also grown in pathogen-free potting mix in a glasshouse to check for seed-borne disease incidence.

Results showed that 7–10 years of grass in a 10-year crop history enhanced soil root hospitality (soil structural condition score was consistently more than 6, average soil aggregate stability of 1.9 mm MWD) to the extent that even though soil-borne disease incidence and severity was often greater, yields averaged 10 t/ha more than potato crops planted after a 6–9-year annual cropping history. In these latter fields, soil conditions were less suitable (soil condition score consistently 4 or lower and average soil aggregate stability 1.2 mm MWD).

Although the formalin treatment did slightly reduce stem canker severity in the glasshouse trial, all plants were infected with this disease and the majority also had root galls. Formalin dipping gave no control to either disease in the field trials.

Although the effect of variations in soil physical quality on potato production is clear, the relative contributions of seed- and soil-borne disease to daughter crops has remained an unsolved issue after the first 2 years of investigations. In Year 3, the project used three methods to trace sources of resultant incidence and severity of *Rhizoctonia* and *Spongospora* diseases:

1. An investigation of the relationship between black scurf severity on seed and the resulting disease severity and incidence on daughter plants (shade-house pot trial). Industry standards stipulate for *Rhizoctonia*, no more than 5% of a seed line (incidence) should have more than 5% tuber coverage of sclerotia (severity), the visible portion of *Rhizoctonia* infection. This assumes that minimising visible signs of disease on seed provides for an improved chance of a cleaner crop. However, this can be complicated by the fact that inoculum fragments not visible to the eye may still exist on the tubers.
2. An investigation of the effect of seed cutting on the resulting seed-borne disease severity and incidence on daughter plants (shade-house pot trial).
3. Comparison of the health of commercially-grown ‘Agria’ daughter crops (G5, 2017–18 season) with previously monitored mother seed lines (G4, 2016–17), and also with selected seed from the 2016–17 season which was subsequently grown in pathogen-free potting mix in a glasshouse (spring 2017) to check for the presence of seed-borne disease (Plant & Food Research SSIF funded projects).

2 MATERIALS AND METHODS

2.1 The effect of seed-tuber black scurf severity on subsequent *Rhizoctonia* disease incidence, severity and yield

This trial had five black scurf severity categories, two formalin dipping treatments and 10 replicates, giving 100 plots (pots in a shade-house).

Soil from fields of the 18 SFF crops surveyed in Year 1 (2015–16) was collected and placed into planter bags, and seed tubers from the matching seed lines were surface-sterilised to reduce seed-borne disease, planted and later assessed for soil-borne diseases. In the following season, formalin-dipped ‘Russet Burbank’ seed was planted in the same soil. This resulted in two seasons of consecutive potato crops, which induced severe black scurf disease (the resting spore stage of *Rhizoctonia* pathogen) on some of the daughter tubers. After harvest, all tubers (washed) were winter stored in a 4°C chiller and then on 30 October 2017 sorted into five black scurf severity classes: 0 = healthy, 1 = 5% coverage of black scurf on the tubers, 2 = 20% coverage, 3 = 46% coverage and 4 = 60% coverage (Figure 1, Figure 3) (20 tubers in each). Tubers exhibiting other *Rhizoctonia* symptoms such as physical deformity or ‘elephant hide’, were excluded from selection.

Figure 1. Daughter tubers grown in soil with a previous potato history, categorised for a range of black scurf tuber coverage severity classes; 0 = healthy, 1 = 5% coverage of black scurf on the tubers, 2 = 20% coverage, 3 = 46% coverage and 4 = 60% coverage.

Tubers were then divided into two groups, one of which was dipped in a 0.5% formaldehyde solution (now an industry standard, Falloon et al. 1997) for 4 min (135 ml formalin in 10 L water). The resulting tubers were stored in a 4°C chiller and planted on 1 November in individual 24 L planter bags filled with pathogen-free potting mix (SARDI Predicta Pt tested for potato pathogens) containing a balanced fertiliser mix of N, P and K. Two logging temperature sensors were buried randomly across the trial at seed tuber depth. Plant emergence was monitored daily and plants manually watered twice per week once established. Two weeks after the majority of plants were emerged, non-emerged bags were checked and tubers inspected for problems, and results recorded.

Near senescence (19 February, 108 days from planting), before stem death, plants were removed from bags, washed and underground stems scored for *Rhizoctonia* stem canker, roots scored for root gall severity and tubers scored for surface diseases:

Rhizoctonia stem canker and black scurf

- Severity of *Rhizoctonia* stem canker (RSC) on each stem of each plant was assessed using a 0 to 6 scale (Figure 2) depending on the amount of stem surface affected (0 = no disease, 1 = 1–10% surface affected, 2 = 11–30%, 3 = 31–50%, 4 = 51–80%, 5 = > 81% surface affected, 6 = dead stem), and the types of stem lesions (flecks, mild severity = 1, splits, moderate severity = 2 or brown lesions, greatest severity = 3) were also recorded. The overall stem canker severity score was calculated using both the severity score and the lesion type score, giving a maximum combined score of 18 (stem dead). Incidence of stem canker was assessed by counting the numbers of stems affected by the disease.
- Incidence of tuber black scurf was determined for all tubers from each plant. Severity of the disease was determined using a 0 to 4 scale (Figure 3), based on proportion of tuber surface affected (Falloon et al. 1995).

Spongospora root galling and powdery scab

- Incidence of *Spongospora* root galling was determined for each plant (presence/absence). Severity of root galling was assessed using a 0 to 3 scale (0 = no galls, 1 = <5 galls/four plants; light infection), 2 = 5–20 galls; moderate, 3 = >20 galls; severe).
- Incidence of tuber powdery scab was determined for all harvested tubers. Severity of the disease was determined using a 0 to 4 scale (Figure 3), based on proportion of tuber surface affected (Falloon et al, 1995).

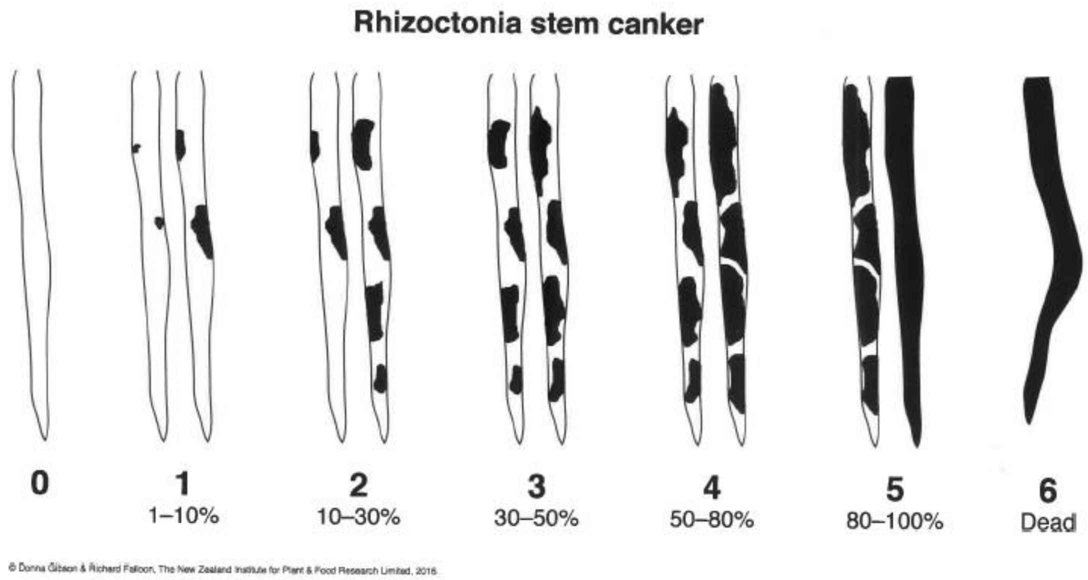

Figure 2. Severity scale (range 0 to 6) for *Rhizoctonia* stem canker (RSC).

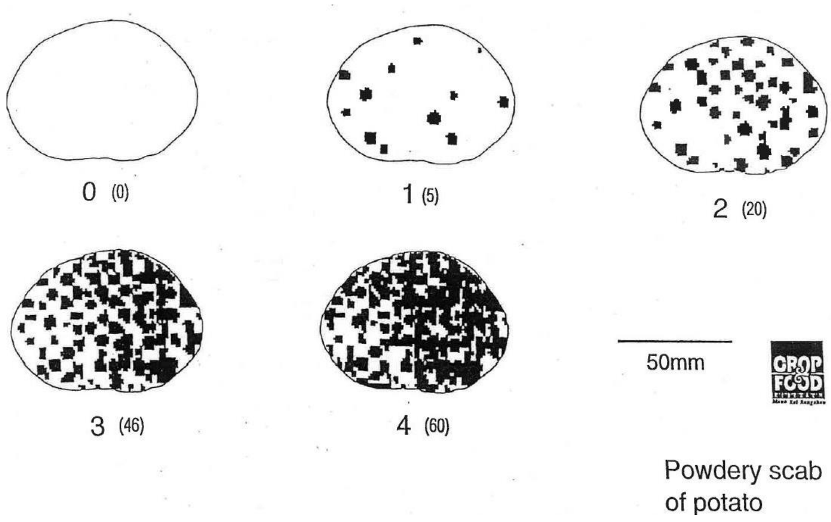

Figure 3. Severity scale (range 0 to 4) for powdery scab, also used to categorise tubers for black scurf severity.

The responses of RSC severity, fresh yield, and emergence were analysed using a mixed model approach, fitted with REML as implemented in Genstat (Genstat 17th edition). Assumptions were checked via standard residual plots and log transformations applied where needed. The incidence of black scurf (BS) on daughter tubers was low and therefore BS severity was analysed only when disease was present. It was analysed using a mixed model approach, fitted with REML, with a logarithmic transformation. The number of stems with RSC was analysed using Binomial hierarchical generalized linear model (HGLM) with a logit link, and the total number of stems was analysed using a Poisson generalized linear mixed model (GLMM). Fixed effects in all models were severity, formalin treatment and its interaction. Random effects accounted for the position of pots (Row, Column) within the glasshouse. Each variable was analysed separately.

2.2 The effect of seed cutting on subsequent *Rhizoctonia* disease severity, incidence and yield

This trial had four cut-seed categories, two formalin dipping treatments and ten replicates, giving 80 plots (pots in a shade-house). Pre-cut, treated and suberized (cut surface healed over) seed is normally planted within 2–3 days of preparation. However, the aim of this project was to compare seed-borne disease infection and plant vigour for seed with a varying number of cut sides.

On 19 October 2017, commercially treated ‘Russet Burbank’ cut seed was collected from a transport truck delivering seed for a commercial crop in Rakaia, Canterbury, and sorted in to four classes based on the number of cut surfaces: no cut surfaces = ‘whole’; one cut surface (halved) = ‘1 cut’; two cut surfaces = ‘2 cut’; three cut surfaces = ‘3 cut’ (Figure 4). On 31 October, half the seed from each cutting treatment was dipped in formalin (the other half not dipped), and then the total population was stored in a chiller at 4°C until planting on 1 November in individual 24 L planter bags filled with pathogen-free growing medium (SARDI Predicta Pt tested for potato pathogens) containing a balanced fertiliser mix of N, P and K. Two logging temperature sensors were buried randomly across the trial at seed tuber depth. Plant emergence was monitored daily and plants manually watered twice per week once established. Two weeks after the majority of plants were emerged, non-emerged bags were checked and tubers inspected for problems, and results recorded.

Figure 4. Commercially prepared 'Russet Burbank' seed, classed according to the number of cuts taken to create a desirable seed size: no cut surfaces = 'whole'; one cut surface (halved) = '1 cut'; two cut surfaces = '2 cut'; three cut surfaces = '3 cut'.

Near senescence (19 February 2018, 108 days from planting), before stem death, plants were removed from bags, washed and underground stems scored for RSC, roots scored for root gall severity and tubers scored for surface diseases as for the *Rhizoctonia* severity trial above.

Seed used in this experiment was also used for another experiment (a Plant & Food Research SSIF funded potato water use efficiency project) in a field situation in the same season. Disease development for the shade-house plants (grown in pathogen-free medium) and for those plants growing in the PFR trial (exposed to soil-borne disease) was compared.

The same statistical methods were employed as for the seed tuber black scurf severity trial, including for root gall severity and tuber powdery scab.

2.3 Comparison of the health of commercially-grown daughter crops with the same seed line grown in a pathogen-free environment

A Plant & Food Research (PFR) SSIF funded project monitored (weekly) six 'Agria' seed crops in Canterbury in the 2016–17 season (planted as generation 4) for seed- and soil-borne diseases. Seed was then collected from these crops and stored over winter in a range of conditions and planted in the 2017–18 season in a replicated trial located in a single commercial crop in Canterbury. Seed health for the six lines was also tested in a pathogen-free environment in a glasshouse. As an extension, two of the 'Agria' seed lines analysed during the 2016–17 season were monitored (as generation 5) for disease in 2017–18 in seven commercial paddocks (located in Pukekohe and Manawatu) for this project (Figure 5).

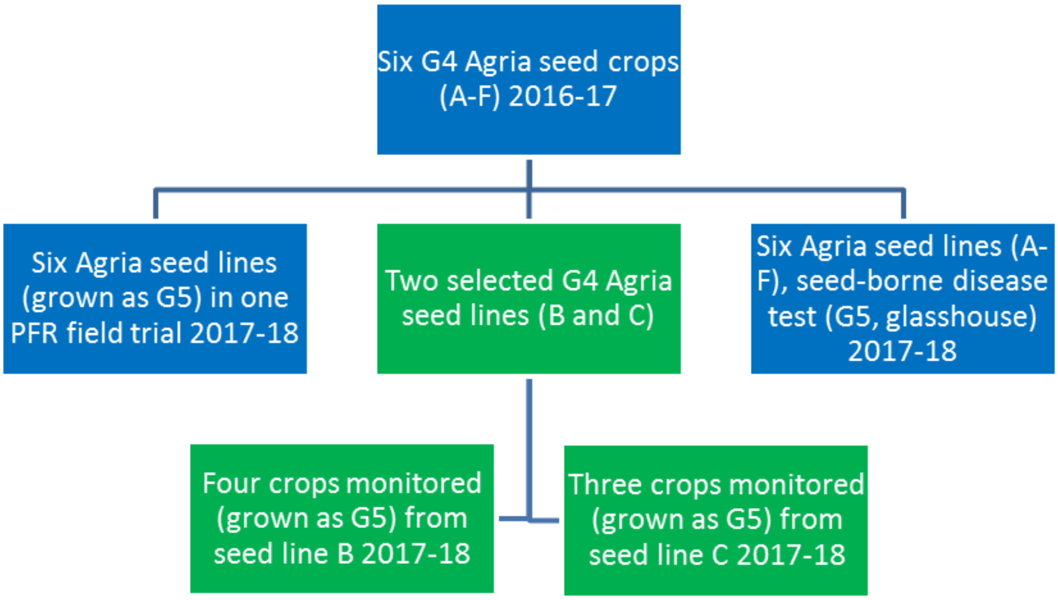

Figure 5. Sequential crop monitoring of 'Agria' seed and commercial crops. The blue boxes show work lead by PFR, and green boxes denote crops monitored for this project.

2.3.1 Commercial crop monitoring

At full canopy, each of the seven crops from the two seed lines (as generation 5) were visited and a 'W' shaped sampling pattern established in the crop, with nine sampling point locations referenced using GPS. Four plants were dug from each point and the underground stems/roots collected, washed and scored for diseases. At harvest, the same GPS locations were used to collect two tubers from two plants at each of the nine points, which were then washed and scored for diseases. The health of these crops was compared with that of the mother crops (generation 4, field grown, 2016–17) as well as to the resulting generation 5 crop, glasshouse grown in pathogen-free environment, to estimate the seed-borne disease component.

2.3.2 Glasshouse seed line health check

The health of the generation 5 seed resulting from the monitored mother crops (2016–17 season) was evaluated by planting eight replicates (tubers) from each line in a controlled temperature glasshouse on 19 September 2017 (Figure 5). Environmental conditions were set to enhance disease development and tubers were planted in individual 24 L planter bags filled with pathogen-free growing medium (SARDI Predicta Pt tested) containing a balanced fertiliser mix of N, P and K. Logging temperature sensors were buried randomly across the trial at seed tuber depth. Plant emergence was monitored daily and plants manually watered twice per week once established.

Near senescence (6 December 2017, 78 days from planting), before stem death, plants were removed from bags, washed and underground stems scored for RSC, roots scored for root gall severity and tubers scored for surface diseases as for the *Rhizoctonia* severity trial above.

The same statistical methods were employed as for the seed tuber black scurf severity trial.

3 RESULTS

3.1 The effect of seed-tuber black scurf severity on subsequent *Rhizoctonia* disease incidence, severity and yield

For the statistical analysis, all non-emerged plants were assumed killed by *Rhizoctonia* infection and were therefore given the maximum average stem disease score of 18 (dead stem). *Spongospora* root galls were present in moderate amounts equally in all treatments and therefore unlikely to introduce bias into yield results.

The original estimations of tuber black scurf (BS) severity on the seed tubers were conducted on a visual basis, thus increasing the potential for variability in the results. However, some clear trends are evident.

3.1.1 Emergence and stem number

All 10 seed tubers successfully sprouted for the treatments 'BS 0%' and 'BS 5%' (dipped and not dipped in formalin) (Table 1). Treatments with a BS severity of 20% or greater had between 1 and 3 seed tubers that did not emerge, due to the increased chance of 'nipping off' of developing shoots.

Emergence was quicker (P = 0.019, 22 days) for the 'BS 0%' treatment, non-formalin treated, compared with all other non-formalin treated severity categories (mean of 25 days). 'BS 60%', formalin treated took the longest of all treatments to emerge (29 days). Emergence in the severely infected treatments was most likely being delayed by fatal sprout damage from the *Rhizoctonia* pathogen.

Over all treatments, the predicted number of stems ranged from 1.6 to 5 per plant. The use of whole seed (more eyes and fewer injury sites than cut seed) probably maintained the chance for all categories of diseased seed tubers to successfully establish a number of stems.

Table 1. Plant emergence for a range of seed tuber black scurf (BS) coverage severities (%) and formalin treatments.

Seed tuber black scurf coverage %, formalin treatment	No. plants not emerged	No. plants emerged
BS 0%, no formalin	0	10
BS 0%, formalin	0	10
BS 5%, no formalin	0	10
BS 5%, formalin	0	10
BS 20%, no formalin	2	8
BS 20%, formalin	1	9
BS 46%, no formalin	1	9
BS 46%, formalin	3	7
BS 60%, no formalin	1	9
BS 60%, formalin	1	9

3.1.2 *Rhizoctonia* stem canker (RSC) and tuber black scurf

At harvest (late canopy growth stage, tops still green) there was no interaction between seed tuber black scurf severity treatment and formalin treatment for RSC severity (P = 0.56). On average, plants from all seed tuber black scurf categories had similar (P = 0.15) severities of RSC (a mean score of 8.4 for all treatments). However, the use of formalin consistently reduced RSC severity across all of the black scurf categories (P = <0.001, Table 2). Without formalin, on average, the RSC severity score was 10.1, and formalin dipping reduced RSC severity to a score of 6.9.

These results show that even tubers with no visible signs of black scurf ('BS 0%' treatment) were still carrying enough inoculum to inflict severe RSC on the resulting plant. This could be due to the fact that seed tubers with varying degrees of black scurf are commonly stored together, allowing the inoculum to spread. Additionally, while formalin dipping had some positive impact on reducing subsequent RSC severity, it is probably not an economically worthwhile exercise for this disease. The same trends were seen in Year 2 of this project.

Table 2. Predicted means for RSC severity for the formalin treatment; a score of < 6 = low yield reduction potential, 6 to 12 = moderate risk of yield reduction, > 12 = high risk.

Formalin	Not dipped	Dipped	LSD
RSC severity	10.1	6.9	1.8

The probabiltiy that RSC would occur was high (70 to 100%) for all treatments, and with the exception the 'BS 60%' treatment, the non formalin-dipped treatments were most likely (100%) to be infected (Figure 6).

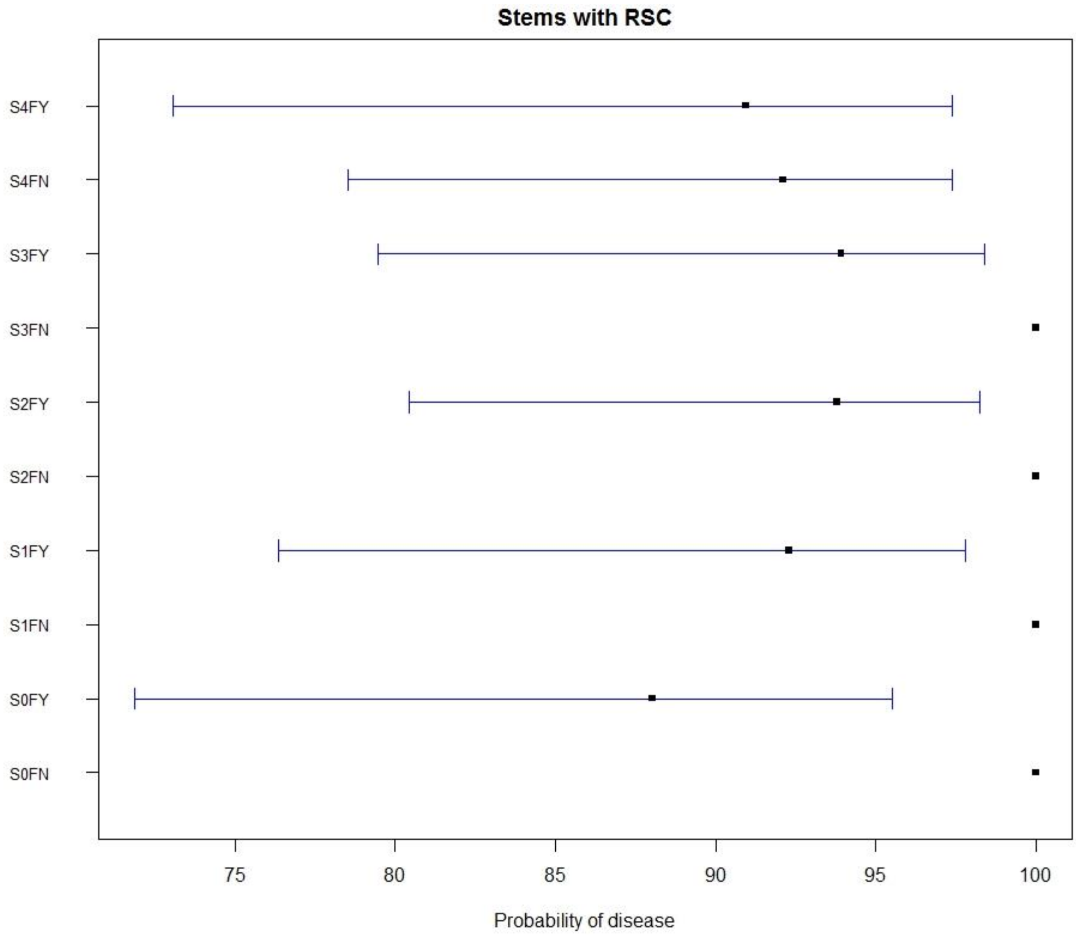

Figure 6. Probability of RSC infection (% likelihood) for black scurf severity and formalin treatments (0 = healthy, 1 = 5% coverage of black scurf on the tubers, 2 = 20% coverage, 3 = 46% coverage and 4 = 60% coverage. FY = dipped in formalin, FN = not dipped). There is a 95% confidence that the chance of RSC will fall within the percentage range indicated by the blue lines. The black square denotes the mean. Treatments are considered different where the lines do not overlap.

Mild black scurf (< 1% tuber coverage) was observed on the daughter tubers, which tended to be more severe (P = 0.058) where initial mother tuber black scurf was more severe. For the seed industry, this shows the importance of limiting inoculum build-up between generations.

3.1.3 Tuber yield

Yield tended to be greater (P = 0.049) from plants grown from seed that had a lower black scurf infection (the 'BS 0%' treatment, Table 3), compared with treatments 'BS 20%' and 'BS 60%'. This relationship was not strongly consistent, probably because visual assessment of the original black scurf coverage of the seed tuber may not have represented the true infection. Even though differences in stem canker severity were not picked up between the BS severity treatments (see section above), increased amounts of black scurf inoculum may have led to increased stolon 'nipping' (where tubers are severed from the plant by *Rhizoctonia* infection) where developing tubers (thus yield) can be lost. Because this happens during tuber initiation it is hard to detect at harvest.

Table 3. Fresh yield (predicted means) of the daughter tubers (g/plant or pot) for the seed tuber black scurf severity treatments (coverage %).

	Fresh tuber yield (g/plant)					
Black scurf severity treatment (tuber coverage %)	0%	5%	20%	46%	60%	avg.LSD
	786	689	606	652	599	137

3.2 The effect of seed cutting on subsequent *Rhizoctonia* disease severity, incidence and yield

For the statistical analysis, all non-emerged plants were assumed killed by *Rhizoctonia* infection and were therefore given the maximum average stem disease score of 18 (dead stem). Of the 10 plants in the ‘Cut 3, not dipped in formalin’ treatment, only one plant survived to provide data on yield and disease incidence and severity for this treatment. Thus, the results below should be treated with caution. Note also that formalin dipping of seed after cutting is not usual commercial practice.

3.2.1 Emergence and stem number

Of the plants that emerged, the ‘Whole’ and ‘Cut 1’ treatment plants emerged 1–2 days earlier than ‘Cut 2’ and ‘Cut 3’, suggesting the former was made up of more vigorous seed material.

All plants emerged from whole seed, dipped or undipped in formalin. Increasing numbers of plants failed to emerge from those tubers that had one or more cut surfaces and that were not dipped (Table 4). Whole tubers had fewer damaged surfaces to harbour disease infection and also had a greater number of eyes to increase the chance successful emergence. The reverse was true for cut seed. This was especially evident for the ‘Cut 3’, where nine of the ten plants from non-formalin treated seed did not emerge, compared with only two not emerging for ‘Cut 3’, formalin-treated seed. This suggests that the plant loss may have occurred either through lack of eyes (blind seed; not a common problem for the ‘Russet Burbank’ cultivar) or the presence of disease on the cut surfaces, killing sprouts (known as ‘nipping off’ when caused by *Rhizoctonia*) and/or rotting tubers.

Table 4. Numbers of emerged and not-emerged plants (of 10 replicates) for each treatment 6 weeks after planting.

Treatment	Not emerged	Emerged
Whole, no formalin	0	10
Whole, formalin	0	10
Cut 1, no formalin	2	8
Cut 1, formalin	1	9
Cut 2, no formalin	3	7
Cut 2, formalin	1	9
Cut 3, no formalin	9	1
Cut 3, formalin	2	8

'Cut 2' and 'Cut 3' treatments had a lower average stem number (2.0 and 1.9 stems per plant respectively) than "Whole' or 'Cut 1' (3.5 and 4.6 stems per plant) (Figure 7). Undipped seed from the 'Cut 2' and 'Cut 3' treatments had more variable and/or lower stem number than dipped seed of the same treatments. This could be indicating that multiple cut surfaces leads directly to increased variability in eye number, and/or that dipping cut seed in formalin helps to reduce sprout loss by limiting disease.

These trends shows that stem number was affected by the way a tuber had been cut, which could lead to further unwanted variability in tuber number and size in the subsequent crop.

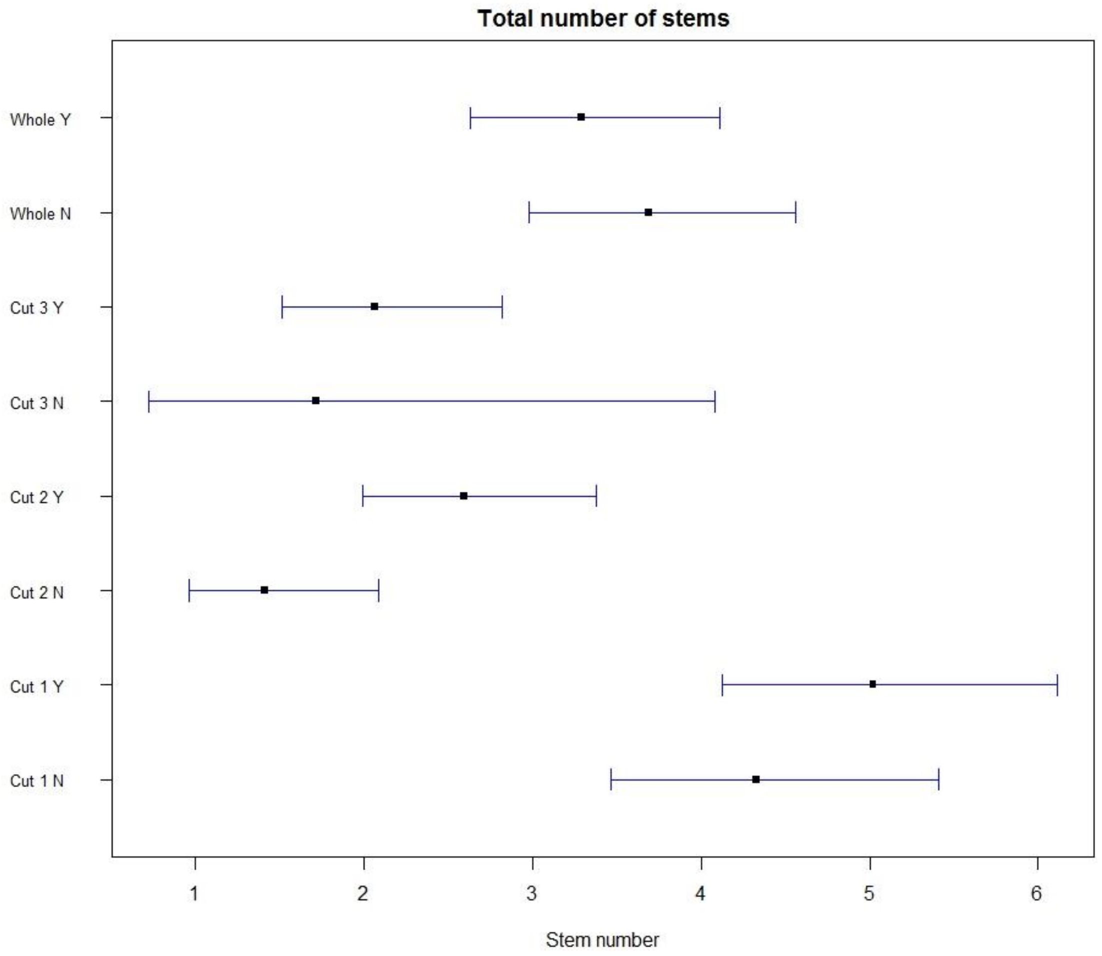

Figure 7. Range and mean for number of stems per plant for the cut and formalin (N = no formalin Y = formalin dipped) treatments. There is a 95% confidence that the stem numbers for each treatment will fall within the range indicated by the blue lines. The black square denotes the mean. Treatments are considered different where the lines do not overlap.

3.2.2 *Rhizoctonia* stem canker and tuber black scurf

Seed material used in this trial was not assessed for presence of black scurf. However, assuming that the principle cause of non-emergence was sprout 'nipping off' by *Rhizoctonia*, the non-appearance of all plants was scored as 'dead' and given the maximum score of 18.

There was no interaction between the use of formalin and cutting treatment (*P* = 0.105), but the mean RSC severity score was higher (*P* = 0.043) for the non-formalin treatment (RSC score of 10.8), compared with formalin dipping (RSC score of 8.8) (Table 5).

Table 5. Predicted means for RSC score for the formalin treatments (N = no formalin, Y = formalin dipped), across the cut treatments (i.e. no interaction).

Formalin	N	Y	LSD
	10.8	8.8	1.9

This shows that formalin can reduce the severity of surface diseases but may not eliminate them. An RSC score greater than six has been shown to cause enough damage to slow yield accumulation in a commercial crop (Sinton et al. 2015).

The effect of seed cutting on RSC severity was highly significant (P = <0.001) due to the non-emergence of nine out of 10 plants from the 'Cut 3', non-formalin treatment (treated as 'dead') (Table 6). This treatment had an RSC score of 13.2, which was significantly greater than the 'Whole' (8.4), 'Cut 1' (9.8), and 'Cut 2' (7.8) treatments.

Table 6. Predicted means for RSC for the cut treatments, across the formalin treatments.

Cut treatment	1	2	3	Whole	avg.LSD
	9.8	7.8	13.2	8.4	2.7

RSC incidence was high, with 100% incidence (i.e. all stems of every plant) in four of the eight treatments ('Whole' with and without formalin treatment, 'Cut 1' with formalin, 'Cut 3' with formalin). All other treatments had at least 50% stems infected with RSC. This shows that any existing level of *Rhizoctonia* infection on seed will most likely affect all stems of those plants. Also, even with a similar amount of RSC infection, plants resulting from whole seed yielded more than some of the cut treatments (see Section 3.2.5)

There was only light, intermittent infection (< 1% coverage of the tuber) of tuber black scurf at harvest, and severity was not related to any treatment. Incidence of black scurf varied from none seen in 'Cut 3' and 'Cut 2', no formalin treatments to ~15% of tubers infected in 'Whole' and 'Cut 1' treatments.

3.2.3 *Spongospora* root galls and powdery scab

There was no interaction between the cut and formalin treatments for *Spongospora* root gall severity (P = 0.279). However, there were apparent differences between cut treatments (P = <0.001) due to the only surviving plant in the 'Cut 3, not dipped' treatment having a low infection (0.88 of a maximum score of 3, Table 7). In reality, root gall severity was moderate to high in all treatments. Root gall incidence per plant was high throughout all treatments, with a 95% certainty that all treatments had between a 40 and 100% risk of infection. This shows that *Spongospora* sporosori (resting bodies) must have been present on much of the seed material. Temperature (15–25^{o}C) and moisture (free water running through the growing medium regularly during irrigation events) conditions in the shade-house were subsequently conducive to multiple zoospore releases from this polycyclic pathogen (Brierley et al. 2008).

Table 7. Predicted means of root gall severity for the formalin and cut treatments. 0 = no galls, 1 = <5 galls/four plants; light infection), 2 = 5–20 galls; moderate, 3 = >20 galls; severe. N = no formalin, Y = formalin dipped.

Formalin	N	Y
Cut (no. sides)		
1	2.9	2.4
2	1.1	1.8
3	0.9	2.1
whole	2.6	2.8
avg.LSD	1.2	

Powdery scab severity on the harvested tubers was light (<1% coverage) and did not relate to treatment.

3.2.4 Seed- and soil-borne disease comparison with field-grown crop

Disease results found in the pot trial were compared with those of a bed-shape by seed depth experiment conducted (2017–18) in a grower's field, where seed from the same source was used for both situations. In the field, RSC had developed equally on stems from all bed shape and seed depth treatments by the mid to late canopy growth stage. RSC severity score per stem averaged 7.6, comparable with the amount seen in the shade-house pot trial (average 8.6, excluding the 'Cut 3' treatment). Both populations showed symptoms of RSC developing from the mother tuber end of the stem, but the field crop had additional symptoms of lesions forming near the ground surface. This latter characteristic could be associated with infection caused by a soil-based pathogen.

3.2.5 Tuber yield

There was no interaction between the cut and formalin treatments for tuber yield, but there were differences between the cut treatments (*P* = <0.001, Table 8), remembering results are to be treated with caution as only one plant of 10 survived in the 'Cut 3, not dipped' treatment. Both the 'Whole' and 'Cut 1' treatments had a greater yield (861 g per plant and 828 g per plant respectively) than the 'Cut 2' and 'Cut 3' treatments (436 g and 531 g, or approximately 43% yield loss). These effects are also likely to occur in a field situation, where weak plants become out-competed not just for light (in a pot trial environment), but also for water and nutrient resources. These findings align with results from a Canterbury crop survey (Sinton et al. 2013) where individual weak plants in several commercial crops were identified and yielded 28 to 80% less at harvest than their more vigorous counterparts.

Table 8. Fresh yield (statistically-predicted means) of the daughter tubers (g) for the cut treatments.

	tuber fresh yield (g/plant)				
Cut (no. sides)	1	2	3	Whole	avg.LSD
	828	436	531	861	227

The relative importance of these results is reflected in the proportions of cut-side categories in the population. Of the 251 seed tubers in the random sample taken from a seed delivery truck, 22% were whole, 42% had one cut side, 18% had two cut sides and 18% had three cut sides. From a yield perspective, this means that 36% of the planted population (two and three cut sides) may have a compromised yield ability.

3.3 Comparison of the health of commercially-grown daughter crops with the same seed line grown in a pathogen-free environment

3.3.1 'Agria' seed crop (G4) health

For the six 'Agria' seed crops monitored in the 2016–17 season, RSC severity remained well below the yield limiting threshold (determined from previous research, Sinton et al. 2015) of a score of 6, although Crop E had a consistently greater RSC severity than the other crops (Figure 8).

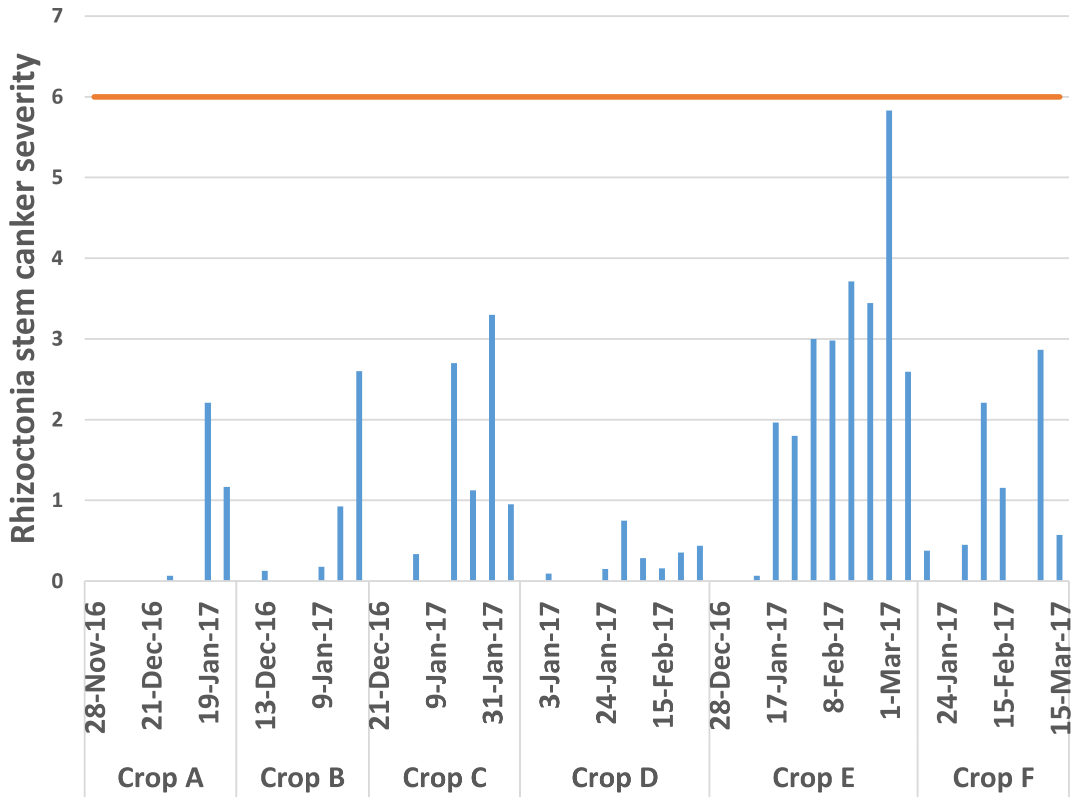

Figure 8. RSC severity at weekly intervals (not all dates shown) for six 'Agria' seed crops during the 2016–17 season. A score of 6, beyond which a yield penalty could occur (red line). The maximum score is 18 = stem killed by RSC. In this study, the commercial crops resulting from crops B and C were followed.

RSC incidence, typically variable across fields, ranged from low (Crop D, ~20% stems infected) to high (Crop E, >90%). RSC incidence was greater in Crop C than Crop B, but both had a lower incidence than Crop E (Figure 9).

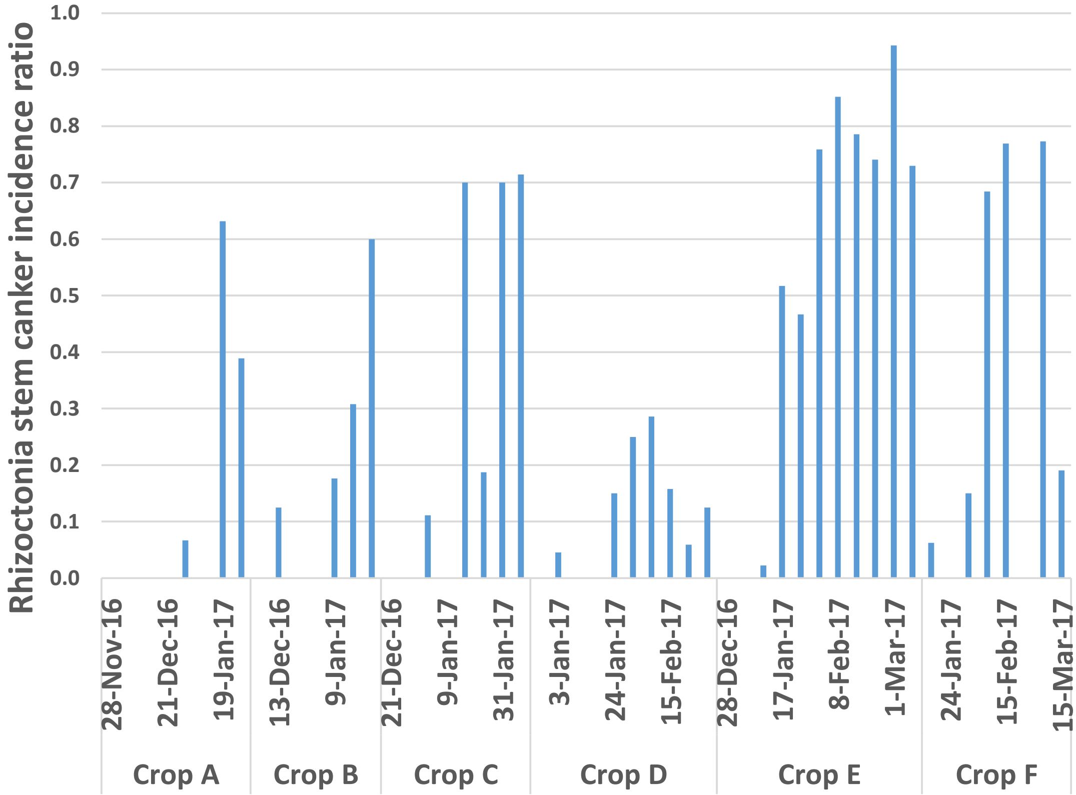

Figure 9. *Rhizoctonia* stem canker (RSC) incidence at weekly intervals (not all dates shown) for six 'Agria' seed crops during the 2016–17 season. An incidence of 1 = every stem had RSC symptoms. In this study, the commercial crops resulting from crops B and C were followed.

Crops B and C were grown in fields that had not grown potatoes in at least the last 7 years, which probably assisted in limiting the build-up of potato-related pathogens in the soil. However, their previous cropping history was diverse. For Crop B, grass dominated the field history and winter forage rape was the last crop before potatoes. For Crop C, cereals dominated the field history. Judging by the amounts of disease measured in the crops that season, previous generations of these lines probably also had low incidence and severity of *Spongospora* and *Rhizoctonia* diseases.

Although *Rhizoctonia* disease severity increased towards the end of crop growth (Figure 8), this was probably not a dominant yield limiting factor, as seed crops are usually sprayed off before natural canopy death to control tuber size. However, the mere presence of *Rhizoctonia* gave potential for an unknown degree of disease transfer to the growing daughter crops.

No root galls were detected on plants from the sampled areas of the seed crops, and no *Spongospora* powdery scab lesions were seen in the harvested tubers.

3.3.2 Glasshouse crop (G5) health

Glasshouse plants grown from Crops B and C had low RSC severity (an average score of <1) at the late canopy growth stage, which was unlikely to affect crop productivity. RSC incidence was also low to moderate (30–40% chance). This shows the benefits of maintaining low disease incidence and severity through the seed crop generations.

Root gall incidence (90% chance) and severity (moderate to severe numbers of root galls per plant) was significant when grown under glasshouse conditions, which were deliberately set to favour disease expression. *Spongospora* is a polycyclic pathogen and probably went through several lifecycles in this environment, producing many root galls. However, the glasshouse assay did demonstrate that the *Spongospora* pathogen was present on most seed tubers. Even though high-risk, *Spongospora* incidence and severity can remain low in subsequent crops if conditions are less suitable for disease development.

3.3.3 'Agria' daughter crop (G5) health

The range of daughter 'Agria' crops from seed lines B and C and their locations are shown in Table 9. All crops were planted using whole seed and were grown in either the Pukekohe district (four crops) or in Manawatu (three crops).

RSC incidence was low to moderate for six of the seven crops, averaging between 1 and 40% of stems showing symptoms. Planting whole, relatively clean seed helped keep amounts of disease low. However, Crop B1 was the worst affected with a 70% RSC incidence. Additionally, RSC severity was greater for Crop B1 (an average score of 4) than the other six crops where amounts were less (a score of < 2). The B1 crop was under stress for much of the season; flooded during early growth and then subjected to a 4–6-week drought during tuber bulking. These conditions left the crop vulnerable to disease.

Rhizoctonia black scurf was present (low severity) at final harvest on tubers of crops B1, B4, C1, C2 and C3, with incidence ranging from 3 to 56%, showing that this pathogen was present on seed line or in soil at the time the crop was grown. Black scurf can develop during storage; this is a problem when potatoes are later to be sold as seed.

No *Spongospora* root galls were observed in the seven crops, even though 'Agria' is a susceptible variety and high incidence and severity was observed for the glasshouse plants. Pukekohe soils are known to have a suppressive effect on the *Spongospora* pathogen. However, 3% of the final harvested tubers from crops B3 and C3 (Pukekohe grown) did exhibit powdery scab symptoms at harvest.

Table 9. Locations of daughter crops from seed crops B and C, and RSC incidence and severity, and tuber diseases powdery scab, black scurf and common scab for four daughter crops ex seed crop B and three daughter crops ex seed crop C.

Seed crop	Daughter crop	Location	RSC incidence (% of stems)	RSC severity 0 = none, 18 = dead stem	Powdery scab % incidence on tubers	Black scurf % incidence on tubers	Common scab % incidence on tubers
Crop B	1	Manawatu	70	4.0	0	3	54
	2	Pukekohe	30	0.9	0	0	69
	3	Pukekohe	40	1.7	3	0	67
	4	Manawatu	1	0.2	0	3	53
Crop C	1	Pukekawa	40	1.5	0	56	100
	2	Manawatu	20	1.0	0	31	36
	3	Pukekohe	20	1.1	3	6	17

Common scab was not seen in seed crops but was prevalent on tubers in all daughter crops at final harvest. This suggests that soil pH levels (> 5.2) or dry conditions may have favoured the disease, which is not known to be yield-limiting but can cause cosmetic damage and sometimes affect marketability. 'Agria' is moderately susceptible to this disease.

4 DISCUSSION AND CONCLUSIONS 2015–18

Diseases caused by soil-borne pathogens result in serious yield losses to many crops, including potatoes. The widespread occurrence of soil-borne pathogens in natural habitats is rare, but outbreaks of soil-borne diseases in agricultural fields are common, due to the frequent growing of susceptible crops in the same soil. Consequently, pathogen populations build up over time. Potato seed planted in *Rhizoctonia*-infested field can produce infected daughter seed tubers which, even when planted in clean field, often produce infected potato crops. The visual selection of asymptomatic seed tubers is the cheapest way to screen seed lines, but does not guarantee pathogen-free material. Treating these screened tubers with a registered fungicide is the current method for minimising potato crop infection by *Rhizoctonia*. In order to assist the removal of infested but asymptomatic seed tubers, a more rigorous tuber grading method, for example, based on DNA technology, is highly desirable.

The practice of seed potato cutting is common in many potato growing countries and has the advantage of reducing the cost by maximising the seed usage, and offering uniformity in seed size. However, the now well-documented negative effects include the potential for pathogen transmission, blind seed, increased risk of seed tuber decay after planting, and reduced plant vigour and production (Platt 1989; Strange & Blackmore 1990). Conversely, in line with our findings, whole potato seed had higher yield than the cut seed, even though disease incidence and severity was similar.

Since 2015 (when this project was initiated), a number of concurrent projects have been conducted to investigate sources of seed- and soil-borne diseases and how to mitigate them:

- This 3-year project, which also included testing the effectiveness of using a biofumigant crop to reduce soil-borne disease immediately prior to a potato crop.
- Two FAR-led in-furrow pesticide (potato registered) type and rate experiments (Linton et al 2015, 2016).
- One FAR-led project testing the effectiveness of formalin as a seed sterilant (Linton et al, 2018. In press).
- A PFR-led and funded multi-year project gauging the health of seed and subsequent daughter crops (under analysis).

In all, 54 potato crops were investigated to help identify key factors influencing growth and ultimately, yield. Main findings were:

- *Rhizoctonia* disease (stem canker) was found in all crops and in 28 of those, the presence of stem canker probably restricted production, especially when occurring in conjunction with degraded soil structure and *Spongospora* disease. No pesticides conclusively controlled this pathogen, and our results are consistent with previous reports (e.g. Platt 1989) where none of the commercially applied fungicide seed treatments had provided reliable *Rhizoctonia* disease control.

- *Spongospora* disease (root galls) was found in 25 of the crops, with the capacity to slow plant function, especially in conjunction with degraded soil structure and *Rhizoctonia* disease. No pesticide conclusively controlled this pathogen.
- Industry and commercially-led soil-borne disease pesticide efficacy studies are being conducted with little regard for the effect on the relative disease severity of underground stems, roots and tubers (yield is the usual parameter for relative efficacy). A method has been developed, and refined by the PFR team, to rate the incidence and severity of *Rhizoctonia* (canker, tuber black scurf) and *Spongospora* (root galls, powdery scab) diseases with respect to likely crop performance impact (paper underway). This should provide a tool to help the industry gauge the likely effectiveness of any method or product testing disease control.
- Work in Year 2 of this project showed that soils from long-term pasture (7 years or more) provided an improved rooting environment for potatoes, compared with those with a history of annual cropping, as demonstrated by increased yields that were measured. This was even though incidence of soil-borne disease was similar or sometimes greater in the ex-pasture potato crops. Long-term pasture increases the proportion of organic matter and soil biota, improves drainage, root exploration and fertility. Conversely, annual cropping involves additional cultivation, which can degrade soil structure, and often involves the growing of weak-rooted crops that do not strongly contribute to long-term soil organic matter build up. Field selection, based on cropping history, could be an alternative approach to improving yields and reducing input costs, given the ineffectiveness of chemical disease control.
- Work in Year 3 of this project showed that the use of cut seed increased the potential for variability in emergence rate, early plant survival, stem number and ultimately yield and tuber quality. The industry is already moving away from this practice towards the use of whole seed.
- Industry standards stipulate for *Rhizoctonia*, no more than 5% of a seed line (incidence) should have more than 5% tuber coverage of sclerotia (severity), the visible portion of *Rhizoctonia* infection. For *Spongospora*, the tolerance is 1%. The success of this method is limited by the fact that pathogen fragments not visible to the eye may still exist on the seed tubers. This probability was illustrated by the findings of the seed-tuber black scurf trial conducted for this project. Recent related work has shown that for *Rhizoctonia* and *Spongospora*, the same disease incidence and severity patterns (i.e. stem canker and root galling) expressed during seed crop growth are likely to be observed in following seed or production crops. Targeted in-season testing (while out scouting for virus and TPP infected plants), could be a simple method to help quantify the degree of disease risk more accurately than the current system used by the industry, which does not account for asymptomatic disease presence.
- The glasshouse experiment (reported here and conducted by PFR), using pathogen-free growing medium, showed that most of the seed tested was infected (mostly invisibly) with *Rhizoctonia* and *Spongospora* diseases. While formalin dipping of the seed reduced *Rhizoctonia* disease severity in the shade-house environment (this project), this treatment has proved ineffective in field-grown crops (Sinton et al. 2017).

5 ACKNOWLEDGEMENTS

The project team would like to thank North Island growers for allowing access to their 'Agria' crops and seed merchants for their help in tracing seed material. Plant & Food Research staff Cameron Marshall, Mika Brown, Jian Liu and Nathan Arnold are thanked for their assistance.

6 REFERENCES

Brierley J, Lees A, Wale S 2008. Powdery scab – Strains and conducive conditions. UK Potato Council Research Review.

Falloon RE, Genet RA, Wallace RA, Nott HM, Marshall JW, Bulman SR, Fletcher JD, Braam, WF 1997. Strategies for control of powdery scab of potato. NZ Vegetable & Potato Growers' Federation Inc., and Foundation for Research, Science and Technology. CropInfo Confidential Report No. 446.

Falloon RE, Viljanen-Rollinson SLH, Coles GD, Poff JD 1995. Disease assessment keys for powdery and downy mildews pf pea, and powdery scab of potato. New Zealand Journal of Crop and Horticultural Science 23: 31–37.

Jamieson PD, et al. 2009. Water and nitrogen uptake and responses in Models of Wheat, Potatoes, and Maize. *In:* Liwang M, Lajpat A, Bruulsema T, eds. Quantifying and understanding plant nitrogen uptake systems modelling. Boca Raton, Florida, United States, CRC Press. Pp. 127–146.

Jamieson PD, et al. 2006. The Potato Calculator: A tool for scheduling nitrogen fertilizer applications. Agronomy New Zealand, Proceedings 36: 49–53.

Linton J, Falloon R, Shah F, Sinton S, Meenken E 2016. Management of soil-borne diseases of potatoes: assessment of pre-planting pesticide treatments for effects on soil-borne diseases and tuber yields. FAR report.

Linton J, Sinton S, Falloon R, Shah F, Richards K, 2017. Management of soil-borne diseases of potatoes: Investigating the effect of pre-plant pesticide treatments on soil-borne diseases and tuber yields. A Plant & Food Research report prepared for: Foundation for Arable Research. SPTS No. 14979.

Platt HW 1989. Potato growth and tuber production as affected by inoculation of cut and whole seed with *Rhizoctonia* solani (AG3) and the used of seed treatment fungicides. American Potato Journal 66: 365–378.

Sinton S, Dellow S, Shah F, Richards K, Michel A, Tregurtha C, Linton J 2017. Increasing potato yield through understanding the impacts of crop rotations and soil compaction – data report, year 2. Plant & Food Research confidential report no. 15420.

Sinton S, Falloon R, Shah F, Dellow S, Michel A 2015. Potato yield gap 2014–15. A Plant & Food Research report prepared for: Sustainable Production potato core funding. Milestone No. 58682. Job code: P/421024/01. SPTS No. 11950.

Sinton S, Falloon R, Brown H, Tregurtha C, Michel A, Dellow S, Reid J, Shah F, Pethybridge S, Searle B 2013. Potato yield gap investigation 2012-13. Plant & Food Research confidential report no. 8706.

Sinton S, Falloon R, Shah F, Meenken E, Michel A, Dellow S, Pethybridge S 2014. Potato yield gap 2013-14. Plant & Food Research confidential report no. 10111.

Sinton S, Falloon R, Shah F, Dellow S, Michel A, Tregurtha C, Meenken E, Linton J 2016. Increasing potato yield through understanding the impacts of crop rotations and soil compaction – data report, year 1. Plant & Food Research confidential report no.13674.

Strange P, and Blackmore K 1990. Effect of whole seed tubers, cut seed and within row spacing on potato (cv. Sebago) tuber yield. Australian Journal of experimental Agriculture 30: 427–431.

APPENDIX

UK Potatoes September 2015 travel report, Jen Linton

Nick Pyke and Jen Linton visited the UK with the objective of gaining a better understanding of Potato Research in the UK and further their information on what is currently taking place within the research space that will link and build on the recently funded three year SFF looking at crop rotations and biofumigation to increase yield.

Nick and Jen met with Mike Storey (ADHB Potatoes), David Firman and Mark Stalham (NIAB TAG), Peter Urwin (Leeds University) and a mixture of researchers at James Hutton Institute.

Key points related to the SFF project are:

- The major research issues for potatoes in the UK are yield and soil quality. These align with key potato research issues in NZ.
- Bio fumigant crops do appear to have some value and there is good scientific data on management of the different species to maximise release of Bioactives. However, there is little quality data on the efficacy against soil borne microbes to date. Leeds University have a 4-year project looking at bio fumigant effect on soil borne pathogens in potatoes. Strong focus on looking at the glucosinalate and isothyocynate profiles of both mustard and radish. Field trials are in their first year of determining factors like cultivar and seed rate and their subsequent level of biofumigant level.
- Incorporation of the crop is also something of importance and to be looked at in Year 2 and 3. Initial experiments show 50% flowering has the highest concentration. Agronomic inputs, e.g. N was also a focus to see if this changed the biofumigant activity (Taking the crop through to flowering could have cross pollination issues in NZ).
- Cover crops and biofumigant crops can provide yield benefits in some situations. It is not clear what the economic benefits or costs are. Similarly it is often not clear if the benefits are due to the crop rotation (break), the increased organic matter (cover crop) or the bioactives produced from the crop (isothyocynates). At present the matching of the right crops, cultivars to soil problems is not possible. Further work is under way in the UK.

A great relationship was formed with David Firman with him subsequently travelled to NZ for our winter conference and multiple grower field days.

DISCOVER. INNOVATE. GROW.