Tomato Potato Psyllid and Blight Management with Mesh Crop Covers: Second Year's Results and Future Research Directions

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Permanent Agriculture and Horticulture Science and Extension

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Corrigendum for version 2

The data in Table 1 (rainfall) been corrected following cross checking with another weather data provider.

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1. Executive summary

Following a successful 'scoping' field trial in 2011/12 that demonstrated the potential for mesh crop covers to control Tomato Potato Psyllid (TPP) and blight on potatoes, an expanded and improved trial was undertaken in 2012/13.

The trial compared two contrasting mesh crop covers: a Cosio glasshouse quarantine mesh and a Crop Solutions field mesh, with an uncovered (null) control on potatoes (cv. Moonlight) to study the effect of mesh on TPP, yield, both gross and marketable, blight, temperature and humidity.

The meshes were highly effective at keeping TPP off the potatoes, even with deliberately imperfect sealing of the mesh to the soil. Even where TPP did get under the mesh, they did not proliferate under the sheets.

The effect of both meshes compared with the control on yield was substantial, with a 23% increase in yield for total yield (tubers > 1 cm diameter) with a maximum yield of 43 tonnes·ha^{-1} and a 125% (more than doubling) of yield for market grade tubers > 125 g with a maximum yield of 30 tonnes·ha^{-1}, with all differences being statistically significant. There was no difference between the meshes. Considering the effect of TPP on potatoes is generally not large in Canterbury, these differences could be small compared with other potato production regions, e.g. Auckland, Manawatu, Hawkes Bay.

The effect on tuber size was also very clear with mesh covered tubers having a 55% to 63% increase in mean tuber weight and a 48% to 58% increase in maximum tuber weight compared with tubers from the control plots.

The effect on sprouting after 51 days of storage in a cool environment was clear-cut with zero sprouts on mesh covered tubers an average of 5.4 sprouts on control tubers.

The visual effect on crop growth was clear, with all treatments emerging at the same time, but the mesh treatments growing faster, with the Cosio the fastest, but with the haulm under the Crop Solutions mesh senescing about two weeks before the Cosio mesh and the haulm never senescing in the control plots.

The effect of mesh on blight (a range of foliar fungal diseases including *Phytophthora infestans* and *Alternaria* spp.) was also visually obvious, with control plots having considerable blight levels, with much lower levels under the meshes, with the Cosio mesh having slightly less than Crop Solutions.

There were no large differences in trapped sporangia numbers between the treatments but the Cosio treatment potentially had slightly lower numbers (although borderline for statistical significance), which correlates with the slightly lower foliar blight levels under Cosio mesh. However, as trapped sporangia are both a cause and result of foliar blight, the strongest conclusion that can be safely reached is that airborne sporangia are unlikely to be a dominating cause of the different foliar blight levels.

The climatic data did not show any large differences between the treatments, including Smith periods, which, coupled with multiple problems with the data loggers, means that the 'safe' interpretation is that temperature and relative humidity do not appear to be the primary drivers of the differences in blight levels among the treatments.

Without any clear cause of the difference in foliar blight, it is possible that there are multiple, cumulative causes, which will require manipulative experiments (as opposed to empirical field trials) to tease out.

In summary, the results are fully consistent with the previous seasons trial, the two meshes produced identical yields, and similar blight effects, indicating that it was not just due to the properties of the Cosio mesh or a fluke result in the 2011/12 season.

Taken together, the laboratory work and two seasons field trials are considered a potentially valuable spring board for future research, including:

Multi-region field trials in New Zealand to empirically validate the results of these trials under a range of climatic and production systems and to compare mesh with current best insecticide treatments.

Understanding the relative contribution of the multiple effects mesh has on the crop, e.g. reducing TPP and other pests, reducing blight (multiple fungal spp.), and the direct climatic and light interception effects of mesh, so that the design and use of mesh can be optimised.

Understanding why TPP do not disperse under mesh, which may lead to better understanding of their host detection and dispersal biology which may lead to improved management.

Resolve if 0.6 mm mesh hole sizes are essential for field use or if mesh with larger hole sizes, e.g. 0.8 mm and larger, are effective, because these are cheaper so they may improve the economics.

Determine if mesh would be effective for potato tuber moth and aphid control / management in New Zealand, so one product could control all three pests.

Confirm if mesh is effective at TPP management on field tomatoes, without causing side effects, e.g. fungal diseases.

Discover the causal mechanism of how the meshes are reducing blight levels and if this can be improved.

Investigate mesh crop covers for the control of a wide range of potato insect pests globally while suppressing blight / foliar fungal pathogens.

Systematically look for insect pests and fungal pathogens of food crops globally to identify those where mesh crop covers could be a practical and economic control / management tool, especially there are issues with agrichemical controls. This is considered particularly relevant to developing countries as mesh crop covers are considered to be an ‘appropriate technology’.

2. Introduction

In 2011, a 'scoping' field trial was conducted (at the BHU Future Farming Centre, Canterbury, New Zealand) to study the potential for mesh crop covers to manage Tomato Potato Psyllid (TPP) (*Bactericera cockerelli* Sulc. (Hemiptera: Triozidae)) on potatoes. Even though the trial used glasshouse quarantine mesh (Biomesh) which is much heavier and less transparent than the purpose designed field mesh, and there was a green bridge between control (uncovered) and mesh (covered) plots, the results were considered positive: Key was that the mesh:

- Dramatically reduced the levels of foliar blight / fungal infestation (species not identified) completely contrary to expectations;
- That even with the green bridge, TPP populations were lower under the sheets than outside, although there was only statistical significance for leaf but not sticky trap, counts;
- Total yield was 35% higher for covered plots and 109% higher for market grade (>125 g) tubers, although this was statistically not significant due to small sample size and large inter-plot variation;
- Control tubers had nearly five times the number of sprouts after storage compared with covered tubers.

The full report on the first trial is available from the Future Farming Centre website www.bhu.org.nz/future-farming-centre/

Despite the simple experimental design, it was considered enough of a success, especially in terms of the reduction in blight, that it should be repeated with improved methodology.

3. Methods / trial design

3.1. Location, soil type and land preparation

The 2012/13 trial was established in the 'Steiner' field at the Biological Husbandry Unit, Lincoln University, Canterbury, New Zealand 43°39'01.67" S 172°27'30.57" E. The soil is a Templeton silty loam (smap.landcareresearch.co.nz), it was under pasture for the previous two years, it received, per hectare, 200 kg Viofos guano phosphate, 500 kg gypsum, 200 kg flour Lime, 1,000 kg ag-lime and 40,000 kg of Living Earth compost, in May 2012 (the previous autumn), to the pasture. The land was ploughed in September 2012, then rotary-hoed (rotovated) to a depth of ~15 cm across the furrows. Next planting beds were created in the same direction as ploughing, while at the same time deep loosening the soil within the beds to ~30 cm with a rigid leg tine cultivator (to remove the wheeling compaction from the first rotary-hoeing and to level the soil). This was followed by a final rotary-hoeing of the beds at ~25 cm deep to create a planting bed / tilth.

3.2. Design, establishment and husbandry

A randomised complete block design with four reps was used, with approx. 10 x 10 m plots with an approx. 2 m buffer of bare soil between plots to prevent a green bridge (Figure 1). Two mesh types were used (Figure 2), the Cosio Ltd. (NZ) mesh from the previous year ('Biomesh' 125 gsm, 0.78 x 0.48 mm holes) and a Crop Solutions Ltd. (UK) mesh ('0.6 mm' size, 0.57 x 0.43 mm holes) plus a null control with no mesh (uncovered). Mesh hole size was measured by microscopy as part of laboratory experiments that were part of the previous years trial.

The cultivar 'Moonlight' (Anderson *et al.*, 2004) was mechanically planted in 0.825 m wide ridges with tubers spaced ~30 cm apart, on 10 December 2012. This is a very late planting date for Canterbury, which was deliberately chosen to maximise exposure to natural infestations of TPP. Moonlight was initially believed to be more susceptible to TPP than many other cultivars but more recent research suggests that Moonlight is no more susceptible than most commonly grown potatoes (John Anderson, The New Zealand Institute for Plant & Food Research Ltd, pers. comm.). Moonlight is considered to have moderate field resistance to late blight (*Phytophthora infestans*) (Anderson *et al.*, 2004).

Figure 1. Experimental layout, 4 January 2013.

Mesh sheets were placed on the crop immediately after planting and secured using metal stakes (Figure 1). Any surplus potato ridges in the Cosio plots (due to different sheet sizes, see Figure 1) were removed by 10 January. Any potato foliage that emerged from under the sheets at any point during the trial was removed along with the rest of the plant, including its seed tuber. To reflect typical practice on medium scale vegetable farms, the sheets were not 'hermetically' sealed, e.g. dug into the soil, but they were pinned close to the ground leaving only small points of ingress for insects.

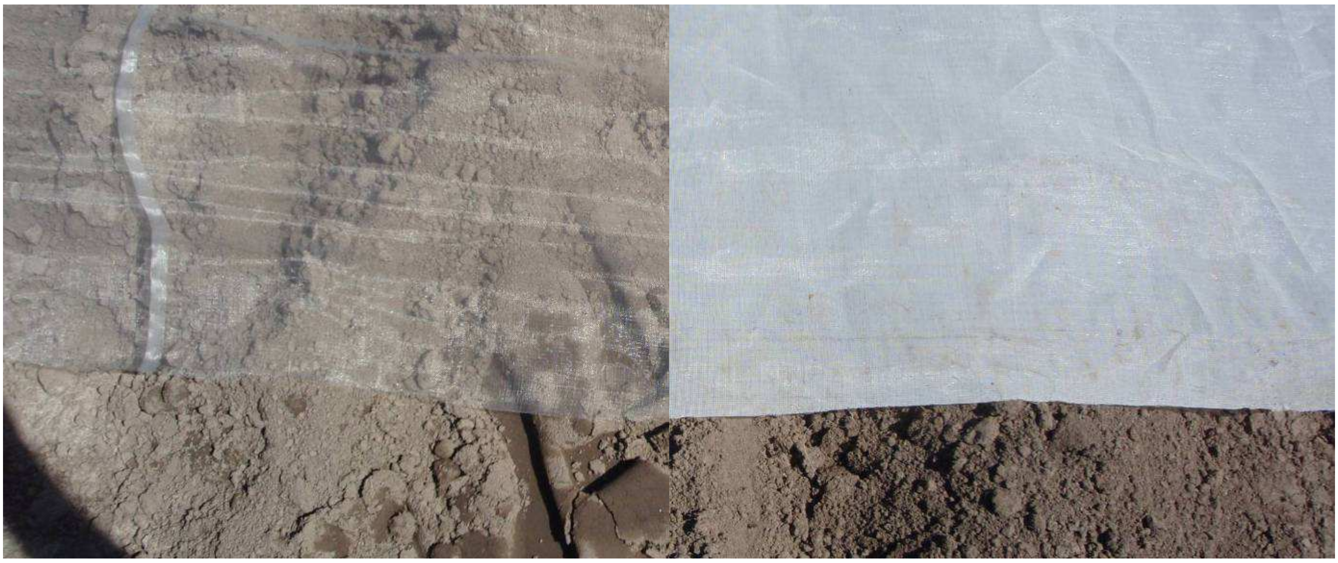


Figure 2. Crop Solutions mesh crop cover (left) and Cosio mesh (right).

The crop was weeded once on 3 January. 24 d after planting, by ridging up with a tractor mounted ridger which required the covers to be removed and then replaced. The crop was irrigated on 21 January with ~30 mm water and 12 February ~35 mm. Rainfall was recorded (Table 1) at the Lincoln, Broadfields weather station, 43°37'36.54" S 172°28'14.51" E approx. 2.5 km to the north of the trial site.

Table 1. Rainfall in 28 day groupings.

Date	Rain mm
11/12/2012 - 7/01/2013	16
8/01/2013 - 4/02/2013	23
5/02/2013 - 4/03/2013	21
5/03/2013 - 1/04/2013	42
2/04/2013 - 29/04/2013	38
30/04/2013 - 16/05/2013	92

3.3. TPP, blight, temperature and relative humidity

TPP numbers, *P. infestans* sporangia, temperature and relative humidity (RH) were recorded throughout the life of the trial with yellow sticky traps, vaseline slides and data loggers, respectively. The measuring equipment was mounted on custom built 'data station' consisting of a 2.5 cm square section wooden post, 80 cm long, with a 15 × 15 cm square 1 cm thick, plywood board, painted white, mounted on the top (Figure 3).

Figure 3. Data station (on side) showing location of sticky trap, vaseline slide and data logger.

Data stations were placed in the center of each plot, under the mesh, on the side of a ridge, with about the first 30 cm of the stake pushed into the soil. The plywood square on the top of the data station provided rain and sun protection (shade) for the data loggers and vaseline slides, and also allowed the mesh sheets to easily slide over the data stations. The posts were orientated so the data loggers were on the southern (shady) side of the data station. Sticky traps and vaseline slides were therefore orientated east-west, with the vaseline coated side of the slide randomly orientated to the north or the south.

TPP populations were recorded using pressure sensitive adhesive 'Back Folding Yellow Rectangle Card Trap' (Alpha Scents Inc. USA, www.alphascents.com), size 23 × 28 cm, folded in half so that both 'sides' of the trap could catch insects (the sides therefore faced north and south). The sub-area on the card from which TPP were counted was 20.5 × 18 cm. The first trap was put out the day after planting (11-Dec), and collection dates were: 11-Jan, 04-Feb, 18-Feb, 06-Mar, 22-Mar, 02-Apr, 15-Apr, 03-May. TPP were identified to species level using a microscope.

P. infestans sporangia were trapped using vaseline coated slides. These were prepared by dissolving 10 g of Vaseline in 50 ml hexane, and then using a paint brush to coat one side of a standard 75 × 15 mm glass microscope slide. Slide collection dates were the same as sticky trap collection dates. Sporangia were counted under a microscope, with two of a total of 12 longitudinal transects on the slide randomly chosen, with the average of the two transects used for analysis.

Data loggers were iButton, DS1921G, Hygrochron^{TM} temperature and humidity data loggers (Maxim Integrated, USA, www.maximintegrated.com). These were initially set at 30 min recording intervals, which was changed to hourly recording on 28 March due to concerns over battery life. Data was downloaded on three occasions, 15 Feb, 28 March, and 7 May (end of trial).

3.4. Tuber yield and sprouting

Potatoes for yield and subsequent analysis were harvested between 1 and 16 May. Due to rain, mechanical lifting was impossible, so tubers were hand dug. The potato plants on the edges of the plots were discarded, due to clear edge effects (much greener growth), with a minimum of 50 cm width of potatoes removed, so that all plots / ridges were standardised at 7.6 m long. Three consecutive ridges were lifted from the centre of the plot, one at a time in block order, will all tubers above 1 cm diameter retained. Tubers were immediately hand washed under running water to remove all soil and then allowed to drain before bagging in paper sacks that held ~20 kg of tubers prior to weighing, i.e., the tubers from each row were kept separate. The total weight of all the potatoes was recorded. Then, a sub-sample of 20 tubers per row / sack was taken, by estimating the number of tubers in each sack, and then dividing the estimate by 20 to give the subsample frequency. Tubers were then blindly (without looking) picked from the bags and every n^{th} tuber, as determined by the subsample frequency, retained to give a total of 60 tubers per plot. These were then individually weighed, the results of which were used to determine the percentage of tubers of marketable grade, taken as tubers >125 g, which was in turn, used to convert total yield into marketable yield. The plot yields, were converted to tonnes per hectare based on the 3 × 7.6 = 22.8 m length of row harvested, with these figures used in analysis, because this allows easy comparison for producers with farm production figures.

After weighing, the subsampled tubers were then placed in new paper sacks, and stored in a cool room, out of direct sun light. Two iButtons, as used in the field trial, were placed in paper sacks among the potato sacks to record temperature and RH. A subsample of ten tubers were then assessed for the number of spouts at 51 d after harvest, and then returned to storage, for additional future measurements. A tuber 'eye' was considered to have sprouted if it was no longer hollow and a shoot apex was visible to the naked eye, e.g. approx. 1 mm long.

3.5. Visual observations

A range of visual observations were made of crop growth, TPP effects and blight levels, with photographic records, throughout the life of the crop.

3.6. Laboratory identification of blight

A number of leaf blight infections were collected on the 9 May from the control plots, but not the mesh plots as the foliage in the mesh plots had senesced by this date. These were isolated in the laboratory and cultured to confirm Koch's postulates. This involved plating one half of the surface sterilised lesion on PDA (amended with Streptomycin and Penicillin) and the other half on V8 agar selective media (amended with Streptomycin and Penicillin). The plates were incubated at 20°C for 7-14 days and the resulting colonies growing from the leaf lesions identified based on colony and sporangia morphology.

3.7. Statistical analysis

Where appropriate, data were analysed by ANOVA. Where there was little difference between the two mesh treatments, but a large difference between the two meshes and the control, a nested ANOVA with blocking was used with meshes vs. control (no mesh) as the main treatment. Where there were clear differences between the mesh treatments, a general ANOVA with blocking was used.

4. Results and discussion

4.1. Crop growth

Crop growth was not quantitatively measured, but anecdotally there were clear visual differences among all treatments. All plants emerged at the same time, i.e., there was initially no difference among plots or treatments, but then the mesh covered potatoes grew faster, with the Cosio growing the fastest. The covered plots also senesced earlier than the control, with the potatoes under Crop Solution mesh senescing around the 20 March, while the foliage under the Cosio mesh, while flattened back on the ground, stayed green for another couple of weeks. Even at harvest in early May, the control foliage, although black from blight, and showing clear TPP symptoms, e.g. aerial tubers, was still alive, i.e., had not senesced. As there was no difference in yield between the two sheets, the earlier senescence of the Crop Solutions covered potatoes could be a useful advantage as it may allow earlier harvest, especially if the Cosio covered crop continued bulking up until full senescence.

4.2. Harvest data

Analysed with nested ANOVA. There was a very clear positive effect on yield from the mesh, with mesh increasing gross yield by an average of 23%, and the net yield of market grade tubers (>125 g) by an average of 125% i.e., more than double (Table 2). Unlike the previous trial, this increase was also statistically significant with the marketable grade difference being highly significant. In comparison the two meshes were indistinguishable agronomically and were statistically identical (Table 2).

The cause of the difference between gross and net yield was because of a large difference in tuber size, (Table 2 and Figure 4), with a 55% to 63% increase in the mean tuber size between the control and two mesh treatments, and 48% to 58% increase in maximum tuber weight (Table 2). There was no difference in minimum tuber weight as all plants produce some small tubers (Table 2) and all tubers above 1 cm diameter were collected. Again there was little agronomic difference between the two mesh treatments on tuber size, which was reflected by the high p-values. The effect is also visually clear in terms of size frequency, with the control tuber size frequency being strongly skewed to smaller sizes, with the peak in the 50 - 100 g size range compared with mesh treatment tubers peaking in the 100 - 150 g size range (Figure 4).

Table 2. Harvest yield data based on nested ANOVA with mesh vs. control as main treatment and between mesh types as the sub-treatment (NS = not significant, * = significant, ** highly significant).

	Total yield ($t \cdot ha^{-1}$)	**Percent increase over control**	**Percent of tubers > 125 g**	**Marketable yield tubers >125g ($t \cdot ha^{-1}$)**	**Percent increase over control**	**Mean tuber weight (grams)**	**Min tuber weight (grams)**	**Max tuber weight (grams)**
Control	34.5		38%	13.1		80	5	210
Cosio	42.1	22%	70%	29.5	125%	130	13	308
Crop Solutions	42.9	24%	69%	29.6	126%	124	8	332
P-value for mesh vs. control	0.026 *			<0.001 **		0.006 *	0.190 NS	0.009 *
$LSD_{0.05}$	6.61			4.02		27.8	10.2	70.5
P-value between mesh types	0.794 NS			0.932 NS		0.651 NS	0.315 NS	0.515 NS
$LSD_{0.05}$	7.63			4.65		32.1	11.72	81.4

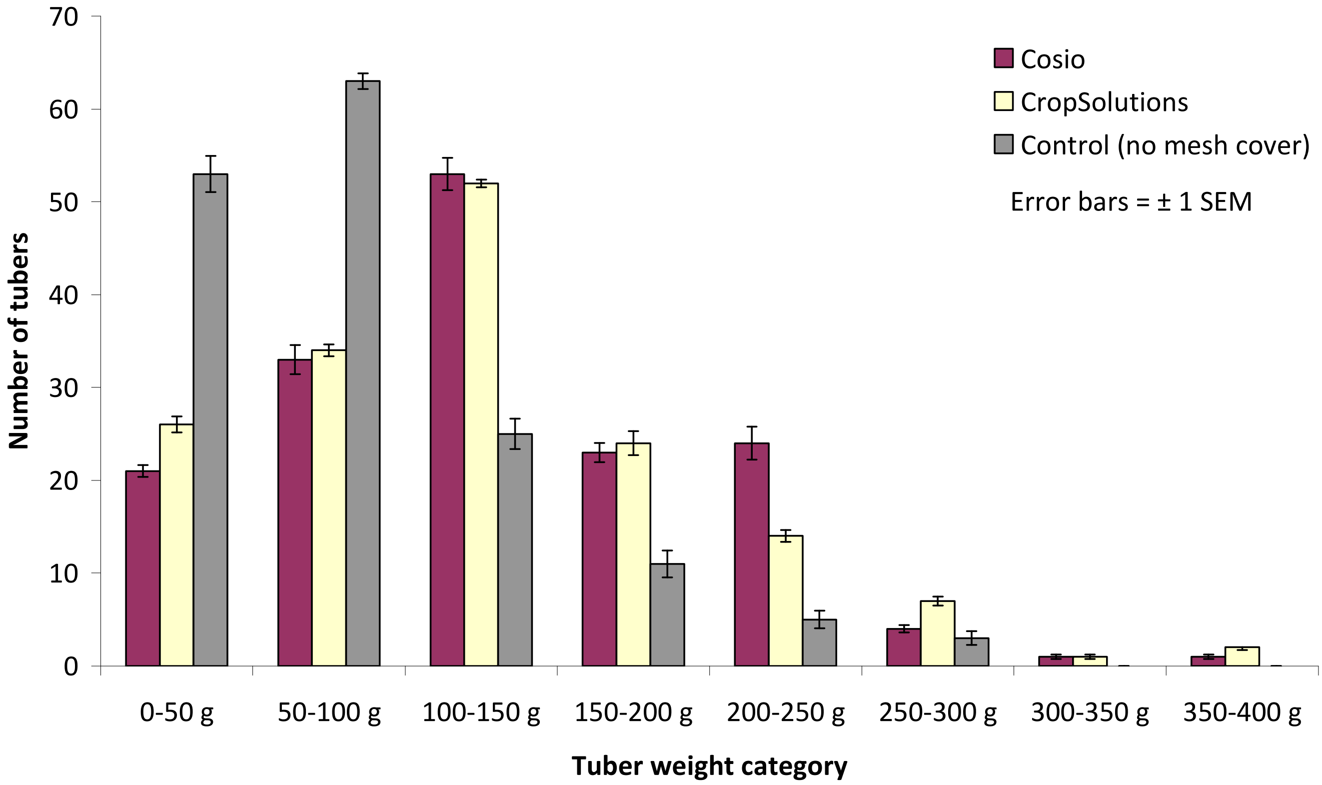


Figure 4. Frequency distribution of tuber size for the two mesh treatments and the uncovered control.

4.2.1. Sprouting

The effect of mesh crop covers on sprouting at 51 days after harvest was unambiguous, with no tubers from the mesh treatments having any sprouts (zero) with the control tubers averaging 5.4 sprouts, $LSD_{0.05}$ 1.15, $p<0.001$, nested ANOVA.

4.2.2. Harvest data conclusions

The increase in yield, both gross and especially marketable, is considered substantial. However, the impact of TPP in Canterbury is by far the lowest of the major potato growing areas, for example 2011 figures for total cost of TPP (crop impact, control costs, other costs) is NZ\$5,100 ha^{-1} for Auckland, \$5,660 Hawkes Bay and \$3,750 in Manawatu, compared with \$540 ha^{-1} in Canterbury (Kale, 2011). This shows that the impact of TPP on Canterbury crops is small compared with North Island, which is backed by a still reasonable total yield from the untreated control plots in this experiment of 35 $tonnes \cdot ha^{-1}$. In comparison, organic growers in the Hawkes Bay (i.e., those without any effective control techniques) suffered complete crop loss due to TPP (Scott Lawson, Lawson's Organic Farms Ltd., pers. comm.). If pre-TPP yields could be achieved using mesh crop covers in Hawkes Bay, and other North Island locations, and the control plot yields were zero, the yield difference would be even more stark.

4.3. TPP

The effect of mesh on TPP caught in the sticky traps was clear, with uncovered plots having high numbers, while covered plots were very low, with a peak in TPP numbers in late March to early April (Figure 5).

The mean of the total TPP caught over the life of the trial were highly significant ($p<0.001$) using a nested ANOVA, with 25.1 TPP for the control and 1.3 for the mesh, $LSD_{0.05}$ 9.5. There was no difference ($p=0.639$) between the mesh types, with 0.3 TPP for Cosio, and 2.2 for Crop Solutions, $LSD_{0.05}$ 2.8.

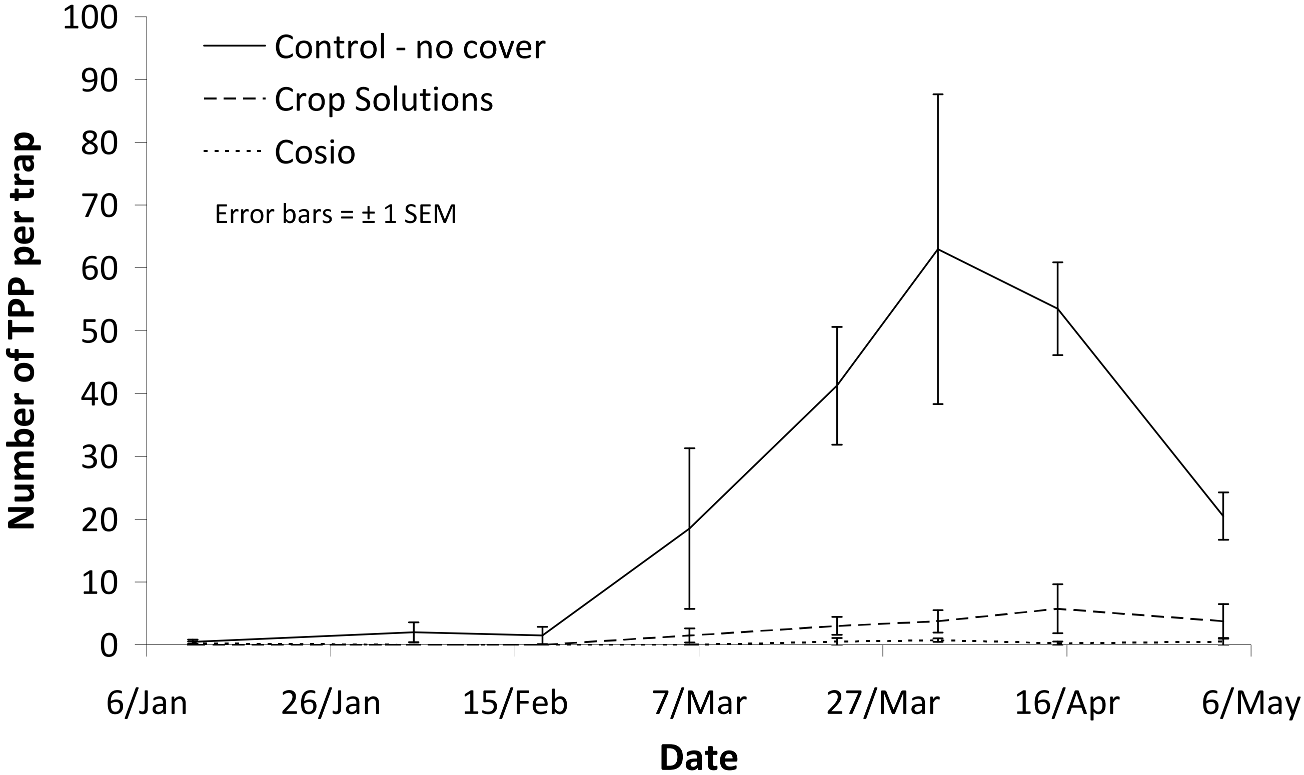


Figure 5. Mean number of TPP caught per trap for eight sampling periods.

4.3.1. Visual TPP observations

The visual effects of TPP on the potato foliage was clear (Figures 6, 7, 8, and 9). Initially yellowing and folding of the leaves, 'psyllid yellows', occurred on the control plots from mid to late February starting on the northern most plots. The psyllid yellows got progressively more severe, along with blight levels (Figure 10). Small numbers of aerial tubers were also observed. In addition the control plants did not senesce, even by late June, (six weeks post harvest and about 10 weeks after the mesh plots senesced) as although the foliage was completely dead from blight, the base of the stems continued to be green and apparently trying to grow. In comparison the crops under mesh showed no signs of TPP damage, with the leaves remaining flat and green until they senesced, at which point they died off completely with the stems rapidly bleaching, i.e., as expected for a potato crop (Figures 6, 7, 8, and 9).

Control Crop Solutions Cosio

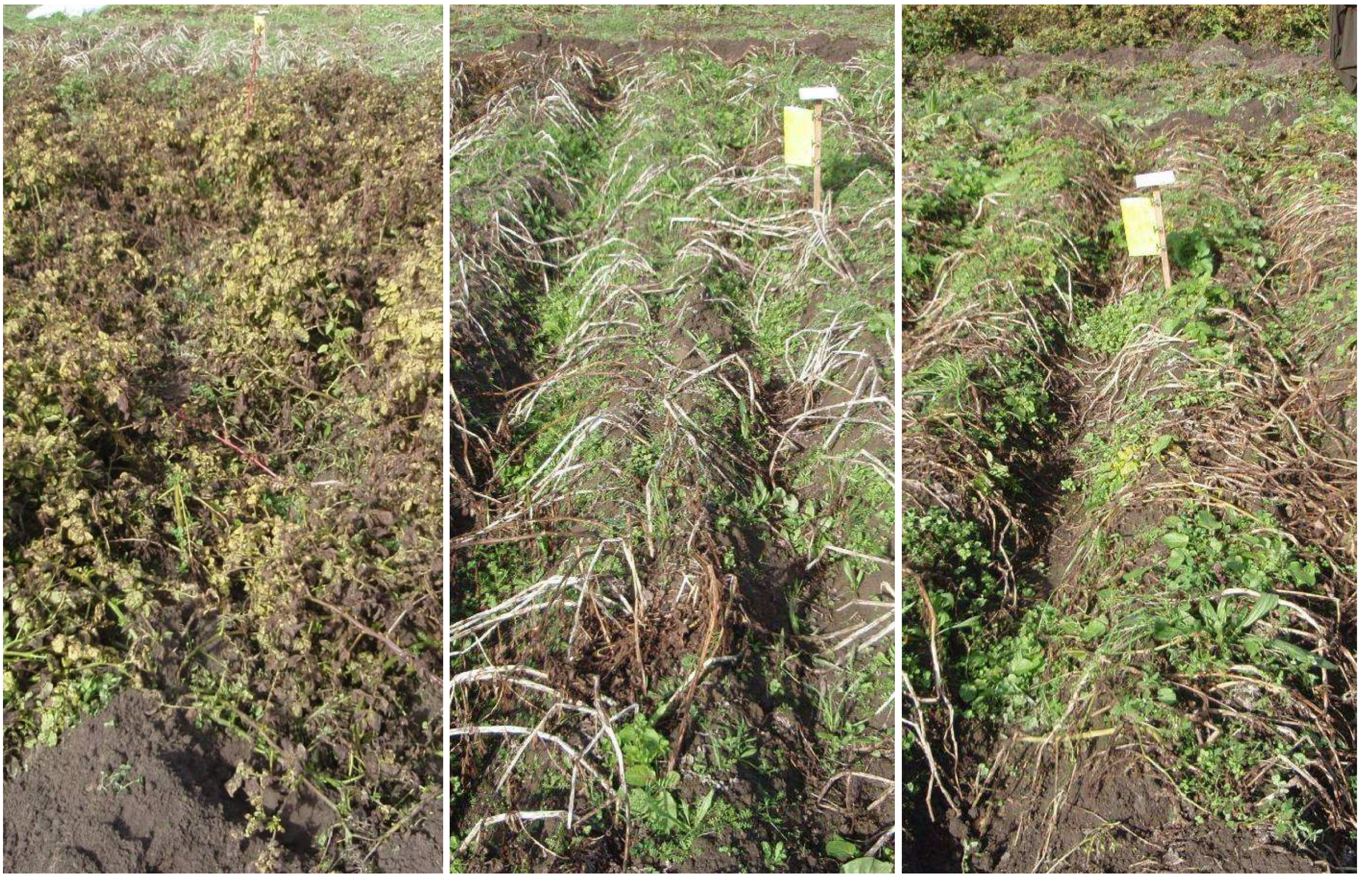
Figure 6. Plot photos of the three treatments on 28 January 2013.

Control Crop Solutions Cosio

Figure 7. Plot photos of the three treatments on 6 March 2013.

Control Crop Solutions Cosio

Figure 8. Plot photos of the three treatments on 16 April 2013.



Control Crop Solutions Cosio

Figure 9. Plot photos of the three treatments on 3 May 2013 (start of harvesting).

Control Crop Solutions Cosio

Figure 10. Photos of potato foliage on 16 April (127 d after planting) showing TPP yellows and blight.

In one plot, TPP got under the edge of the cover (due to the anchoring method trying to simulate how mesh would be used on-farm, i.e., not hermetically sealing the covers). However, what was informative, is that the psyllid not move very far under the sheet as evidenced by the distribution of TPP affected plants (Figure 11).

Figure 11. Photo of TPP affected plants under mesh (bottom right quarter of photo).

In comparison, there were aphid (unidentified species) outbreaks under three sheets during February and March. These 'flared up' from unnoticeable populations to high numbers and back to zero within about month, with a range of aphid predators and entomopathic fungi found under the sheets with the aphids. This clearly demonstrated that if aphids do get under the sheets their populations can grow very quickly, due to parthenogenesis and high reproductive rates, plus they also move under the sheets without obvious hindrance. For example, the winged adults were swarming on the under surface of the mesh. This indicates that if mesh is to be used for aphid control, the sheets need very good closure, probably digging into the soil, to keep aphids out.

In contrast with the aphids, TPP got under the sheet, but, only infested a small area of consecutive plants, even though it had six or more weeks to colonise the whole under sheet area, which indicates that TPP do not readily move under the sheets. This is also consistent with the previous years results, where, even though there was a green bridge around the entire sheet edge, for the entire trial, which allowed psyllids to get under the sheets from all sides, they only moved slowly towards the centre of the sheet. This is considered a particularly interesting behaviour, that clearly requires further study. However, from a practical farming perspective, it means that hermetically sealing sheets / avoiding all points of ingress, is not essential for TPP, because, even if insects do penetrate the sheet, this does not appear to result in population outbreaks, unlike aphids.

A useful contrast can also be drawn with carrot and cabbage root flies (*Psila rosae* and *Delia radicum*). The adults reside and breed in field margins (non-crop areas), with the females emerging at dawn and dusk to look for host plants to lay their eggs on. Once they have completed egg laying, they then return to the field margins. This typically means that the crop plants next to field margins have high infestation rates, while plants in the field center have low or no infestation. This behaviour, when combined with mesh crop covers, means that if egg-laying females get under the sheets, they only tend to penetrate a few meters into the crop, and as the adults breed in the field margins, even if females get under the sheet, this will not result in an outbreak, as unlike aphids, the flies' full lifecycle can not be completed under the mesh. It therefore appears that although mesh can be a physical barrier to a range of pests, the behaviour of the pest, including how it mates and reproduces, determines how mesh must be managed to ensure effective control.

4.3.2. TPP conclusions

One of the factors that makes TPP such a damaging pest is that very low numbers can cause significant crop and economic losses. For example, Munyaneza et al. (2009) found that only a single infected psyllid is needed to infect a plant with the bacterial pathogen *Candidatus* Liberibacter solanacearum, which causes zebra chip disease in potatoes, and can reduce yield by 70%. In addition, *Candidatus* Phytoplasma australiense, has more recently been associated with TPP in NZ, and it is thought that some of the symptoms of TPP not related to Liberibacter, e.g. aerial tubers, may be due to Phytoplasma and that it may also contribute to yield loss.

As very small numbers of TPP, even individual psyllids, can cause significant yield loss, economic population thresholds are therefore very low. Mesh crop covers are considered unique among control technologies, including insecticides, in that they prevent psyllids from reaching and feeding on the crop in the first place, thus completely preventing plant infection with Liberibacter and/or Phytoplasma and therefore preventing the associated damage. If mesh covers are dug in, as is done on large areas in the UK, e.g. 100 ha^{-1}, and thus 'hermetically sealing' the crop under the covers, then the small amounts of TPP ingress that occurred in this trial would be expected to be effectively reduced to zero, thus preventing any crop damage.

4.4. Blight

The number of *P. infestans* sporangia trapped on the vaseline slides over the whole trial period is shown in Figure 12. There is a slow increase in trapped sporangia numbers over time, with a rapid final increase from April, which was commensurate with the visual level of blight on the leaves and is considered typical of blight infections. A non-nested ANOVA of the total sporangia counts was borderline for statistical significance at p=0.051, with total sporangia counts of: Control 388, Cosio 185 and Crop Solutions 376 ($LSD_{0.05}$ 175.2). Taken in conjunction with the Figure 12, it appears that there is little difference between the treatments, and if the result is a false negative (type II error) then the biggest difference would be between the Cosio mesh and the two other treatments (Crop Solutions mesh and the control). If so, this would correlate with foliar disease levels as the Cosio treatment had the lowest visual blight symptoms.

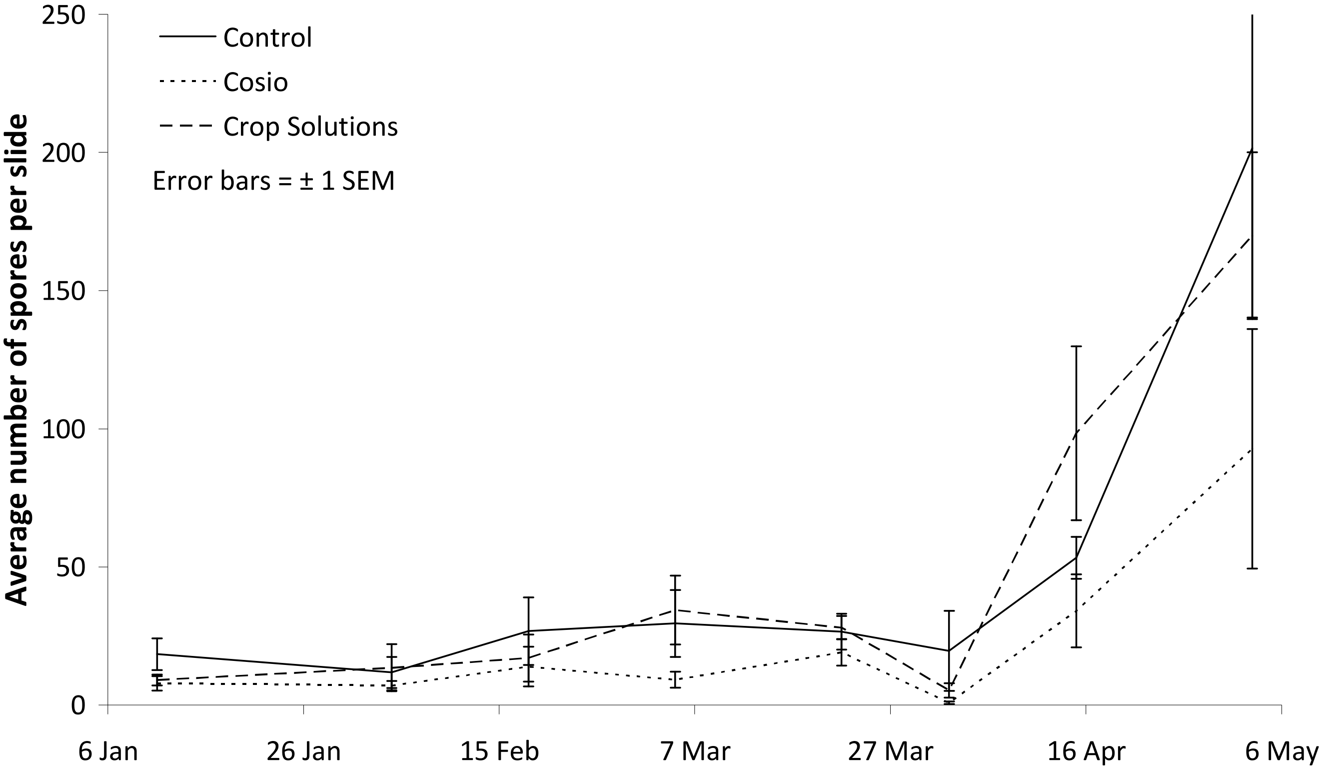


Figure 12. The mean number of *P. infestans* sporangia trapped on vaseline coated slides over the life of the trial.

In addition to the limited biological and statistical differences, determining what these results mean is also somewhat open, as the sporangia counts are both a cause of foliar blight levels and also a result of foliar blight, i.e., the number of sporangia is a causal factor for the amount of blight on the plants and the amount of blight on the plants is a causal factor of the number of sporangia. The lack of a clear difference among the sporangia numbers is therefore considered to be the strongest inference as it indicates that some of the hypothesized mechanisms that could be reducing sporangia and therefore foliar blight under the covers, e.g. an electrostatic charge on the sheets or lower wind velocities, appears less likely. It is also potentially further evidence that there may not be ‘one’ factor driving the differences in blight levels, but that it is a cumulative function of many factors, e.g., temperature, RH, wind speed, light levels / spectrum, etc., and that more manipulative experimental methods are therefore required to determine causality.

4.4.1. Visual blight observations

The visual differences among the treatments was again very clear, with both meshes having much lower blight than the control (Figures 13, 14 and 15 (and Figures 6, 7, 8, 9 and 10)), with the Cosio mesh having lower levels than the Crop Solutions mesh. As the crops under the covers senesced earlier than the uncovered potatoes, a full visual comparison at the time of harvest is not possible, however, by the start of harvest (3 May) the control plots were extensively covered with blight (Figure 16).

Figure 13. Blight levels on control / uncovered plots, 16 April.

Figure 14. Blight levels on Cosio mesh, 16 April.

Figure 15. Crop Solutions mesh - potatoes had already senesced by 16 April except for plants around the plot edges.

Figure 16. Level of blight on control plots at harvest on 3 May.

4.4.2. Laboratory identification of blight

The majority of the fungal colonies that grew from the leaf lesions plated on V8 and PDA were identified as *Alternaria solani* by colony and sporangia morphology. A few colonies identified as *Alternaria alternata* were also recovered. *Phytophthora* sp. was only isolated from one leaf lesion plated on V8. A few other fungi (such as *Epicoccum* and *Penicillium* types) were also recovered but only at low levels. No *Rhizoctonia* like colonies were isolated. The low levels of *Phytophthora* may be due to the advanced stage of the crop and partial decomposition of the leaves under multiple fungal infection.

4.4.3. Blight conclusions

Unfortunately, quantitative measurements of foliar blight levels were not taken, which has limited the ability to compare foliar blight with sporangia numbers from the slides. In future trials, regular leaf assessments are considered essential, ideally with laboratory analysis to confirm the blight species, through agar plating and preferably DNA analysis.

Despite the lack of quantitative measures, the visual effects of covers on blight was clear with obvious reduction in foliar blight levels under the covers, which is consistent with the previous years results. This indicates that the blight reduction under the meshes is a real effect, and not just an aberration of the 2011/12 trial. However, unlike the TPP results where there was no difference between the two meshes, there was a difference in blight levels, which was marginally reflected in sporangia counts. If this difference persists in future trials it may provide indicators as to what is causing the blight reduction. However, empirical field trials are probably unlikely to be able to provide the kind of data to accurately determine causality and clearly further research, using more manipulative methodologies is required. In conclusion, the fact that blight was clearly much lower under both mesh covers than the control, indicates that there is a real effect at work. If the effect holds up under higher blight pressure, and/or causal mechanisms can be uncovered and improved upon, then mesh crop covers have the potential to become a physical control method for blight. The caveat being is that a lot more research is required to ensure that the effect is truly reliable.

4.5. Climatic data

Various problems were encountered with the iButton data loggers, a number failed (ran out of power / battery) and some gave dubious readings, e.g. 0% RH and/or RH values considerably and consistently different from other loggers. After removing data that was considered unreliable and also combining some datasets (from the three data download dates) only two complete 'replicates' for the control and Cosio treatments and one for Crop Solutions were produced that could be considered reliable. This is not sufficient for statistical analysis, especially as some datasets were produced from data from different replicates / blocks. Without statistical analysis it is not possible to determine if differences are real or due to natural variation. However, as temperature and RH are physical variables (rather than biological, for e.g.), it is expected that the level of variation would be low, i.e., there would be little difference within treatments, and therefore that the data can be considered sufficiently reliable to be able to draw some conclusions.

4.5.1. Smith periods

A Smith period is the conditions required for potato blight to infect a plant, being two consecutive days where min temperature >10°C and on each day at least 11 hours when the relative humidity is greater than 90%. The number of Smith periods for the entire life of the crop was 10 for the control (both data sets were 10), and 10.5 for Cosio (10 and 11 from the two data sets) and 9 periods for the Crop Solutions (one data set) (Figure 17).

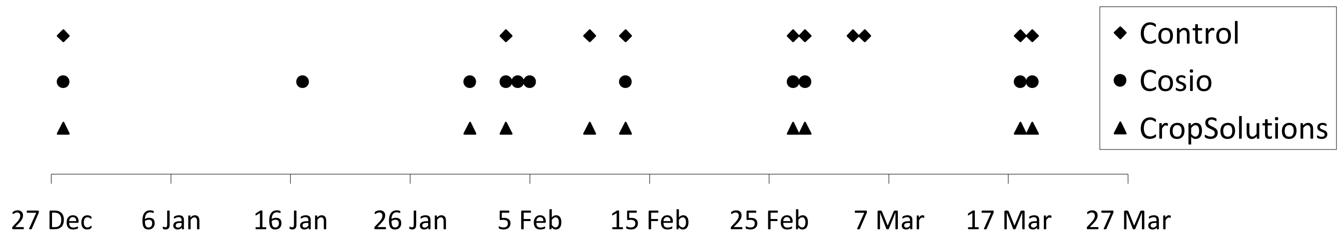


Figure 17. Dates of the Smith periods for the three treatments.

With only two Smith periods difference between the treatments, the periods occurring at similar times, and the Cosio treatment having the largest number of Smith periods but the lowest foliar blight, it is considered unlikely that differences in Smith periods among the treatments is driving the differences in foliar blight. In addition, it is also possible that the number of Smith periods are due to systematic differences in the data logger readings, so, the differences may also be due to measurement error. This also works the other way in that the differences could be larger. Over interpretation of this data should therefore be avoided.

4.5.2. Temperature and RH

The effect on temperature and RH under the sheets, compared with the control are not physically large (Table 3). This is to be expected as one of the design aims of mesh crop covers, is to have the minimum effect on under-sheet climate, as compared with frost cloth which aims to create a significant, e.g. 6°C, temperature increase under the cloth.

Table 3. Mean, minimum and maximum temperatures and relative humidity over the entire trial period of 140 days.

	Temperature			RH		
Treatment	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Control	17	-1	37	80	21	100
Cosio	18	1	41	80	17	100
CropSolutions	18	0	40	78	18	100

However, even thought there is only 1°C difference in the mean temperature, this is averaged over the entire 140 day life of the crop, so the 1°C difference equals 140 extra growing-degree days (aka heat units). As potatoes need between 800 and 1,500 growing degree days (GGD) an additional 140 GDD should have a noticeable effect on crop growth and a reduced time to maturity. However, the caveat regarding lack of statistical analysis and data logger variability noted in regard to Smith periods also applies to mean temperatures, so this difference could also be due to variation among the data loggers, so in interpreting this result, it is best concluded that the difference is small, not that there is an unambiguous difference in a given direction among the treatments.

In terms of the maximum and minimum temperatures, there is less of a difference for minimum temperatures (up to 2°C) than maximum (up to 4°C), the exact reasons for this are not known, but are probably a combination of factors such as reduced air movement in the crop, trapping solar radiation, etc. With an up to 2°C increase in minimum temperatures under the covers, they could potentially provide a small amount of frost protection but (much) less than purpose designed frost cloths that can provide up to 6°C of frost protection.

The effect of sheets on RH is also not large, and with the difference potentially due to variability among the iButtons, interpretation other than noting that the difference is small, is not considered prudent.

The following charts (Figures, 18, 19, 20, 21 and 22) show the weekly averages of mean, minimum and maximum temperatures and RH for the life of the crop (there is no max RH chart as that was 100% for all weeks, so produces a graph which is a straight line).

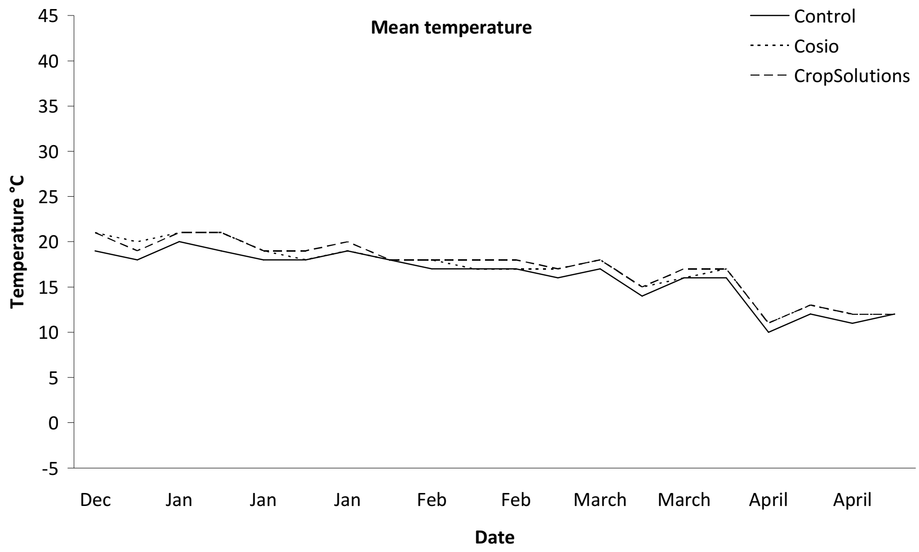


Figure 18. Mean temperature chart for the life of the crop.

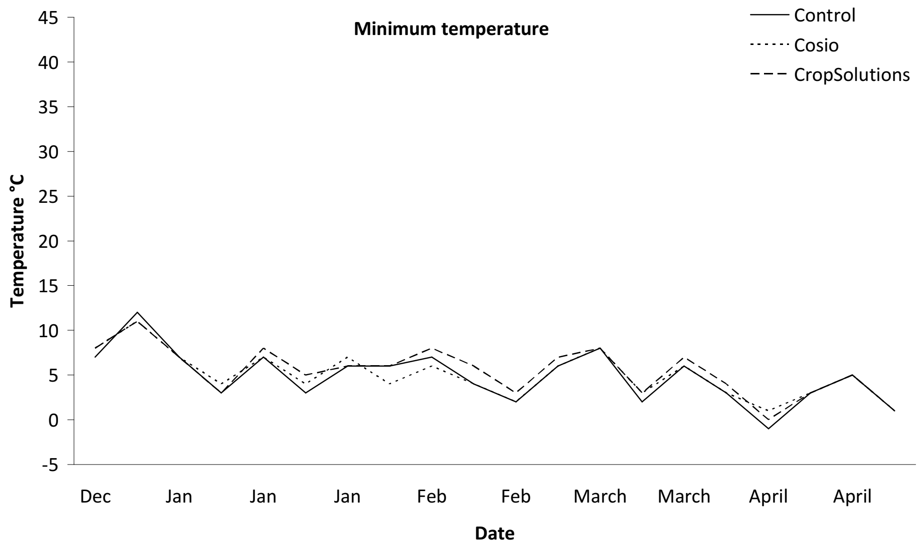


Figure 19. Minimum temperature chart for the life of the crop.

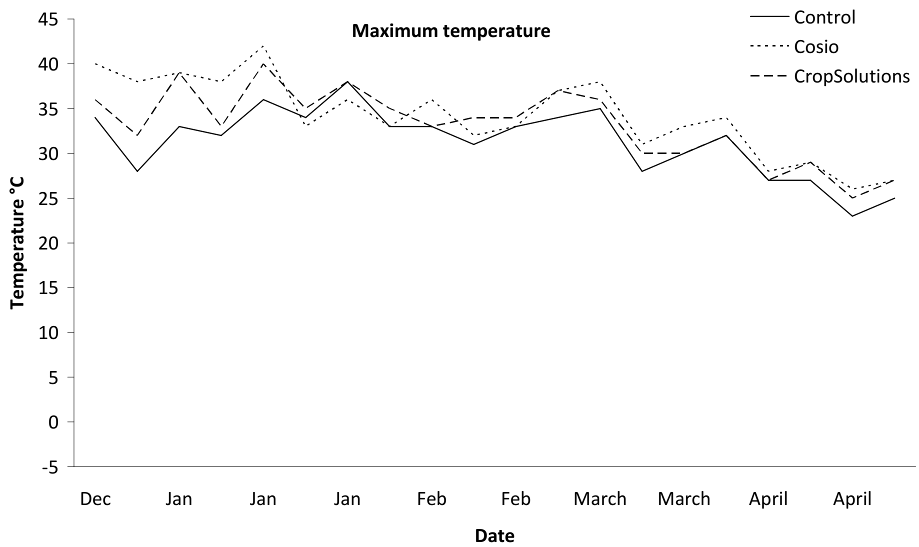


Figure 20. Maximum temperature chart for the life of the crop.

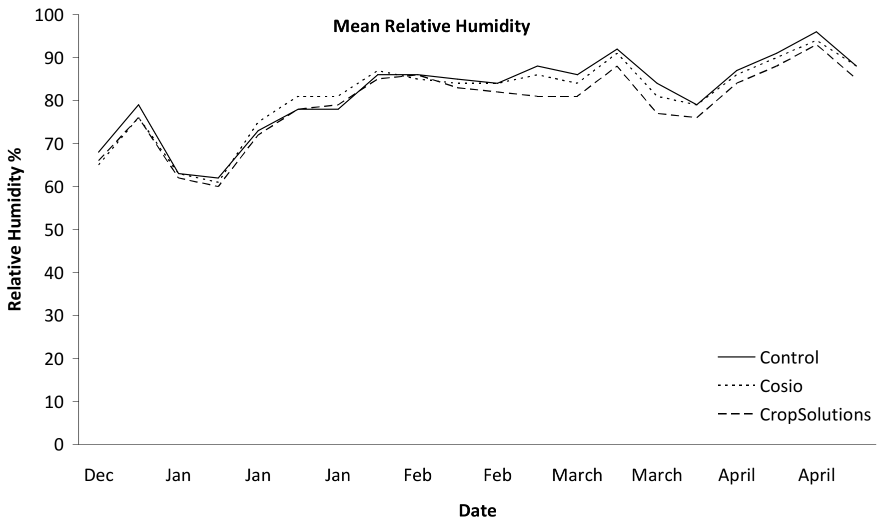


Figure 21. Mean relative humidity chart for the life of the crop.

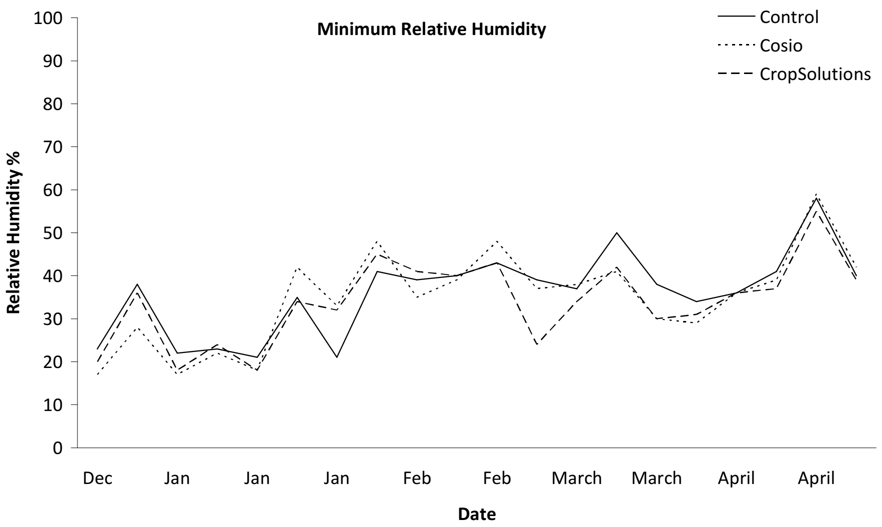


Figure 22. Minimum relative humidity chart for the life of the crop.

4.5.3. Climatic conclusions

Without statistical analysis of the climatic data, it is most prudent to interpret these results as failing to show any large difference among the treatments, and therefore that the large differences in blight levels among the treatments therefore do **not** appear to be primarily driven by climatic factors. If correct, then other effects of the sheets, e.g. reduced in-crop air velocity and changed light spectrum, may be more likely to be the main causes of differences in blight levels, or, there is the potential for a 'many little hammers' situation, where there are multiple causal mechanisms, which individually have a small effect on blight, but when combined have a large impact.

4.6. Economics

While mesh is effective at controlling TPP and shows positive potential for blight management, at a farm level the economics of using mesh, especially against current treatment options, i.e., insecticides, is a key driver of uptake by producers. However, at this stage, economic analysis is considered premature: Mesh is not yet on the NZ market, so local prices are not confirmed, though indicative prices are around \$0.80 m^2 (ex. GST) / \$8,000 ha, but deprecated over ten+ years = \$800 ha·year. On the yield side of the equation, only two results are available, both from Canterbury where TPP impacts are lowest and against a null control, so a full cost benefit analysis is not yet possible.

5. Future research

The consistent results of the 2011-12 and 2012-13 experiments, including the addition of the purpose designed, Crop Solutions field mesh in the 2012-13 trial is confirmation that the results are sound, including for the effect of mesh on blight. As the results are clearly positive it is considered that this research could be a valuable spring-board for a wide range of future research, both providing confirmation of these results and also expanding the use of mesh on potatoes and other crops to manage a wide range of pests.

5.1. Yield and other agronomic validation - multi region trials

The most important follow-on research from a commercial production perspective is comprehensive validation of these results by multi-site field trials. This is because while mesh is considered highly reliable as an insect barrier, it is likely that the effects of mesh on yield and other crop production parameters are not clear cut, for example, different cultivars may react differently to covering with mesh, and the interaction of mesh, cultivar and climate, is likely to be complex. As the effect of mesh on yield is going to a major factor in deciding if mesh will give sufficient return on investment. i.e., if using it is profitable, it is strongly recommended that multiple (on farm) field trials should be conducted in the main potato growing areas of New Zealand, especially those with contrasting climates. Canterbury, Hawkes Bay and/or Gisborne and the Pukekohe areas are considered good choices: Canterbury being dry and 'warm', Hawkes Bay / Gisborne dry and 'hot' and Pukekohe warm and moist. These areas also have varying TPP populations with the levels being (much) lower in Canterbury than Hawkes Bay where TPP can kill entire crops (i.e., zero yield). There may also be other factors at play, such as TPP population pressure being so high that digging in the sheets to minimise the potential for TPP ingress, may be vital.

In addition mesh needs to be compared with insecticide management of TPP, because for most growers, this is the current default management technology that mesh would have to replace, so it is the technology they will most want to see compared with mesh on both an agronomic and economic basis.

The rule of thumb for empirical agronomic field trials is at least three years trials in three locations (the three by three rule) are required to ensure an effect is reliable, with five seasons trials in five locations required for a high degree of accuracy (e.g. for cultivar comparisons with a few percentage points difference in yield). Therefore, on-farm field trials should be undertaken in all the main potato growing areas, and ideally several sites within each area, e.g. with contrasting cultivars, ideally for three seasons, to provide sufficiently reliable data for producers to be able to make informed decisions, including calculating economic returns.

5.1.1. Effect of mesh on Liberibacter and Phytoplasma

It is considered likely that if mesh crop covers can reduce in-crop TPP populations to effectively zero, then the amount of Liberibacter and Phytoplasma infection of plants would also effectively be reduced to zero. However, this should be checked as part of the above field trials, as it is only a hypothesis at this stage and lacks validating data. If the hypothesis is correct then mesh could be a useful research tool for producing Liberibacter and Phytoplasma 'free' plants in the field, rather than having to use insect proof glasshouses etc.

5.2. Resistance management and lowered economic barriers to wider use on other crops

A key concern with the use of insecticides for TPP management is evolved resistance. Current recommendations include using only one chemistry / mode of action for one generation, which in practice means changing chemistry every month. Mesh crop covers could be an important tool in resistance management, in that they would allow all insecticide spraying to cease and therefore, reduce the potential for resistance to evolve. In addition if widespread resistance does emerge, mesh crop covers are likely to be the only control option left.

Once mesh covers are required for one crop, the economic costs of using mesh on other crops on the same farm is lowered as the intellectual and capital investment in mesh management machinery has already been made. As there is increasing pressure to lower pesticide use on all crops, the need to use mesh on one crop could be a springboard to its use on a range of other crops thereby reducing pesticide use and/or facilitating the use of biological controls / IPM (integrated pest management) programs.

Therefore, analysing and testing the potential for using mesh for TPP resistance management, and as a replacement for insecticides on other crops, is considered to be an important avenue of research.

5.3. Blight

The effect of mesh crop covers on blight is considered to be of a completely different order to their effect on TPP. Common experience indicates that if you completely cover a crop with a physical barrier which is impervious to an insect, then 100% control is assured. Also there is a wealth of practical and research experience of using physical barriers for insect pest control. In contrast, the effect of mesh crop covers on blight was (1) completely the opposite of what common experience suggested and (2) the causal mechanisms by which the covers reduce blight, is still almost completely hypothetical (these experiments have only shown that of the factors measured, none is likely to be the primary cause of lower blight). It is therefore unsafe to assume that the effect on blight seen in the two trials at the BHU would occur again, especially in other locations with higher blight pressure, different climates, etc.

It is therefore considered that a two pronged approach to future research is required:

1. The effect of mesh on blight must be measured (e.g. sporangia counts, foliar disease levels, etc.) in the field trials described above, along with environmental variables that affect blight, (e.g. temperature, RH, leaf wetness, air velocity, etc.) to provide a substantial empirical data set.
2. Based on hypotheses that are informed by the empirical data set, 'manipulative' experiments, i.e., based in laboratories and glasshouses, where individual parameters can be manipulated, e.g. temperature, humidity, light spectrum, air velocity, etc., would be required to enable cause and effect (causality) to be determined.

Only by determining causality, which is the primary objective of science, can the phenomenon be fully understood and therefore improved, and potentially new approaches to blight, and other foliar fungal pathogens be developed, e.g. manipulating the light spectra under the covers.

5.4. Multiple effects of crop mesh

The beneficial effect of mesh covers on the crop has multiple causes, e.g. reducing TPP damage, modifying the under-sheet climate, reducing blight infection levels, as well as affecting other foliar pathogens and pests, e.g. aphids. This means the results from these experiments are due to all of these factors interacting, and it is impossible from this experimental design to determine their relative contributions (both positive and negative).

From a producers perspective this is rather academic as it is the net effect of the crop covers on profitability that is the critical measure. But from a scientific perspective, these are important issues, as understanding individual causal effects, i.e., what is going on 'under the hood', is essential if significant understanding and progress is to be made. Therefore, from a scientific standpoint, individual effects, for example, the direct effect of mesh covers on crop production in the absence of pest and disease pressure, need to be determined, so the relative contribution of the different effects can be measured.

In addition to separating out the individual effects, it is considered vital to understand how mesh achieves its effects, i.e., the causal mechanisms, especially for blight control. This will be vital if mesh crop covers are to be 'proven' reliable, because, without understanding the causal mechanisms, it will not be possible to say why the mesh is having an effect, and only that there is a body of empirical data indicating that the effect is consistent, i.e., correlation does not prove causation. Also, understanding causation will be vital if improvements are to be made, as correlation / empirical data, gives little indication of how improvements could be achieved.

It is therefore considered vital that both empirical field trials and manipulative experiments are undertaken to establish the individual effects of mesh crop covers and the causal mechanism(s) by which mesh is controlling blight and other non-obvious effects, e.g. increased crop growth in the absence of pests and diseases.

5.5. Anchoring systems

For TPP control, it is clear that the mesh is a highly effective barrier, which is as expected as a wide range of research, and common experience, demonstrates that many types of mesh are very effective insect barriers, e.g. fly screens.

However, in this trial TPP did get under the mesh, but, as it was unlikely that the psyllids penetrated the mesh, they must of got in under the sheet edges due to the deliberately imperfect anchoring system (that was designed to simulate how mesh would be used in market garden situations). Digging in the mesh should mean that mesh is as close to 100% effective at keeping TPP of the crop as is possible in real-world farming. Plus as large scale users in Europe are now digging in hundreds of hectares of mesh, this is clearly a viable technique, and may even be cheaper than anchoring systems that pin mesh to the ground, as no anchors are needed and burial of sheet edges is mechanised. Therefore, the additional benefit of digging in the mesh in terms of providing the most insect-proof barrier possible, should be tested / used in future research where practical, e.g. where mechanical access in the crop, e.g. for interrow hoeing, is not required.

5.6. Mesh hole size

While the initial laboratory research using no-choice tests that preceded the 2011/12 (first) trial showed that 0.64 mm hole size was the maximum size that ensured zero penetration of mesh by TPP, even at larger hole sizes, not all the TPP got through, with only 15% penetration for hole sizes up to 0.83 mm (Table 4).

Table 4. Percentage of TPP adults (n=5) that penetrated mesh with a range of hole sizes, in a no-choice test over seven days.

Length of hole mm	Width of hole mm	Percentage of TPP that penetrated mesh	SEM
1.42	1.42	80%	0.0%
1.33	1.33	90%	5.8%
1.84	1.03	60%	8.2%
0.83	0.83	5%	5.0%
0.83	0.83	10%	5.8%
0.77	0.77	15%	9.6%
0.64	0.64	0%	0.0%
0.78	0.48	0%	0.0%
0.57	0.43	0%	0.0%
0.40	0.40	0%	0.0%

A 0.6 mm hole size is smaller than the 'standard / common' mesh hole sizes used by growers (which is typically 0.8 mm). The smaller the hole size in mesh the more expensive it is, so to maximise economic returns the largest size mesh is generally the most desirable. As the penetration rate of 0.8 mm mesh in the no-choice tests was low, which, combined with the observations that TPP do not disperse very fast under mesh, and in the field the ‘no-choice’ conditions of the laboratory experiments do not apply, i.e., TPP that alight on mesh in the field have the option of flying off again in search of other food sources, it is possible that in real-world use, the cheaper 0.8 mm mesh would be sufficient to keep TPP off the crop, or at least, even if small numbers of TPP do get through the mesh, the larger hole mesh may still improve economic returns, due to the trade off between reduced mesh cost even with an (slight) increase in crop damage.

Therefore, testing a range of mesh hole sizes in field trials, up to 1.0 mm, would be valuable, both from a economic / agronomic perspective and also from a scientific perspective in that it would add to the empirical data on psyllids behaviour which could inform more fundamental research into TPP behaviour, which in turn could provide valuable information on new management techniques. In addition, as the effectiveness of different mesh hole sizes could vary with TPP population pressures, multi-region tests are considered essential. Including larger mesh hole sizes in the multi-region field trials (page 25) could be an efficient means of achieving this.

At the same time, larger hole sizes may affect the mechanisms that reduce blight levels, and crop growth, e.g. under sheet air velocity, light spectra, temperature, RH, etc., so the effect of different mesh hole sizes on blight and other aspects of crop performance also need to be measured.

5.7. Limited TPP movement underneath covers

The anecdotal observations that TPP infestations appear to be inhibited from spreading under the mesh is considered novel, unusual, and contrary to expectations, so therefore is in clear need of further research to understand it. One hypothesis is that the adult TPP, which are also the dispersal stage, both fly and jump, and that the covers may be inhibiting this behaviour and therefore limiting dispersal under the sheet. However, a wide range of other causes (and hypotheses) are likely.

Complimenting this, were the results of the laboratory study, where even at larger mesh sizes not all of the TPP penetrated the mesh. This may indicate that mesh is not just a physical barrier preventing TPP accessing a crop, but that it has other effects on their behaviour, e.g. mesh could be ‘camouflaging’ the crop from the psyllids or be some kind of other sensory barrier.

As little is known about the behaviour of TPP, including how it finds its hosts, developing a better understanding of why psyllid spread so slowly under mesh covers and why not all of the psyllid adults penetrated mesh when they were physically able, could be a valuable avenue of research that has the potential to deepen the fundamental understanding of TPP and that could also provide new information that can be translated into additional means to control / manage TPP, and related pests.

5.8. Potato tuber moth and aphid management

Potato tuber moth (PTM, *Phthorimaea operculella*) is a major pest of potatoes globally, including the North Island of New Zealand, e.g. the Gisborne region. PTM is difficult to control chemically as the larvae either mine the leaves or burrow into tubers protecting them from contact insecticides and the adult moths fly, so they can move between crop and non-crop areas, so spraying them has a reduced effect. In addition at a global level PTM is resistant to a wide range of pesticides.

PTM has a lifecycle not-dissimilar to cabbage & carrot root flies, and TPP, in that the adults are the dispersal stage, and in the case of the flies, the adults need nectar and pollen as food, which often do not occur within the crop, so they may have to move out of the crop to feed. Mesh covers are well proven as effective control measures against pests such as root flies and butterflies (e.g. cabbage white (*Pieris rapae*)) so crop covers should therefore have a high likelihood of being a effective control for PTM, on the proviso that the suppressant effect of mesh crop covers against blight holds up under North Island climates. If so, mesh may also be a valuable control measure for PTM worldwide.

Aphids are also a pest on potatoes, mainly seed potatoes in New Zealand as they are vectors of viruses, but globally they are a significant food potato pest. Some initial work has been undertaken in the United Kingdom testing mesh for aphid control which found it effective (Mike Smith, Wondermesh UK, pers. comm.). However, the anecdotal experience from this trial showed that if aphids do get under the mesh they can proliferate as they can complete their lifecycle under the sheets. The use of mesh for aphid management on potatoes therefore also needs further research.

5.9. Tomatoes

Tomatoes are the other main field crop impacted by TPP for which mesh sheets should be a good solution. However, all the issues that apply to potatoes, also apply to tomatoes, e.g. the effect of mesh on yield and blight (tomatoes and potatoes are both susceptible to *Alternaria solani* i.e., 'early' blight). If the use of mesh is to be validated for tomatoes, the same trials being undertaken for potatoes will also need to be conducted for tomatoes.

5.10. International research

While this research has focused on managing TPP on potatoes in NZ, there is considered to be considerable potential for the use of mesh crop covers in other countries for managing / controlling a wide range of potato insect pests with suitable lifecycles, e.g. Colorado potato beetle (*Leptinotarsa decemlineata*), a range of caterpillars (cutworms, armyworms, loopers), tuber flea beetles (*Epitrix tuberis*), blister beetles (*Epicauta* spp.), potato leafhopper, (*Empoasca filament*), lygus bugs (*Lygus* spp.), etc. This is again considered dependent on mesh crop covers suppressing blight and/or other foliar fungal diseases under a wide range of climatic conditions, or if the blight suppressant effect can be improved.

Mesh crop covers could be a particularly valuable management technique for developing countries where there are multiple problems with agri-chemical abuse, e.g. incorrect application, lack of protective clothing, poisonings, etc., as once purchased, the mesh will last many years, it could be used on many other crops against a range of pests and there are no (obvious) issues with toxicity or other potential harmful effects.

There may also be even wider potential for mesh crop covers to control insect and other pests and/or a range of fungal diseases on a range of crops beyond potatoes, especially if the effect of covers on blight can be elucidated, improved and expanded to other foliar pathogens.

5.11. Research conclusions

It is therefore hoped that these results will provide a springboard for a range of research, from controlling TPP and blight on potatoes in NZ through to managing a range of pests and fungi on crops world-wide.

6. General conclusions

This trial is considered to be a significant success: most important is that the effects of the mesh on both TPP and blight are consistent with last years trial. In addition the results were similar for both the Cosio glasshouse quarantine mesh and the Crop Solutions field mesh, for both TPP and blight, demonstrating that the effects are not unique to the Cosio mesh nor were an anomalous result. Thirdly, the results were consistent under contrasting different weather conditions (wet the first year, dry the second).

The TPP results, show that the mesh is highly effective at keeping TPP off potatoes, and TPP does not appear to rapidly spread or multiply under the sheets (unlike aphids) which means that ingressions will not result in under-sheet population explosions. The effects on yield, are substantial, both total yield and especially for market grade tubers, where yield more than doubled, against a control with a reasonable yield level, indicating that where TPP has a much larger negative effect on crops, including complete crop loss, the yield and economic benefits would be considerably larger still.

The effects of the meshes on blight is also substantial, with both meshes clearly reducing blight levels, indicating that again, it is not just due to a specific attribute of the Cosio mesh (although the Cosio mesh had lower blight levels, showing there were differences between the sheets, which may provide useful leads towards the causal mechanism). However, the causal mechanisms are not much clearer than after the previous years trial. The climatic data show the sheets only slightly modify the climate, with only one out of ten difference in the number of Smith periods. However, this data is still considered preliminary as there is no knowledge or data prior to these two trials to go on (i.e., unlike mesh keeping a wide range of pests out). What the data does indicate is that climatic effects are less likely, or unlikely to be the main driver of the lower infection rates of the covered crops. The sporangia counts also indicate that they are not the major driver of the differences between treatments, and as they are both cause and effect of foliar blight and there are no quantitative measurements of leaf blight, interpreting the spore counts is difficult. The blight effect may therefore be the cumulative effect of multiple factors, but that is also hypothetical until the investigative research is undertaken.

It is recommended that the next step for TPP control using mesh is on-farm trials, ideally, in the key growing areas, e.g., Canterbury, Hawkes Bay, Gisborne and Pukekohe, on both potatoes and tomatoes, of a range of cultivars and a range of makes of mesh with different hole sizes . This should produce sufficient data to give sufficiently robust conclusions to allow farmers and growers to decide if it is economically viable to use mesh on farm and to start testing it themselves.

In regard to supply of mesh, off the back of this research, Europe mesh manufacturers / suppliers are now actively interested in establishing a market for mesh crop covers in New Zealand.

Having mesh available in NZ means that mesh crop covers will also then be available for producers to use against a wide range of pests on other field crops, such as cabbage and carrot root fly, caterpillars, aphids, and vertebrate pests, as European farmers and growers have been doing for over a decade.

Finally, having a supply of mesh in NZ also means that if / or when, another insect pest incursion occurs in NZ, producers will have a non-chemical control option on the shelf, allowing for rapid deployment, especially if mesh crop covers are already in use for the pest / crop combination overseas.

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8. References

Anderson, J. A. D., Lewthwaite, S. L., Genet, R. A. & Braam, W. F. (2004). 'Moonlight': A new dual-purpose main crop potato (*Solanum tuberosum*) cultivar. *New Zealand Journal of Crop and Horticultural Science, 32*(1), 153-156. http://dx.doi.org/10.1080/01140671.2004.9514290

Kale, A. (2011). *Economic and business impacts of potato psyllid on the potato industry. Elak Consultants report to Potatoes New Zealand*. Wellington: Potatoes New Zealand

Munyaneza, J., Buchman, J., Sengoda, V. & Crosslin, J. (2009). *Potato Psyllid Transmission of Liberibacter and its Impact on Zebra Chip Development*