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P17-05: The effects of formaldehyde potato seed treatment on plant health and yield

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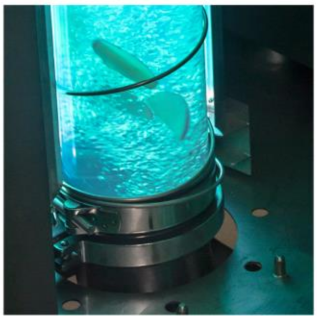


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1 INTRODUCTION

The yield-limiting potato diseases *Rhizoctonia* stem canker and *Spongospora* root galls are commonly present in many New Zealand potato crops. *Rhizoctonia solani* can cause early damage to developing tubers through stolon and root nipping, and later to mature plants through the formation of stem canker. If stolons are severely affected, tubers are unable to form. Root galls restrict uptake of resources by infecting the wider root network. To control these diseases, fungicides and pesticides are routinely applied to seed tubers and cropping soils at the time of planting.

Previous work (Linton et al. 2015–16 and 2016–17) has strongly indicated that commonly used pesticides are in fact not controlling these two important soil-borne diseases. The 2015–16 study found there was no tangible yield advantage from any of a range of different pre-planting pesticide treatments including Nebijin, Exp Trt F15/02 and 03 – penflufen, and combinations of Monceren and Amistar (single and double rate).

In the 2016–17 season, the products Nebijin, Monceren and Amistar were again tested, along with Pinnacle®, Maxim® and formaldehyde (the latter, which is not registered for use on potatoes, was used as a seed dip). Yield reductions were recorded from some of the treatments, including Maxim, Monceren × 2 rate + Amistar × 2 rate and Nebijin and formaldehyde.

Observations of disease development in various studies have shown that the use of whole seed tubers (compared with cut seed) may result in increased plant vigour, helping to reduce the effects of seed-borne *Rhizoctonia solani* and *Spongospora*. Cut seed may bring additional pathogen inoculum to a crop, spread and deposited on seed tubers during cutting operations.

In this trial, a range of formaldehyde rates (0.5% – conventional, 1% and 2%) along with a control treatment, were further tested as a method of controlling seed-borne disease for whole and cut seed. Their subsequent effect on yield was also investigated.

2 METHODS

2.1 Trial site and treatments

The trial was carried out at Seadown, South Canterbury during the 2017–18 season, within a commercial potato crop. Formalin contains the active ingredient formaldehyde at a concentration of 40% and the optimum rate for dipping seed potatoes is 0.5% formaldehyde (Falloon et al 1997). In this trial there were four treatments of 0.5%, 1% and 2% formaldehyde and a control (no dipping) (Table 1). These rates were applied to both cut and whole seed, giving a total of eight treatments. Seed was dipped as whole in the various formaldehyde solutions, then half were cut once (by hand). The trial had six replicates.

Table 1. Treatments showing formaldehyde rate applied to whole and cut seed tubers.

Treatment	Cut or Whole	Formaldehyde rate
1	Whole	Untreated
2	Whole	0.5%
3	Whole	1.0%
4	Whole	2.0%
5	Cut	Untreated
6	Cut	0.5%
7	Cut	1.0%
8	Cut	2.0%

2.2 Crop planting and management

The trial was planted on 24 October 2017 using a two row commercial potato planter. Plots were four rows wide by six metres long. Seed was placed on the planter cups individually to ensure no misses and a two-seed gap was left between plots. The cultivar used for the trial was ‘Innovator’, as was the remainder of the commercial paddock. All inputs and crop management after planting including water, insecticides, fungicides and fertiliser were applied by the grower.

2.3 Emergence

The trial was assessed for emergence and vigour six weeks after planting (7 December 2017). Due to large plot size and a wide variation in plant emergence rate, emergence was estimated as a visual percentage. A zero percent score was given where no plants in the plot had emerged and 100% given where all plants had emerged. Vigour was scored on a 1–9 scale with 1 = poor vigour and 9 = strong vigour.

2.4 Disease assessments

Incidence and severity of diseases were assessed at three crop growth stages (emergence, 7 December 2017; full canopy, 15 January 2018; and late canopy, 18 February 2018). At these stages, soil-borne diseases were likely to be manifesting on underground stems, roots and/or the daughter tubers. At each growth stage, above-ground stems and leaves from four plants per plot were checked for any diseases and then discarded. All underground stems were washed free of soil and assessed for incidence and severity of diseases.

Different diseases were detected on stems and tubers from the harvested plants, but *Rhizoctonia* stem canker and *Spongospora* root galling and tuber powdery scab greatly predominated.

1. ***Rhizoctonia* stem canker (RSC) and black scurf**

   - Each stem was given an RSC severity score using a 0 to 6 scale. Each score correlated with a range of proportions of stem surface covered by symptoms: 0 = no disease; 1 = 1 to 10% of stem surface affected; 2 = 11 to 30%; 3 = 31 to 50%; 4 = 51 to 80%; 5 = 81 to 100%; and 6 = dead stem. Each stem was also given a lesion type score: 0 = no symptoms; 1 = flecks on the stem surface; 2 = flecks and splits along the stem; and 3 = brown lesions and splits along the stem or a dead stem. A weighted factorial of the two scores, divided by the number of stems in the sample, was used to calculate mean RSC severity per stem. There is a higher risk of yield reduction where RSC severity becomes greater than a score of 6 (Sinton et al. 2015), especially when the disease is widespread and present in conjunction with other yield limiting factors.

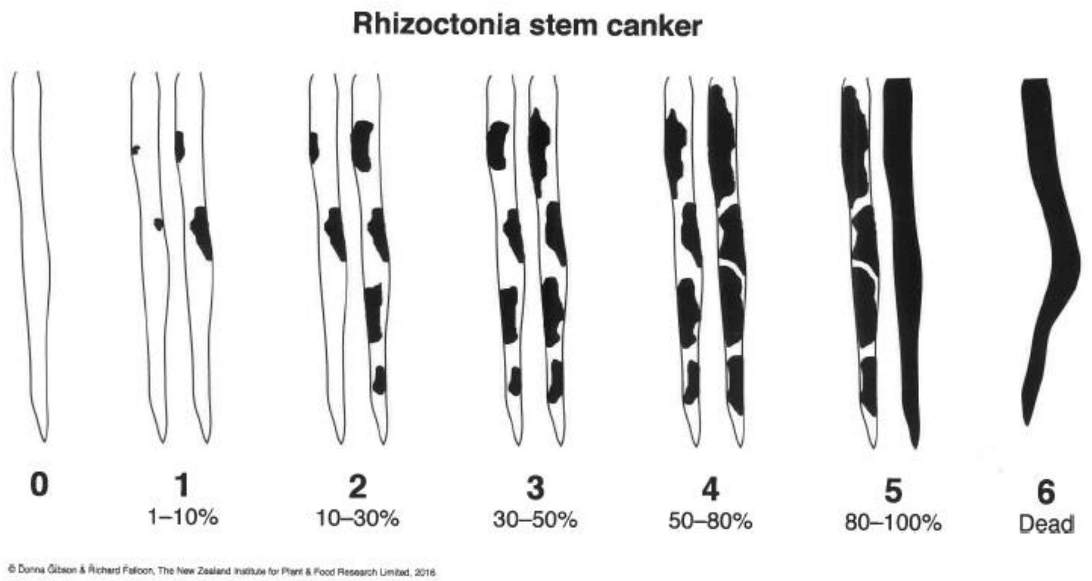

Figure 1. Severity scale (range 0 to 6) for *Rhizoctonia* stem canker (RSC), based on disease coverage percentage of the stem. This was used in addition to noting lesion type (flecks, splits and lesions).

- Incidence of tuber black scurf was determined for a 10-tuber sample from each plot at final harvest. Severity of the disease was determined using a 0 to 4 scale (Figure 2), based on proportion of tuber surface affected (Falloon et al. 1995).

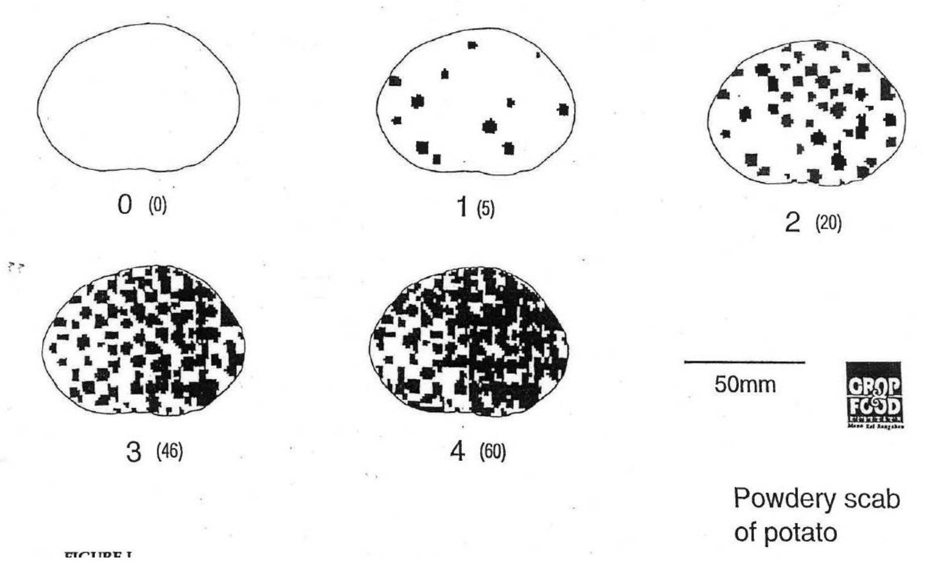

Figure 2. Severity scale (range 0 to 4) for black scurf severity, also used to categorise tubers for powdery scab severity.

2. ***Spongospora* root galling and powdery scab**

- Incidence of *Spongospora* root galling was determined for a combined four plant sample (presence/absence). Severity of root galling was assessed for all four sampled plants together, using a 0 to 3 scale (0 = no galls, 1 = <5 galls/three plants, mild infection; 2 = 5–20 galls, moderate infection; 3 = >20 galls, severe infection).
- Incidence of tuber powdery scab was determined for a 10-tuber sample from each plot at final harvest. Severity of the disease was determined using a 0 to 4 scale, based on proportion of tuber surface affected (Falloon et al. 1995).

2.5 Yield assessment

At crop senescence (14 March 2018) tuber yield assessments were carried out for a 3 m section of each plot (two rows by 1.5 m). All of the tubers were hand dug and sorted into size categories, to end-user specifications of ‘marketable’ (greater than 65 mm diameter) and ‘unmarketable’ (less than 65 mm diameter). All tubers in the two categories were weighed and counted, and these tuber yields were converted to tonnes per hectare (t/ha).

2.6 Statistical analyses

Plant vigour was analysed using a mixed model approach, fitted with REML as implemented in Genstat (Genstat 17th edition). Assumptions were checked via standard residual plots. Emergence % was analysed using Binomial generalized linear mixed model with a logit link, nbinomial = 100. Fixed effect in the model were cut, formalin treatment and its interaction. Order was considered and the highest p-value reported. Random effects accounted for the position (Row, Column) within the field. Each variable was analysed separately.

Mean *Rhizoctonia* stem canker (RSC) severity and root gall severity was analysed using a mixed model approach, fitted with REML as implemented in Genstat (Genstat 17th edition). Assumptions were checked via standard residual plots. Number of stems with RSC and root gall incidence was analysed using Binomial generalized linear mixed model with a logit link, nbinomial = tot no. stems and 1 respectively. Fixed effect in the model were cut, formalin treatment, date and all interactions. Order was considered and the highest p-value reported. Random effects accounted for the position (Row, Column) within the field. Each variable was analysed separately.

All parameters (except powdery scab incidence on tubers at harvest) 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. Number of tubers with PS was analysed using Binomial generalized linear mixed model with a logit link, nbinomial = tuber no. in final harvest. Fixed effects in the model were cut, formalin treatment and its interaction. Order was considered and the highest p-value reported. Random effects accounted for the position (Row, Column) within the field. Each variable was analysed separately.

3 RESULTS

3.1 Plant emergence and vigour

- There were strong visual differences in plant establishment and vigour (Figures 3 and 4).
- More plants emerged from whole seed, and/or cut seed untreated with formaldehyde.
- As formaldehyde rate increased, plant establishment percentage decreased, more significantly so for cut seed (untreated had a mean of 90%, dropping to 43% with the 2% formaldehyde treatment).

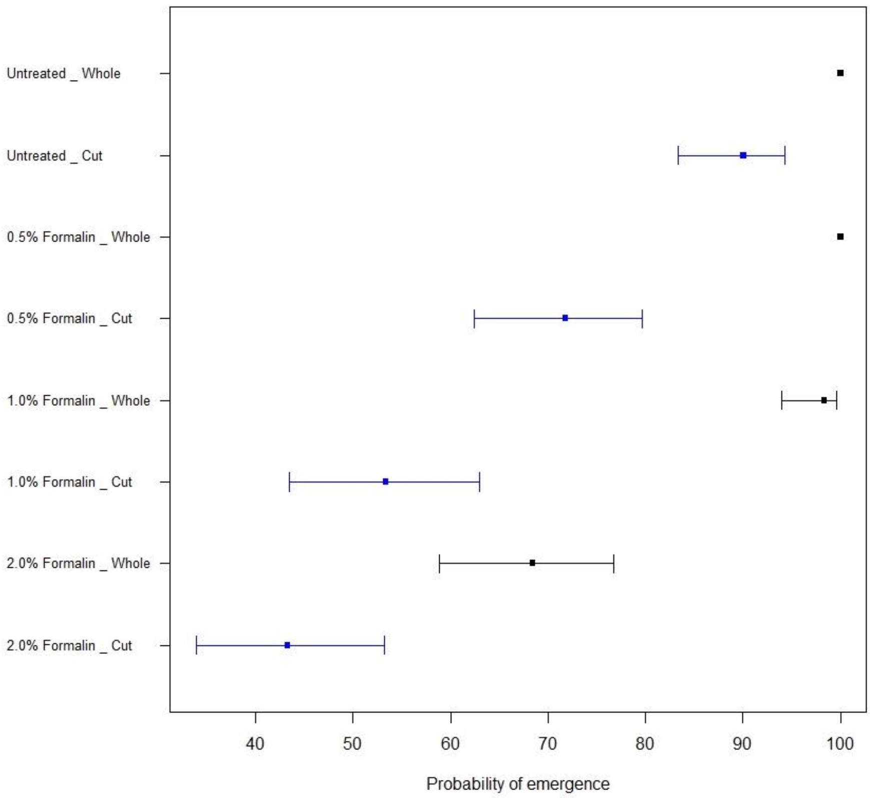

Figure 3. Probability of emergence for the cut/whole and formaldehyde treatments. The lines represent the range of values that have a 95% certainty of containing the population mean (significant differences occur where the lines do not overlap). The square points denote the mean. Blue colouration represents cut tubers and black is whole.

Figure 4. The left photo shows a vigour score of 2 (1 = lowest score), right photo vigour score of 9 (maximum score).

- For plant vigour at emergence, there was no interaction between formaldehyde rate and cut/whole treatments (p = 0.148).
- On average for the formaldehyde treatments combined, the use of whole tubers increased plant vigour compared to cut (Table 2, p = <0.001).

Table 2. Plant vigour for whole/cut seed treatment (1 – 9 scale with 1 = poor and 9 = strong).

Plant vigour	Cut	Whole	LSD
	4.9	7.2	0.5

- On average for the cut and whole treatment combined, the higher the formaldehyde rate, the lower the plant vigour (Table 3, Figure 5, p = <0.001).

Table 3. Plant vigour for the formaldehyde treatments.

Formaldehyde rate	Plant vigour
Untreated	7.7
0.5% Formaldehyde	6.8
1.0% Formaldehyde	5.7
2.0% Formaldehyde	4.1
avg. LSD	0.7

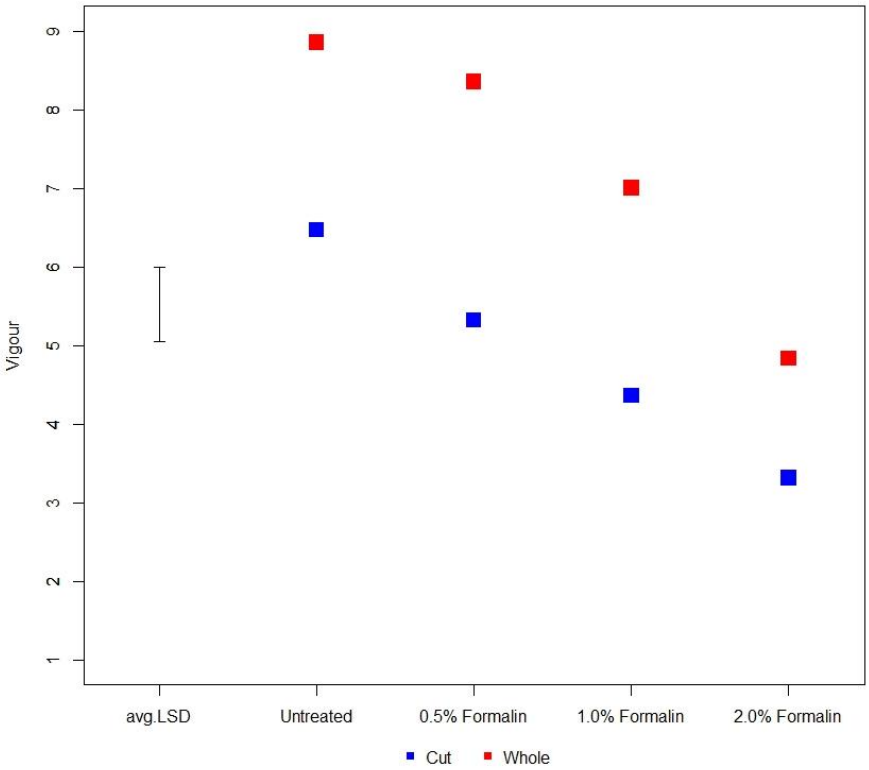

Figure 5. Vigour assessed on a 1–9 scale (1 = poor, 9 = strong) six weeks after planning (7 Dec) for four formaldehyde rates for both whole and cut seed.

3.2 Disease assessments

The main diseases found during the plant growth were *Rhizoctonia* stem canker on underground stems (dark brown lesions and stem splitting), *Spongospora* root galls on plant roots during crop growth and powdery scab on the harvested tubers.

3.2.1 *Rhizoctonia* stem canker (RSC)

- There was no three way interaction between formaldehyde, cut/whole treatments and growth stage (p = 0.586) for RSC severity.
- There was a two way interaction between formaldehyde and cut/whole treatments (Table 4, p = <0.001) for RSC severity. Treating with formaldehyde reduced disease severity for plants grown from cut seed, compared to untreated, especially at the high formaldehyde rate. Formaldehyde treatments had less impact on disease resulting from whole seed.
- Untreated cut seed had a greater RSC severity (score of 7.0) than uncut seed (score of 4.9), showing that the process of cutting may have caused disease to be spread, or had made the seed more vulnerable.

Table 4. Predicted RSC score means for the formaldehyde and cut/whole treatments.

RSC severity	0.5% Formaldehyde	1.0% Formaldehyde	2.0% Formaldehyde	Untreated	avg LSD
Cut	5.5	5.2	3.3	7.0	1.4
Whole	6.4	6.5	6.2	4.9	

- RSC disease severity through time varied for the cut/whole seed and formaldehyde treatments (Figure 6). Severity increased steadily over time for the plants grown from untreated cut and whole seed treatments, and was more severe for the cut-seed plants than the whole-seed plants.
- By the end of the season, severity was less for plants grown from cut seed that had been treated with the 2% formaldehyde rate, compared to plants from whole seed dipped in 2% formaldehyde.

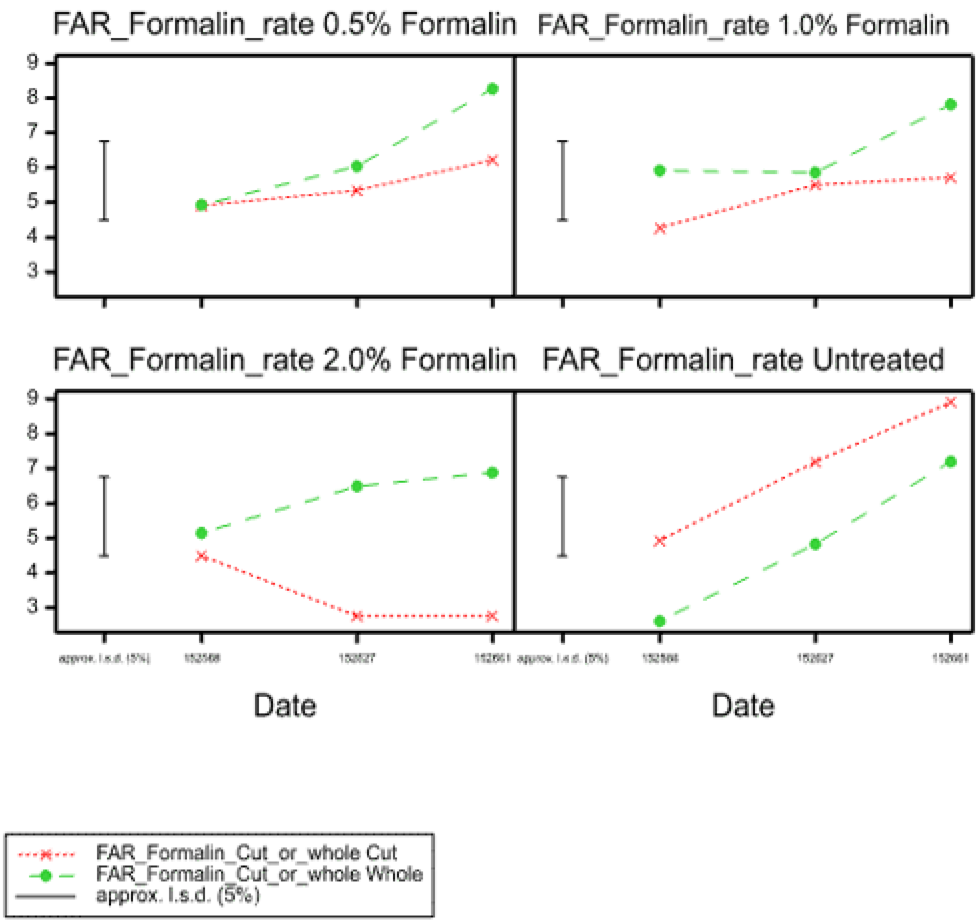

Figure 6. The interactions for RSC development on underground stems for three time points (emergence, full and late canopy), for the cut/whole see and formaldehyde treatments. The green dashed line represents the whole seed treatment and the red dotted line cut seed. On the Y axis scale the maximum RSC severity score is 18 (dead stem). Yield can begin to be negatively impacted when a score is greater than 6 (Sinton et al. 2015).

- In general, formaldehyde dipping of whole seed had less influence on seed-borne disease than it did for cut seed (Figure 7). Plants grown from cut seed (those that survived emergence) had much lower RSC disease severity when treated with 2% formaldehyde, compared to untreated seed.

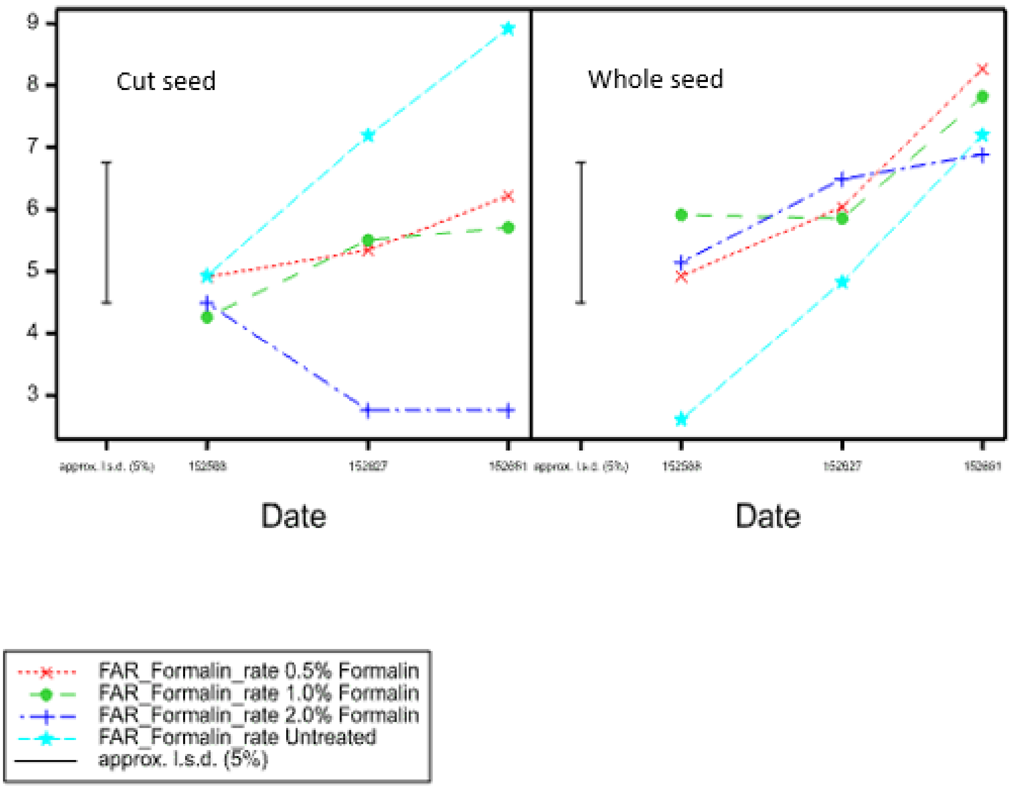

Figure 7. Mean RSC disease severity for the cut/whole seed and formaldehyde treatments for three time points (emergence, full and late canopy). On the Y axis scale the maximum RSC severity score is 18 (dead stem). Yield can begin to be negatively impacted when a score is greater than 6 (Sinton et al. 2015).

- In general, RSC incidence was high throughout the trial (data not shown). For most treatments, there was a high chance (60 – 80%) that stems would be infected with RSC. However, there was a tendency for a lowered chance (20 – 70%) of incidence for the plants grown from the cut, 2% formaldehyde treatment.
- Widespread RSC throughout a crop increases the risk of yield loss, especially when present along with other yield-limiting factors.

3.2.2 *Spongospora* diseases

- *Spongospora* root galls were evident at emergence (relatively early for this disease), with low to medium severity (Figure 8). Plants from untreated whole seed had a higher root gall severity than untreated cut seed.

- Plants grown from treated cut seed (all formaldehyde rates) generally had a lower root gall severity than uncut seed, only at the emergence growth stage, suggesting that the efficacy of formaldehyde is short lived, or that the *Spongospora* pathogen was already in the soil.
- From full canopy onwards, root gall severity was moderately severe for all treatments.

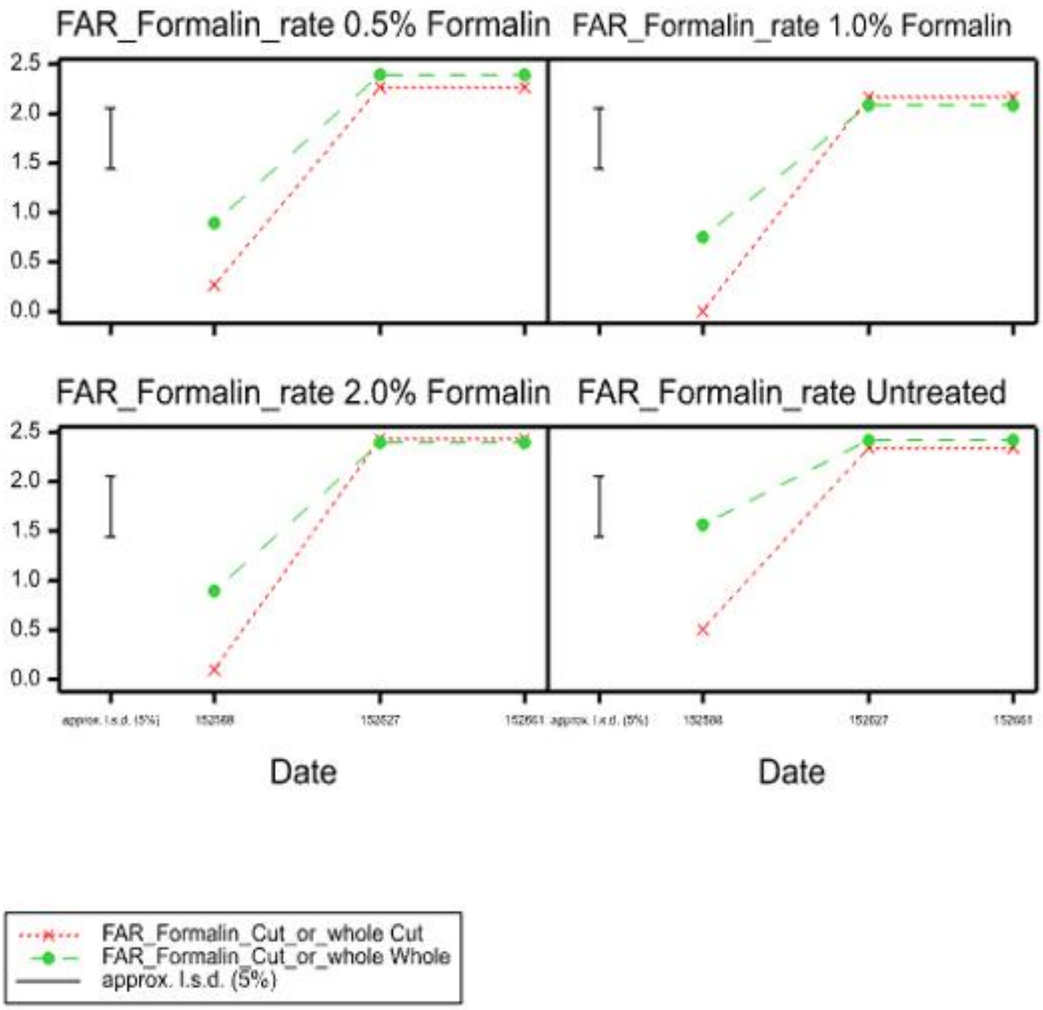

Figure 8. *Spongospora* root gall severity at three time points (emergence, full and late canopy), using a 0 to 3 scale (0 = no galls, 1 = <5 galls/three plants, mild infection; 2 = 5–20 galls, moderate infection; 3 = >20 galls, severe infection). The green dashed line represents the whole seed treatment and the red dotted line cut seed.

3.3 Potato yields

The commercial crop in which the trial was established had suffered a high degree of secondary tuber rot by harvest in March, triggered by excessive rainfall during the season, on a compacted soil with a high clay content. In each plot of the trial, visual estimates were made of the percentage of rotting tubers within the harvest area, along with percentage completely rotted tubers not able to be measured. For these parameters, rotting appeared to be random with no distinction between treatments (data not shown).

There was no difference between the treatments for gross yield (Table 5), these results possibly affected by the presence of tuber rot ($p = 0.774$ for the interaction, $p = 0.82$ for cut/whole seed main effect, $p = 0.193$ for the formaldehyde rate main effect).

Table 5. Predicted means for gross yield (t/ha), by formaldehyde and cut/whole seed tuber treatments.

Gross yield (t/ha)	0.5% Formaldehyde	1.0% Formaldehyde	2.0% Formaldehyde	Untreated	avg.LSD
Cut	56.2	54.9	50.2	51.8	13.4
Whole	62.3	56.9	49.7	49.1	

4 DISCUSSION

Last season (2016–17), a FAR pesticide trial included seed treatment with a commercial rate of formaldehyde (0.5%, Linton et al. 2017). Results showed that formaldehyde dipping whole seed caused a small reduction the number of emerged plants (1.5%) and significantly reduced early plant vigour, compared to plants grown from undipped whole seed. Plants from the dipped treatment had RSC symptoms that were 12% more severe than untreated seed, and yield was reduced by 8%. *Spongospora* root galling was more severe in plants grown from formaldehyde-treated seed, compared to non-treated.

In this study, for whole seed, emergence percent was reduced only by the high (2%) formaldehyde rate, and early plant vigour reduced as formaldehyde rate increased (average for cut and whole, as there was no interaction). RSC symptom severity was similar for formaldehyde-dipped whole seed compared with undipped. However, in this trial, plants grown from cut seed benefited from formaldehyde dipping, with a reduction in stem canker severity. Initial root gall severity (at emergence) was lower in the dipped treatment, but there was no difference in severity between the dipped and undipped treatments later in the season.

In a pot experiment (using pathogen-free growing medium) conducted for the third year (2017–18) of a FAR soil-borne disease SFF project at Lincoln (Sinton et al. 2018, in press), commercially prepared cut and uncut seed was dipped in 0.5% formaldehyde (commercial rate) before planting. Normally seed is dipped when whole, then cut. Results showed that 100% of plants (n = 10) emerged from both the dipped and undipped whole seed, whereas increasing number of plants did not emerge where seed tubers had a greater number of cut sides and were undipped. Dipping cut seed markedly increased plant survival, but had little effect on RSC severity during plant growth. Root gall severity was moderate to severe in all treatments.

Large amounts of tuber rot in this trial precluded the chance of detecting any potential yield differences between the treatments. However, formaldehyde dipping reduced marketable yield from 75 to 69 t/ha (8%) in the 2016–17 pesticide trial.

Results from these different studies suggest that formaldehyde-dipping whole seed (using current methods) is not beneficial (and may even be detrimental) to later plant health, resulting in the same, or increased, levels of *Spongospora* and *Rhizoctonia* disease severity (and incidence). In 2016–17 formaldehyde dipping whole seed caused an actual yield reduction.

For cut seed, it may be advantageous to dip in formaldehyde after cutting to improve emergence and plant survival rates, as demonstrated by the pot trial. Before use, this method would need further investigation. However plants from cut seed are known to have low vigour and produce more variable stem numbers per plant, compared to graded whole seed. This in turn can cause variable tuber sizes and/or reduced yield.

5 CONTRIBUTIONS

This trial was funded by Potatoes New Zealand through the Foundation for Arable Research (FAR). The trial was designed and established by FAR, and the plot yields were assessed by that organisation. The New Zealand Institute for Plant and Food Research Limited (PFR) carried out the assessments of diseases on plants from the trial, and assisted with statistical analyses of the trial data. This report has been prepared by PFR and FAR.

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