Initial Results for Tomato Potato Psyllid (TPP) Management with Mesh Crop Covers

July 2012. Report number 3-2012

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Permanent Agriculture and Horticulture Science and Extension

www.bhu.org.nz/future-farming-centre

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Farm, like you'll farm for ever

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Citation Guide

Merfield, C. N. (2012). Initial results for tomato potato psyllid (TPP) management with mesh crop covers. Lincoln, The BHU Future Farming Centre

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2. Summary

- Initial trials of mesh crop covers indicate that they are an effective control measure for TPP. However, the statistical significance of the field trial was mixed, so the results must be treated with caution.
- Contrary to expectations potato blight was much lower under the covers. This may have been a fluke result and it is possible the opposite may be found in later trials.
- This is the result of only one field trial, which needs to be repeated to confirm the results. On this basis it would be unwise for farmers and growers to 'bet the farm' and purchase large amounts of mesh solely for TPP management.
- However, it is suggested that producers who can afford to take some financial risk, do consider purchasing mesh to cover a small proportion of their crop, to test it under their production systems. Ideally that would be done as part of a properly randomised replicated trial to ensure the rigour of the results. This can be done in conjunction with the BHU Future Farming Centre who can provide assistance and statistical analysis for free.

3. Introduction

The tomato potato psyllid (TPP, *Bactericera cockerelli*) is a pest that invaded New Zealand around 2005-06. It attacks / hosts on, a wide range of fruit, vegetables and non-crop species within the Solanaceae family. To date most research at directly managing TPP has been based around xenobiotic insecticides, with a smaller amount of working looking at 'softer' eobiotic chemicals (e.g., neem) and biological control. While this approach has initially been successful with a number of previously unregistered or new xenobiotic insecticides now available to control TPP, they are not an ideal solution because:

- Evolved resistance is a continual threat.
- Solanaceae field crops had mostly moved to integrated pest management programs that used no, or a few highly selective xenobiotic insecticides, but the need to spray for TPP means that the biological and ecological control mechanisms that previously kept other pests in check no longer work, so additional insecticides are required to control insects that were previously managed biologically.
- TPP is something of an 'ultimate' pest, in that it has systemic phytotoxic 'saliva' that can cause significant damage, even death, to crops, especially potatoes and tamarillos, from very small numbers of insects (e.g., less than ten). It can also carry the bacterial pathogen *Candidatus* Liberibacter solanacearum, which causes zebra chip disease in potatoes. This means that even small populations can cause significant yield loss and even plant death, far beyond that due to the amount of sap they extract from the plant. This means that economic thresholds for TPP are very low, i.e. approaching zero, compared with other sap feeders such as aphids. This requires a commensurately more intensive spraying regime: Systemic insecticides only work after the TPP has fed on the plant, and therefore potentially caused a considerable amount of damage through their phytotoxic saliva and/or Liberibacter infection before they are killed by the insecticide; contact insecticides need to be applied frequently and thoroughly to the undersides of the leaves where TPP 'hide' to kill them before significant damage is caused.
- Organic and other producers who do not wish to, or cannot, use xenobiotic insecticides, e.g., due to market requirements, currently have no effective TPP management options, as the eobiotic (soft) sprays have no or a very limited effect; biological controls are still under development and typically take considerable time to bring to fruition, and no ecological (cultural) approaches (e.g., rotations) appear to be able to provide sufficient control of TPP.

Therefore, as both a short and longer term strategy there is a vital need to rapidly find effective non-chemical TPP management approaches.

4. Mesh crop covers

'Mesh crop covers', generally just called 'crop covers' but also 'insect mesh' '… crop mesh', '… crop sheets' '… nets' etc. along with a plethora of trade names, are a common tool in Europe for the management of a wide range of insect and vertebrate (e.g., rabbits, birds and deer) pests on a wide range of vegetable crops. There are now hundreds of thousands of hectares of mesh crop covers in use in Europe, with some individual farms using hundreds of hectares. Nor is its use confined to organic agriculture: main-stream producers are increasingly reliant on mesh crop covers because they have run out of pesticide options, for e.g., against cabbage root fly on brassica root crops.

Mesh crop covers should not be confused with 'frost cloth' either spun-bonded (aka 'nappy liner') or knitted (e.g., Mikroclima™) (Figure 1). Frost cloth, as the name indicates, has been designed to protect crops from frost, by increasing the under-cloth temperature, often by several degrees. This means that frost cloth can also used to extend the production season, both in spring and autumn, sometimes by several weeks. In contrast, crop mesh has been designed to have as **little** effect as possible on the temperature, relative humidity (RH), and other climatic factors under the cover. This means that crop mesh can be used in the middle of summer, when frost cloth would likely cause such high under-cover temperatures that the crop may be harmed, even killed.

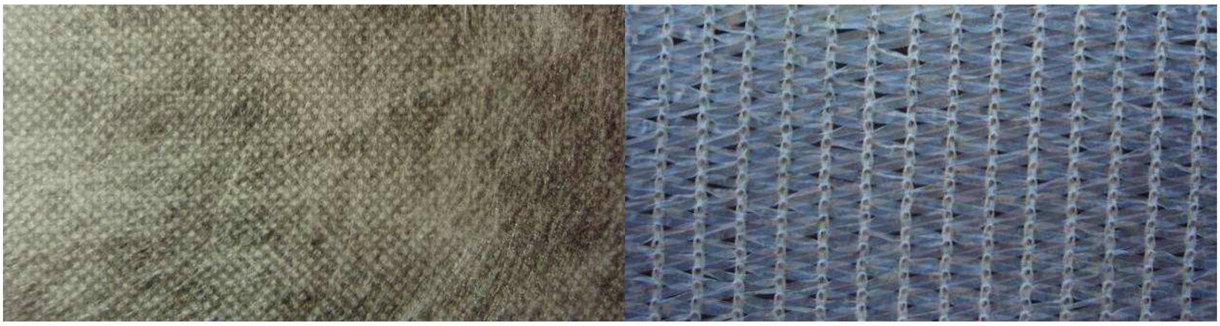

Figure 1. Spun-bonded frost cloth (left) and Mikroclima™ knitted frost cloth (right).

Crop mesh is woven from monofilament materials such as nylon and polypropylene, i.e. it looks like cloth made of fishing line (Figure 2). It comes in a range of hole sizes from around 0.3 mm which is small enough to keep out thrips, to around 4.0 mm which is an effective butterfly, hail and vertebrate pest barrier (Figure 2).

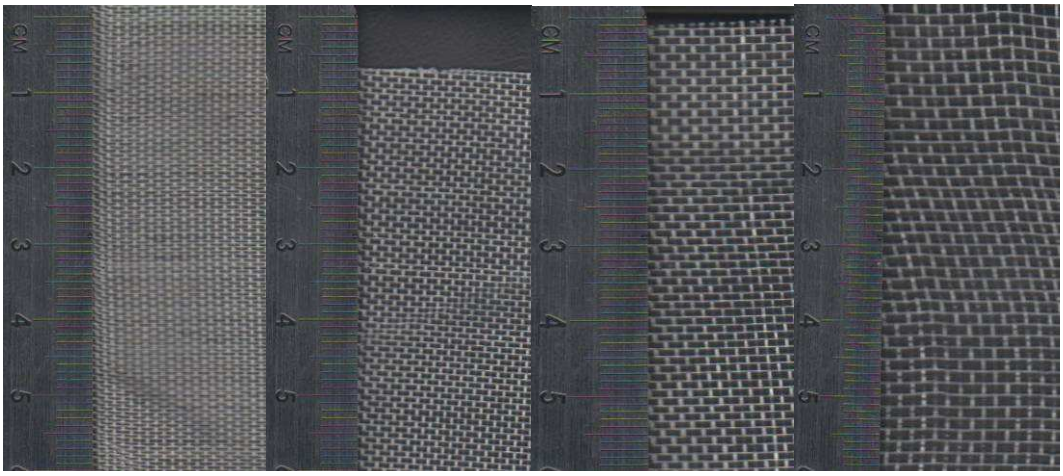

Figure 2. From left to right, four grades of mesh crop covers, 0.3 mm (thrips), 0.6 mm (aphids), 0.8 mm (flea beetle), and 1.3 mm (root fly) hole sizes.

4.1. Hole size range

A range of hole sizes are used because covers with smaller holes are heavier per square meter of cover because they contain more material, so they are more expensive and are more effort to handle (e.g., they are bulkier), and they also intercept more light and have lower 'breathability' i.e. there is a lower exchange of air and water vapour through the cover. Therefore, in practice the largest hole size that keeps the pest out is used as this is cheapest, makes handling easier and minimises the effect of the cover on the under-cover climate. At the same time if mesh crop covers are needed against a range of pest sizes, then from a practical point of view, growers may only use one or two mesh sizes, e.g., a small and medium.

4.2. Lifespan

Mesh crop covers are also designed to have a much longer life than spun bonded frost cloth - which may only last for one use for the thinner grades. Most manufacturers claim a 10 year life is possible for mesh crop covers, but that clearly depends on the duration and time of year it is out in the field and exposed to sunshine and therefore UV light, which degrades 'plastics'; how often it is handled; and how carefully or badly it is handled. New Zealand UV light levels are often considerably higher than in the EU, at least compared with higher European latitudes, so UV degradation may be more rapid in NZ. Different brands of mesh crop cover are made from different types of plastic, which vary in their durability and inherent UV resistance and also may have different amounts of UV inhibitors added to the plastic. This means there can be significant differences in the durability and UV resistance among the different brands of mesh crop covers.

4.3. Cost

The cost of mesh crop cover is considerably more than spun bonded frost cloth. Mesh crop covers costs vary from about NZ$0.80 to 2.00 / m^2 depending on brand. Knitted frost cloth costs $0.96 / m^2 at the time of writing. NB Prices will vary over time, especially for imported materials which are subject to currency variations and shipping costs. Suppliers are often keen to 'discuss prices' for purchases of larger amounts, e.g., more than one hectare. These figures should therefore be taken as indicative only.

4.4. Supply

The supply and use of mesh crop covers to date has mostly been confined to Europe, with their use only now spreading to North America. At the time of writing mesh crop covers are not available 'off the shelf' in NZ. However, off the back of this research, European manufacturers are interested in supplying product direct from overseas and local horticultural plastics manufacturers are also interested in production and supply.

The manufacturers of mesh crop covers and glasshouse quarantine mesh (see section 4.5 below) that supplied material for use in this research are (in alphabetical order):

- www.cosio.co.nz
- www.cropsolutions.co.uk
- www.empak.co.nz
- www.gromax.co.uk
- www.svenssonglobal.com
- www.quantumgrow.co.nz
- www.redpath.co.nz
- www.wondermesh.co.uk

The provision of this list of suppliers is not an endorsement of the companies or their products. There are other manufacturers and suppliers of mesh crop covers who are not on this list. You are recommended to conduct your own (internet) search for suppliers.

4.5. Glasshouse quarantine mesh

It is important to note that a closely related product to mesh crop covers is available 'off the shelf' in NZ. This is used as a 'glasshouse quarantine mesh' over vents etc. a common trade name for which is 'Biomesh'. However, this mesh is considerably tougher, heavier, less translucent, typically more expensive than crop cover mesh and only comes in narrower widths, e.g., less than three meters wide, while mesh crop covers come in widths up to 15 meters or so. For these reasons it is not considered the optimum product for field crop use. However, due to the financial constraints of this research it was not possible to purchase purpose made mesh crop covers from Europe. Instead glasshouse quarantine mesh was used which worked well and achieved positive results.

4.6. Compatibility with spraying

Mesh crop covers can be sprayed through (at least in some situations / products) though they are not suitable for driving over so alleyways are required for spraying. Mesh crop covered that have been sprayed may need to be treated as a hazardous material, e.g., under OSH (Occupational Health and Safety).

5. Research - TPP management with mesh crop covers

5.1. Possibilities and pitfalls

Mesh crop covers appear to be a ideal solution to TPP management because they should prevent TPP from getting to the crop in the first place and therefore prevent them causing any harm at all, unlike insecticides which require the psyllids to alight on the plant (and to feed for systemic insecticides) to be able to kill them and therefore potentially cause significant harm before they are killed. The reason mesh crop covers are not an ideal solution in practice is that they complicate crop management, as they have to be removed for field operations such as mechanical weeding, and they are expensive. Their value therefore depends on cost vs. benefit calculations. They may also be cost effective against the some insecticide options, particularly when the level of control mesh crop covers provide is taken into account, and especially for speciality crops such as seed potatoes where the mesh should also provide exceptional control of other insect pests.

At the same time while mesh crop covers are normally a very effective control measure, there are reports of situations where pests circumvents the mesh, e.g., by walking over and then under the mesh, or laying eggs through the mesh. In addition, while mesh crop covers are designed to have the minimum effect on the under-cover environment, e.g., in terms of temperature, RH and light levels, there is inevitability some change, e.g., increased RH, which could negatively effect other aspects of crop production, e.g., increase fungal diseases. Because of these possible pitfalls research was required.

5.2. Optimum mesh size and TPP behaviour

5.2.1. Laboratory experiment on mesh size and egg laying

Laboratory experiments were conducted to determine the maximum size of mesh hole that is complete barrier to 100% of psyllids, and also if they would lay eggs through the mesh. No choice tests were used with consisted of a capsicum leaf touching the underside of a small piece of mesh with five adult TPP placed on the other side, housed in a small container with no other food or water. Only adult psyllids were tested as these are the only mobile stage and therefore the only point in the psyllid lifecycle where they would encounter mesh crop covers. Adults are also the only egg laying stage of the lifecycle.

The results were very positive. No psyllids penetrated mesh where the hole size was less than 0.64 mm Table 1. This indicates the maximum hole size is between 0.64 and 0.77 mm, i.e. around 0.7 mm although the exact size needs to be confirmed.

Table 1. Percentage of TPP adults that penetrated mesh with a range of hole sizes.

Length of hole mm	Width of hole mm	Percentage of TPP that penetrated mesh
1.42	1.42	40%
1.33	1.33	45%
1.84	1.03	30%
0.83	0.83	3%
0.83	0.83	5%
0.77	0.77	8%
0.64	0.64	0%
0.78	0.48	0%
0.57	0.43	0%
0.40	0.40	0%

At larger hole sizes the percentage of psyllids that penetrated the mesh only increased slowly, which indicates that the psyllids were not actively trying to penetrate the mesh, even though they had no food or water on the ‘outside’ side of the mesh while there was food (the capsicum leaf pressing against the mesh) and water on the ‘inside’ of the mesh. Also no eggs were laid through the mesh - only when TPP penetrated the mesh. If the psyllids could detect the capsicum leaf through the mesh, it would be expected that as soon as the mesh hole size was sufficient to allow them through, the majority of them would penetrate the mesh. This indicates that the psyllids ability to detect the capsicum leaf were impaired by the mesh, i.e. the mesh was somehow ‘camouflaging’ the capsicum even though it was touching the ‘underside’ of the mesh the psyllids were ‘standing’ on.

Based on these results a field trial was undertaken.

5.2.2. Field experiment with mesh crop covers on potatoes

5.2.2.1. Methods

Due to limited funding, only one type of mesh crop cover was able to be tested. That was donated by Cosio Industries Ltd. (www.cosio.co.nz) and was a HDPE 125 gram/m^2 quarantine mesh/netting with a hole size of 0.78 × 0.48 mm, which blocked 100% of psyllids in the laboratory experiments. This is manufactured in 3.3 m widths so it was cut and sewn into approx 10 × 10 meter squares (i.e. 100 m^2).

The mesh was placed in a crop of moonlight cultivar potatoes sown 15 December 2011, in a randomised complete block design with four replicates (Figure 3) grown at the Biological Husbandry Unit, Lincoln University, New Zealand, 43°38'59.67" S 172°27'30.51" E. The mesh was initially anchored to the ground using electric netting stakes, but these were later substituted for custom made steel stakes (see section 13).

Figure 3. Start of field experiment.

Figure 4. Experiment on 23 March 2012

Placing the mesh crop covers within a continuous field of potatoes proved to be a mistake, as the growing potatoes pushed the covers up thereby creating a 'green bridge' between the covered and not-covered plots, which allowed psyllids to move into the covered plots from the edges. This means that had the covered plots been physically separated from the not-covered plots (e.g., by a strip of grass, thus breaking the green bridge) the results may have been more in favour of the mesh crop covers.

5.2.2.2. Results

The key measurements were tuber yield, psyllid populations and level of potato blight.

Tuber yield was determined by hand digging eight plants from the centre of each plot and recovering all tubers, i.e. regardless of size. Tubers were then washed and individually weighed. After yield measurements were taken, a subsample of 20 tubers per plot were stored at household temperatures in the dark for 40 days and then the number of sprouted eyes per tuber was recorded.

Psyllid populations were estimated by one direct count of adult and immature psyllids on 13 potato leaves per plot on 23 March and two samplings using one yellow sticky trap per plot on 30 March and 13 April with the traps left in the crop for one week.

Potato blight was visually assessed throughout the trial.

Yield

There was a clear agronomic and economic difference between covered and non-covered plots, but yield and number of tubers were not statistically significant at the 0.05 level while average tuber weight and sprouting was (Table 2). Analysis was conducted on both the total harvest, and also with tubers less than 125 g removed, as these are typically considered 'undersize' for many market outlets.

Table 2. Tuber yield results.

Measurement	All tubers		P	Tubers > 125 g		P
	+ cover	- cover		+ cover	- cover	
Average yield tonne / hectare	68	51	ns	46	22	ns
Average number of tubers per plant	11.6	13.3	ns	4.0	2.3	ns
Average tuber weight (grams)	75	118	<0.05	202	176	<0.05
Average number of sprouts per tuber	0.54	3.2	<0.05	No data	No data	

The yield in the covered plots was 35% more than not covered plots for all tubers and 109% more when undersize tubers were excluded, i.e. the yield more than doubled (Table 2) but despite this large agronomic difference there was no statistical difference, so care is required interpreting the result.

There were slightly more tubers on the non-covered plants than covered, which is expected as a key effect of TPP is to increase the number of tubers but reduce their size, but the result was not statistically or agronomically significant so nothing should be inferred from this (Table 2). When only market grade tubers (> 125 g) were analysed there were nearly twice the number of tubers from the covered plants than then not covered plants, however while this is agronomically significant it was not statistically significant (Table 2).

The effect of TPP on tuber size is clearly seen in the average tuber weight for the not covered plants when all tubers are included being 58% smaller than the covered tubers. When the small tubers are excluded the difference is considerably less, which is to some extent an 'artefact' of excluding the small tubers, but even then, the tubers from covered plants are still 15% larger which shows that all tuber sizes were reduced by psyllids (Table 2).

There was a very clear difference in the number of sprouts per tuber, with not-covered plants with a 494% increase in the average number sprouts from the not-covered potatoes (Table 2 and Figure 5).

Figure 5. Example of tuber sprouting from not-covered plants (top) and covered plants (bottom).

Psyllid populations

There were very clear differences in the number of psyllids found from the three samplings, (Table 3) though the second sampling date was not statistically different.

Table 3. The number of psyllids found on three sampling dates.

Sample date	Sample type	With cover	No Cover	P
23-Mar	Average number of all psyllids per potato leaf	1	11	<0.05
30-Mar	Average number of adult psyllids per sticky trap	21	79	ns
13-Apr	Average number of adult psyllids per sticky trap	23	94	<0.05

Potato blight

The difference in potato blight levels was very clear (Figure 6) with covered potatoes still remaining green at the end of the trial (8 May 2012) though with clear blight spots on the leaves, while the not-covered potatoes were brown with blight with all leaves shrivelled.

Figure 6. Photos of potato blight on not covered (left) and covered (right) plants at harvest on 8 May 2012

Figure 7. Photo of potato blight on not covered (background) and covered (foreground) plots at harvest on 8 May 2012

5.3. Discussion - what it all means and why you should NOT yet bet the farm on mesh crop covers.

5.3.1. The caveats

While the above results are promising, there are a number of reasons why you should **not** (yet) bet the farm by covering your entire potato crop (or other solanaceae crops) with mesh crop covers.

The first caveat is the above results are just one field trial in one location. It is **not** safe to assume that you will achieve the same result on your farm or holding, especially if you have different potato cultivars, different crop species, e.g., tomatoes, different soil, climate and TPP levels, i.e. your mileage **will** vary. While the results for psyllids are entirely expected, based on the laboratory results, and the widespread use of mesh crop covers in Europe, against a diverse range of insect pests with very high levels of success, the low levels of potato blight on the covered crop may entirely be a fluke due to the unusual weather of the 2011-12 Canterbury 'summer' (or rather the lack of a typical Canterbury summer). It is possible that in normal years potato blight is much worse under covers than not covered. As a comparison, cultivar trials follow the 'five-by-five' rule, i.e. for the data to be considered truly robust, the comparisons need to be undertaken at five representative locations over five seasons, i.e. a total of 25 trials. To be able to give robust confirmation of the above results ideally three years trials at least three quite climatically different potato growing locations, e.g., Canterbury, Hawks Bay and Pukekohe would be required, i.e. the 'three-by-three' rule. At each of these trial sites ideally a range of mesh crop covers should be tested.

The second caveat is the mesh crop cover used in this experiment is not a purpose designed mesh crop cover rather it is a quarantine mesh for use in glasshouses. The mesh is therefore heavier and more opaque than purpose designed mesh crop covers so its effect on the under-cover climate, i.e. temperature, light levels and RH may well differ significantly and therefore have a significantly different (better or worse) affect on potato blight and crop performance as a whole.

The third caveat is that for the main yield results there was no statistical significance between the covered and the not covered plots, even though there was a very large difference agronomically and economically. This **may** have been a 'false negative' i.e. there is a real difference but the statistics failed to pick it up. This could be due to the green bridge between covered and not-covered plots meaning psyllids got into the covered plots, decreasing the difference between treatments and/or increasing variability; the sample size from the plots was too small, i.e. sampling only eight plants was not enough. Alternatively the statistics may, in fact, accurately reflect the results so while there is an apparently large difference in yield there is in fact none and the result is entirely due to random variation.

The fourth caveat is the potato blight results were entirely unexpected. They could therefore be a 'false positive' i.e. the apparent difference is not real, or it was a 'statistical fluke' and 99% of the time blight would be worse under covers.

The only way to address the above caveats is to do 'more research'.

5.3.2. The positives

While the statistics did not support the large agronomic yield differences, there were statistically and agronomically significant and differences in average tuber size sprouting, and psyllid numbers (no numerical data was collected on potato blight so no statistical analysis is possible). Considering the problems with the green bridge between covered and not covered plots, this could be cautiously interpreted as encouraging and well worthwhile repeating and ideally expanding. The BHU Future Farming Centre will be repeating the experiments again next season, and addressing the green bridge issue, by separating the plots and anchoring the covers to soil level throughout the life of the crop, monitoring TPP populations throughout the life of the trial, and using temperature and RH recorders to get a better understanding of potato blight. If external funding is obtained, then the experiments could be expanded significantly.

5.3.3. Multiple effects

It is also important to note that the covers affected the potato yields in (at least) three ways: reducing TPP populations, reducing potato blight levels and probably altering the under-cover microclimate. The first two of these multiple effects would be expected to increase yield, the last could have both positive and negative effects, e.g., reduced light levels reduced photosynthesis, while changes in temperatures could be both beneficial and harmful. While this is something of an 'academic' problem, as from a producers perspective, it is the combined effects that count, it is important to understand the comparative contributions of the effects so that the positive ones can be enhanced and negative ones reduced, e.g., by changing the type of material that the mesh crop covers are made from. This requires much more involved experimentation than 'simple' field trials, with commensurate cost.

5.3.3.1. Do try this at home

Therefore while it would be exceptionally imprudent to start using mesh crop covers across your entire potato or other solanaceae crops it may be worthwhile experimenting using mesh on a small area of crop to see how it performs under your farming conditions and to also gain experience handling and using the covers. However, as there is no off-the-shelf domestic supply of purpose made crop covers the cost of importing mesh from Europe in small quantities may well make this an impractical option for smaller scale growers. The alternative would be to purchase the glasshouse quarantine mesh used in this experiment, sewing it together if larger covers are required. However, the cost of sewing covers may well equal or exceed the cost of the mesh itself, if typical costs of sewing sheets are similar to that paid to join the covers used in this experiment. For smaller growers three meter wide sheets may be sufficient.

If you are interested in undertaking on farm trials of your own, please do contact me at charles.merfield@bhu.org.nz as I will provide free advice on setting up a trial so it is scientifically valid, and if suitable data is produced I can analyse the results and use it to build up a fuller understanding of the effects of mesh crop covers on field crops, i.e. help fulfil the 3×3 rule.

6. Working with mesh and any kind of floating crop covers

While mesh crop covers can be an exceptionally effective pest management tool, it has the downside of complicating field operations, a problem that applies to all floating crop covers, e.g., frost cloth. The key issues are:

- Storing, transporting, laying and retrieving covers;
- Anchoring covers;
- Partial removal of covers for in-crop work.

6.1. Storing, transporting, laying and retrieving crop covers

New and especially used covers need to be stored under protection from sunlight and rain to maximise their lifespan and make them easier and more pleasant to handle, as wet covers can be double the weight of dry covers, and when wet, biological material caught in the covers tends to rot. Ideally covers should only be put into long term storage, e.g., overwinter, when they are dry. Vermin such as mice and rats consider all forms of crop covers to be great nesting and hibernation sites. They can do substantial damage gnawing holes through covers - to the point of rendering them useless, and some species carry diseases that can be picked up by humans, e.g., Weil's disease / Leptospirosis when the covers are handled. Vermin control in crop cover stores is therefore essential.

Mesh crop covers are generally the heaviest of the floating crop covers and covers larger than 500 m^2 (10 m × 50 m) are likely to be too large to manually handle, especially when the covers have been used or are wet. Where significant areas of covers are needed, mechanical handling systems are normally required (Figure 8). These facilitate storage and transport as well as laying and retrieving covers.

Figure 8. Three examples of floating crop cover handling systems all using removable bobbins.

6.1.1. Laying covers

To lay a floating cover squarely and evenly:

1. First open / unroll and lay the cover in its approximate final position, with the cover fully inside the area that it will cover when fully laid;
2. Anchor one corner, and then work along the side (long edge) from that corner, pulling the cover against the anchor, while putting in additional anchors along the long edge. Depending on wind conditions, anchor type, cover type, and crop height and type, anchors will need to be placed about five to fifteen meters apart.
3. Once one side is fully anchored, go to the **middle** of the other side and pull the cover across the crop / against the anchors on the opposite side, until it is square, and then place the first anchor. Then working from the middle to one end, pull the cover against the anchor just placed and also the anchors on the opposite sides. Then repeat for the other half of the cover, again starting in the middle of the long side.
4. Anchor the ends (short edge) if required.

6.2. Anchoring covers

Anchoring any type of floating crop cover in the field is a problem that does not have a perfect solution. Unlike surface sheet mulches (such as plastic mulch, through which crops are planted) it rarely makes sense to dig any kind of floating crop cover into the soil. Also, as covers come in widths up to 15 meters or so, and are much heavier than plastic sheet mulches, plastic mulch laying machines are entirely unsuited to laying floating crop covers.

The main approaches are to keeping all kinds of floating crop covers on the crop are:

- Purchase purpose made plastic spikes from crop cover suppliers;
- Purchase or make up 'U' shaped anchors from thick gauge metal wire;
- Some form of sack / bag / net with about 5-10 kg of soil / sand / gravel / stones;
- Custom steel stakes.

Each of these approaches have a number of pros and cons and what suits one grower may not suit another. The main issues for the four types are: (see also Table 4)

The purpose made plastic spikes work well, but they can be expensive; they require workers to bend over / squat down to push and more importantly pull the spikes out, which is a health and safety concern; they generally don't have the strength to be inserted into wheelings, so they have to go into the softer bed which provides less anchorage. Being plastic, breakages are inevitable; being small they have a habit of getting lost, even when brightly coloured; and they put holes in the covers, which may or may not be a problem depending on the cover type.

The U wire anchors have the advantage of being cheap (especially if made on farm), they only make small holes in the cover, but they don't hold covers as firmly and plastic anchors and as they don't have much compressive strength they have to go in the bed which further reduces their anchoring ability. They are hard to get hold of to pull out as they don't have any protruding parts once in place; they have the same issue of workers needing to bend down as plastic spikes; if bent their strength is lost so they have to be thrown away; they are very easy to loose because they are hard to see against the soil and among crops which means they can get caught in tillage and harvesting equipment, potentially causing damage and wires left in the field are a general health and safety hazard.

The weighted sack option is often the cheapest as suitable sacks / bags are available on farm, e.g., used fertiliser sacks, and fillings such as soil are plentiful and cheap! The bags can hold the covers firmly, they don't make holes in the covers, and they are placed in the wheelings, but they are the most trouble to move around as the weight of the bags quickly adds up meaning that tractors are required as one person can only carry two to six bags depending on the weight of the bags and the strength of the person. Also many bags have limited or no UV stabilisers so they can break down in a year or few, so they need to be continually replaced, and if materials other than soil are used to fill them, when (not if) the contents get spilled in the field this can cause problems.

Custom, mild-steel stakes (Figure 9) (construction information below) are more expensive, though they can be comparable in cost with purpose made plastic spikes. They have the advantage that workers don't have to bend over to use them; they hold the covers very firmly, especially as they are strong enough to be pushed into the wheelings, they will last a very long time even when left as bare steel and can only be ‘broken’ if they go through a powered tiller such as a rotary hoe / rotovator, as any less serious bends can be straightened. Their size means they are harder to loose, but if they are left in the field and go through equipment, especially delicate harvest equipment, they can do significant damage. Painting the stakes in bright colours, electro plating or galvanising them makes them much easier to see than when rusty, but at increased cost. They are easier to move around than bags, as a worker can carry ten or more, but they are more work than plastic spikes and wire anchors (of which workers can carry hundreds). Steel stakes make holes in the covers similar to plastic anchors.

Table 4. Summary of the attributes of the four main types of floating crop cover anchors.

Anchor type	Cost	Durability	Stooping required	Handling	Insert into	Anchoring ability	Lost easily	Pierce covers	Damage equipment
Plastic spikes	High	Medium	Yes	Good	Bed	Medium	Med	Yes	Med
U wire anchor	Cheap	Medium	Yes	V good	Bed	Low	High	Yes	Med-high
Weighted bags	Free/cheap	Low	Partly	Poor	Wheeling	Medium	No	No	Low
Steel stakes	High	High	No	Medium	Wheeling	High	Med	Yes	High

6.3. Partial removal of covers for in-crop work

To undertake in-crop work, it is best NOT to completely remove the covers unless they are only one bed wide.

1. Remove the anchors from the ends and one side of the cover, placing the anchors in the adjacent bed, then pull the cover back to over half its width, e.g., if the cover covers five beds, fully uncover three beds including the wheelings.
2. Undertake the crop work in the uncovered beds.
3. As per the instructions in section 6.1.1 above ‘Laying covers’ re-anchor the cover starting from the middle of the side (long edge).
4. Then repeat item 1., 2. and 3. above, but on the other side of the cover.

6.4. Making mild-steel stakes.

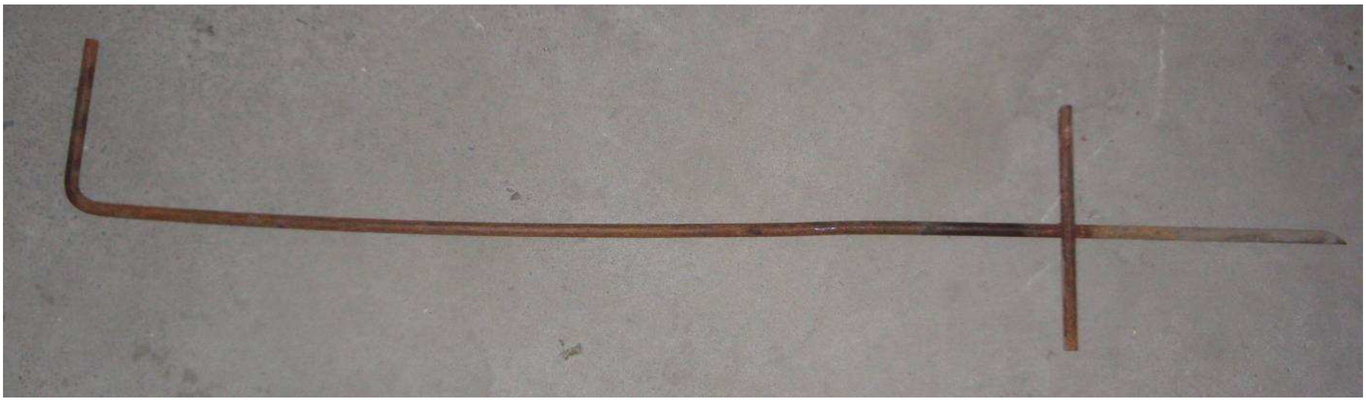

Figure 9. Custom steel stake for holding down floating crop covers.

Steel stakes are made from mild steel round bar 12 mm / ½" in diameter. 12 mm round bar typically comes in six meter lengths which will make four stakes. To make the stakes (read this list in conjunction with Figure 10 and Figure 9)

1. Cut the six meter bar in half, to make two 3 m lengths;
2. Cut **two** 200 mm length from each of the 3 m lengths, which gives two 2.6 m lengths and four 200 mm lengths;
3. Cut each of the 2.6 m lengths in half at 45° or as sharp an angle as possible (to make the point that will go into the ground) this produces four 1.3 m lengths, with one end cut square and the other at 45° or sharper;
4. Make a 90° bend 150 mm from the square cut end on each of the 1.3 m lengths (to form a handle);
5. Weld the 200 mm length to form a 'cross' 300 mm from the sharp end of the 1.3 m length with the cross piece in the same plane as the handle (for easy storage) .

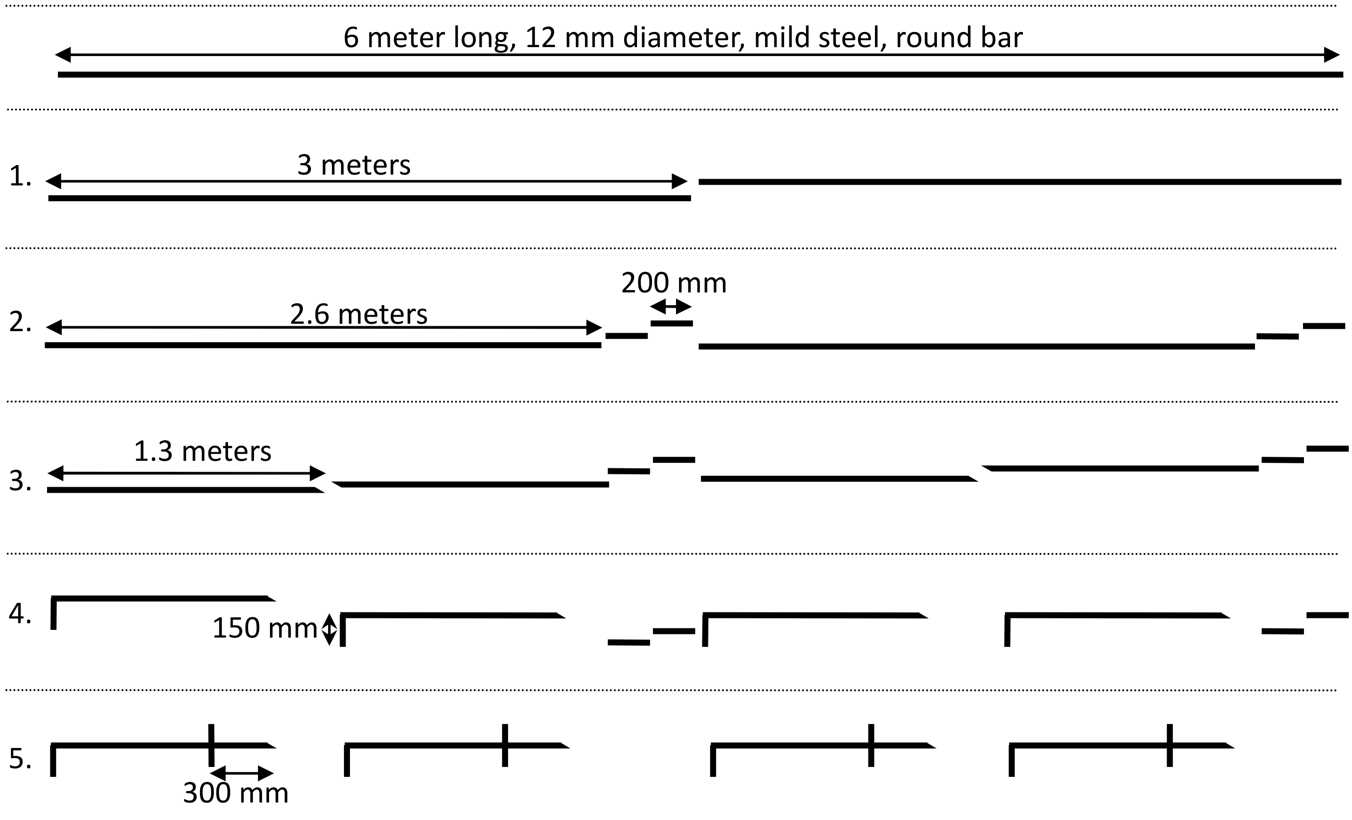

Figure 10. Diagram of the production of custom metal floating crop cover stakes. Numbers refer to the above instructions.

7. Sources of general information on TPP

This report does not aim to give general information on TPP. The following are examples of good quality general / producer orientated online information on TPP.

- http://www.potatoesnz.co.nz/Overview/What-we-are-working-on/Psyllid.htm
- http://www.biosecurity.govt.nz/pests/potato-tomato-psyllid
- http://www.freshvegetables.co.nz/research/reports_public.html

8. Acknowledgements

Dr Roddy Hale and the students of BIOS 273, Lincoln University, New Zealand, for counting TPP populations and cleaning and weighing the tubers from the field trial.

Dr Whitney Cranshaw, Colorado State University, USA. For wide ranging advice on TPP, training BIOS 273 students on TPP identification, and initiating and conducting the sprouting experiment.

Mr Ivan Barnett, The Biological Husbandry Unit Organics Trust, for growing the potato crop and assistance with harvest and other tasks.

The Biological Husbandry Unit Organics Trust for funding and hosting the trial site.

The suppliers of mesh as listed in section 4.4 of this report and in particular Cosio Industries Ltd. who donated the mesh for the field trial.

Mr Luc Tran, Lincoln University, for providing advice, TPP adults and controlled environment room space for the laboratory trial.

Dr David Saville, Saville Statistical Consulting, Lincoln, and Dr Simon Hodge, Lincoln University, for statistical advice.

Dr Nadine Berry, Plant and Food Research, Lincoln, New Zealand for providing TPP adults for laboratory work.