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Mesh Crop Covers for Non-Chemical Potato Pest & Disease Control. Field Day, 14 March 2017

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The BHU Future Farming Centre

Permanent Agriculture and Horticulture Science and Extension

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Citation Guide

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1. Summary

1.1. The issues

- Tomato potato psyllid (TPP, *Bactericera cockerelli*) arrived a decade ago / 2006.
- Main response was insecticides with work on integrated pest management (IPM) programs ongoing using softer chemistry, population forecasts and monitoring.
- Agrichemicals face multiple issues including pest resistance, consumer 'resistance', legislative restrictions and a lack of new chemistry.
- Organic potato growers don't have effective agrichemicals.
- Non-chemical TPP controls are therefore required.

1.2. The solution

- Mesh crop covers evolved from frost cloths to provide the same insect barrier effect but without the temperature rise of frost cloths. They are a physical barrier to pests, the same as fly screen on a house. They are woven monofilament plastics such as polyethylene, and come in a range of hole sizes e.g., 0.3 mm to > 10 mm to keep out insect pests as small as thrips to vertebrates such as birds, rabbits, etc. It has been in use for two decades with some 100,000 ha (1,000 km^2) in use across Europe with 100s ha on individual farms with sheets sizes up to 40x200 m, with a full range of handling equipment available, i.e., it is well and truly farm proven technology.
- Mesh crop covers appeared to be an obvious non-chemical solution for TPP management on potatoes except that they may increase blight.

1.3. Research findings

- Laboratory experiments by the FFC established 0.6 mm hole size as the largest that will exclude adult TPP.
- A field trial in 2010-11 using Cosio biomesh produced the first serendipitous discovery that mesh decreases, rather than increases blight levels.
- A second field trial in 2012/13 confirmed the blight effect in two mesh covers (Cosio and Crop Solutions) with very different levels of light transmission, and ruled out changes to under-sheet temperature or RH or the number of *P. infestans* spores as the cause of blight effect.
- Subsequent field trials of mesh in IPM trials with FAR and PFR in Canterbury, Manawatu and Pukekohe found that aphids were penetrating the mesh. This was believed to be due to a green bridge of haulm on both sides of the mesh allowing aphid nymphs to easily get through the mesh.
- The 2015/16 spectral filter trial found a clear correlation between foliar blight symptoms and UV light levels. There was a very similar correlation for foliar TPP symptoms and UV light levels, i.e., reducing UV significantly reduced TPP symptoms which is assumed to be correlated with TPP populations.
- Also in 2015/16 a small piece of mesh with a hole size of 0.15 x 0.35 (ultra fine mesh) was tested in a green bridge situation and no aphids penetrated it. This produced the second serendipitous discovery that the under sheet climate was much more humid, as evidenced by frequent under-mesh condensation, which considerably increased yield and tuber size, while achieving exceptional blight control.
- The current field trial was designed to compare the original 0.6 mm mesh with the ultra fine mesh and full monty agrichemical control of blight and insects. However, the delivered mesh hole sizes were larger than requested viz. 0.3, 0.4 and 0.7 mm vs. 0.15, 0.3 and 0.6 mm so the climatic altering effects and aphid proof nature of the original ultra fine mesh have not be able to be replicated.

- In addition, it has been a very poor year for blight and TPP with very low amounts in the control plots.
- The trial has been further complicated by aphids getting under all mesh treatments. It is possible that aphids were introduced on researchers' clothing going under the mesh to collect samples, but two replicates that were not sampled were equally infested. As there is no green bridge in this trial, it is now hypothesised that winged adults are alighting on the mesh, are able to detect (smell / taste) the crop underneath so they stay on the mesh and then produce nymphs that are able to penetrate 0.3 mm and larger mesh holes.
- Aphids are a particularly problematic pest due to exceptionally fast asexual reproduction with live birth which in combination with the mesh keeping out naturally occurring aphid bio-control agents means that even one aphid penetrating a sheet can produce an outbreak within a matter of weeks and certainly months. Aphids are also a key vector of potato viruses, which is of particular importance for the seed industry.

1.4. Summary of current knowledge

- Mesh is giving consistent control of blight across all trials and under mesh on-farm and there is a strong correlation between reduced UV levels and foliar blight symptoms. However, there are two blight species: early blight (*Alternaria solani*) and late blight (*Phytophthora infestans*). Measurement of blight control to-date is based on visual symptoms, as opposed to more objective measurements (e.g., laboratory analysis), so the effect of UV on the individual blight spp has not yet been confirmed.
- Mesh is a highly effective means of controlling TPP on potatoes as it is an effective barrier, and, it appears that the UV blocking effect means that even if TPP gets under the mesh, it does not thrive.
- Mesh is expected to block all other potato insect pests, such as tuber month, with the exception of aphids, but requires testing.
- The ability of potato aphids, mainly believed to be the green peach aphid / peach-potato aphid (*Myzus persicae*), to circumvent mesh crop covers is believed to be a global first. Mesh is successfully used to keep cabbage aphids off broccoli and other brassicas in Europe.
- The ability of ultra fine mesh to increase yields through altering the under-sheet microclimate requires substantiation.

1.5. Future research

- The two main areas requiring research are blight and aphids
- A causal link between UV light levels and both early and late blight needs to be established.
- A solution for the aphid problem is required for both the seed industry and food crops.
  - How aphids are circumventing mesh?
  - The maximum hole size that is completely proof against all potato aphid spp and life stages in real-farming conditions.
  - Even with fully aphid proof wear and tare will introduce 'damage-holes'. It needs to be established if aphids are able to find and penetrate damage holes.
  - Due to wear and tear it is likely that a backup to control aphids will be required, especially for seed production. A range of aphid biocontrol agents have been commercially available for decades, and need to be tested for the ability to effectively control aphids that do penetrate mesh, including the use of plants to provide additional resources such as pollen and nectar.
  - For food crops, some organic growers are successfully managing aphids by not completely sealing the mesh, leaving some of the perimeter sufficiently open for aphid biocontrol agents

to also get under the sheet and control any aphids that do get in. The efficacy of this approach needs to be determined.

- The effect of ultra fine mesh(es) to increase yield through under-sheet microclimate modification, as well as improved blight control compared with 0.6 mm mesh needs to be confirmed.
- Mesh needs to be tested against other potato pests to confirm efficacy.
- Very small pests, such as thrips and mites, need to be monitored in future trials to confirm if their populations expand in the absence of biocontrol agents, as occurs with aphids.
- The impact of UV light on TPP behaviour needs to be understood, to guide practical means of TPP management on protected crops such as tomatoes, for example, UV blocking plastic sheets or using UV light to attract and kill TPP, as is done with UV insect electrocutors in commercial food premises.

2. Introduction

Tomato potato psyllid (TPP, *Bactericera cockerelli*) arrived in New Zealand a decade ago / 2006. The main response was to use a range of insecticides to manage it, however, this set back the integrated pest management (IPM) programs in potatoes and significantly increased the number of agrichemical applications. There is ongoing work on TPP IPM programs with softer chemistry, population forecasts and monitoring, but these are still dependent on agrichemicals.

Agrichemicals face multiple issues including pest resistance, consumer 'resistance', legislative restrictions due to health & environmental concerns and a lack of new chemistry. Organic potato growers don't have effective agrichemicals against TPP. Non-chemical TPP controls are therefore required.

The newly approved TPP parasitoid *Tamarixia triozae*, may in the longer term manage TPP populations, but at the same time, only 10% of classical biocontrol introductions result in complete pest control, so good control in all affected crops is not guaranteed. Therefore shorter term and alternative non-chemical control of TPP is therefore still required. Mesh crop covers are one such technology.

2.1. Mesh crop covers

Mesh crop covers have been used in Europe for over two decades for pest control, from small insects such as thrips, through to vertebrates e.g., birds, rabbits, deer, etc. They evolved from frost cloths aiming to provide the same barrier effect but without the temperature rise of frost cloths and with much greater durability. They work by being a physical barrier for pests, the same as fly screen on a house. They are woven monofilament plastics such as polyethylene (like fishing line), and come in a range of hole sizes e.g., 0.3 mm to > 10 mm to match pest size. Mesh has been in use for over two decades with some 100,000 ha (1,000 km^2) is in use across Europe with 100s ha on individual farms. With sheets sizes up to 40x200 m, with a full range of handling equipment available, mesh is farm proven technology (Figure 1) and can therefore be easily rolled out in NZ. Seed & Field Services Ltd. www.seedandfield.co.nz, being the current agent for Crop Solutions mesh.

Figure 1. Use of mesh crop covers in Europe.

Mesh crop covers therefore appear to be an obvious means of non-chemical management of TPP on potatoes.

3. Mesh crop cover research

While mesh appears to be an obvious means of TPP control, it has not been used for this purpose before so the maximum hole size that will achieve zero penetration by TPP needed to be established and field tests conducted to field test mesh against TPP and check for other effects. The major concern in this regard is that mesh would exacerbate potato blight.

3.1. First year's trials

Laboratory experiments determined that a 0.6 mm hole size could not be penetrated by adult TPP (nymphs have limited mobility). A field trial, using donated Cosio 125 gsm Biomesh glasshouse quarantine mesh was used to test for the impact of mesh on blight. This produced the opposite / serendipitous result of what was expect with blight levels under the mesh dramatically lower than outside (Figure 2).

Figure 2. Left photo - 2011 / first mesh crop cover field trial. Right photo - foreground green potatoes have just had mesh cover removed, brown potatoes at the rear were uncovered and are dead down to the ground (with the exception of volunteer artichokes.

As the trial was designed to test for blight, the mesh sheets were placed on a continuous crop of potatoes, but despite the green-bridge between the covered and uncovered areas of potatoes, TPP numbers were also significantly reduced under the mesh. This was also unexpected and unexplained.

A full report on the trial is available at www.bhu.org.nz/future-farming-centre/information/crop-management/pest-management/tpp

3.2. Second year's field trial

In 2013 a second field trial was conducted with the Cosio biomesh and a donated Crop Solutions 0.6 mm field mesh. The green-bridge of the first trial was eliminated Figure 3.

Figure 3. Second years field trial with Cosio (white) and Crop Solutions (transparent) mesh

Mesh treatments had significantly higher yields, with a 24% increase in total yield (43 t/ha for mesh) and 126% increase in marketable yield (tubers >125 g) due to the tubers in the TPP affected control being smaller. There was also a clear impact on tuber quality in terms of storage length and number of sprouts, with tubers from the controls sprouting after 50 days with an average 5.4 sprouts while there were no sprouts on tubers from under mesh. TPP was considerably reduced by mesh with total average numbers being 25.1 for the control and 1.3 for the mesh, the ingress being due to mesh not being dug in. A clear blight reduction was seen again (Figure 4).

Control Crop Solutions Cosio

Figure 4. Photos of potato foliage (127 d after planting) showing TPP yellows and blight.

To determine the cause of the blight reduction, temperature, relative humidity and late blight (*P. infestans*) spores were recorded. There were the same number of Smith periods, a one degree increase in average temperature and the same RH. Spore numbers were the same under and outside the sheets. It was concluded that environmental conditions were not the cause of blight reduction nor was the mesh acting as a barrier to spore dispersal. It was hypothesised that a spectral filter effect may be the cause.

A full report on the second years trial is available at www.bhu.org.nz/future-farming-centre/information/crop-management/pest-management/tpp

3.3. FAR field trials

In 2014, with Potatoes NZ funding, FAR and Plant & Food Research, included 0.6 mm hole size mesh crop covers donated by Wondermesh, in insecticide trials (Figure 5).

Figure 5. Left and center, FAR insecticide and mesh trial; right *Myzus persicae* adult and nymph on centimetre scale ruler.

While the mesh was fully effective at keeping TPP out and reduced blight, aphids, believed to be *Myzus persicae*, which is a small aphid (Figure 5), penetrated the mesh and then rapidly multiplied due to the absence of predators. It was considered that presence of potato haulm on the outside of the mesh was a source of aphids which then walked onto and through the mesh i.e., aphid infestations were to some extent an artefact of the trial design as a commercial crop would not have potatoes growing around the edge of the mesh.

The rapid aphid multiplication, due to the mesh protecting them from their natural enemies / biocontrol agents (e.g., ladybirds, lacewings, hoverflies, midges, parasitoids etc.), is considered to be an interesting 'accidental' experiment. The control plots had an average of three aphids a leaf, while the potatoes under the mesh got as high as 300 aphids a leaf before they were controlled with Chess. The difference of 297 aphids between control and mesh indicates the level of aphid biocontrol occurring, even in commercial potato fields being sprayed with insecticides. This demonstrates the potential for improved aphid control through IPM programs, such as the provision of floral resources and alternative habitat for the BCAs.

3.4. Spectral filter experiment

in 2015 a spectral filter experiment, funded by the Lincoln-Massey Universities Partnership for Excellence with collaboration from Dr Jason Wargent at Massey University and Prof. Rainer Hofmann & Dr Simon Hodge at Lincoln Uni, compared a number of mesh crop and polythene covers with contrasting UV transmission properties Figure 6.

Figure 6. 2015 spectral filter experiment using cloches.

Reducing UV transmission caused a clear reduction in both blight and TPP foliar symptoms Figure 7. Of particular importance are the pairwise comparisons between the two UV blocking and transparent meshes and two + & - UV polythene sheets as the only difference between these the pairs of covers is UV transmissivity (see Table 1 for details of covers used).

Control

Crop Solutions mesh

Cosio mesh

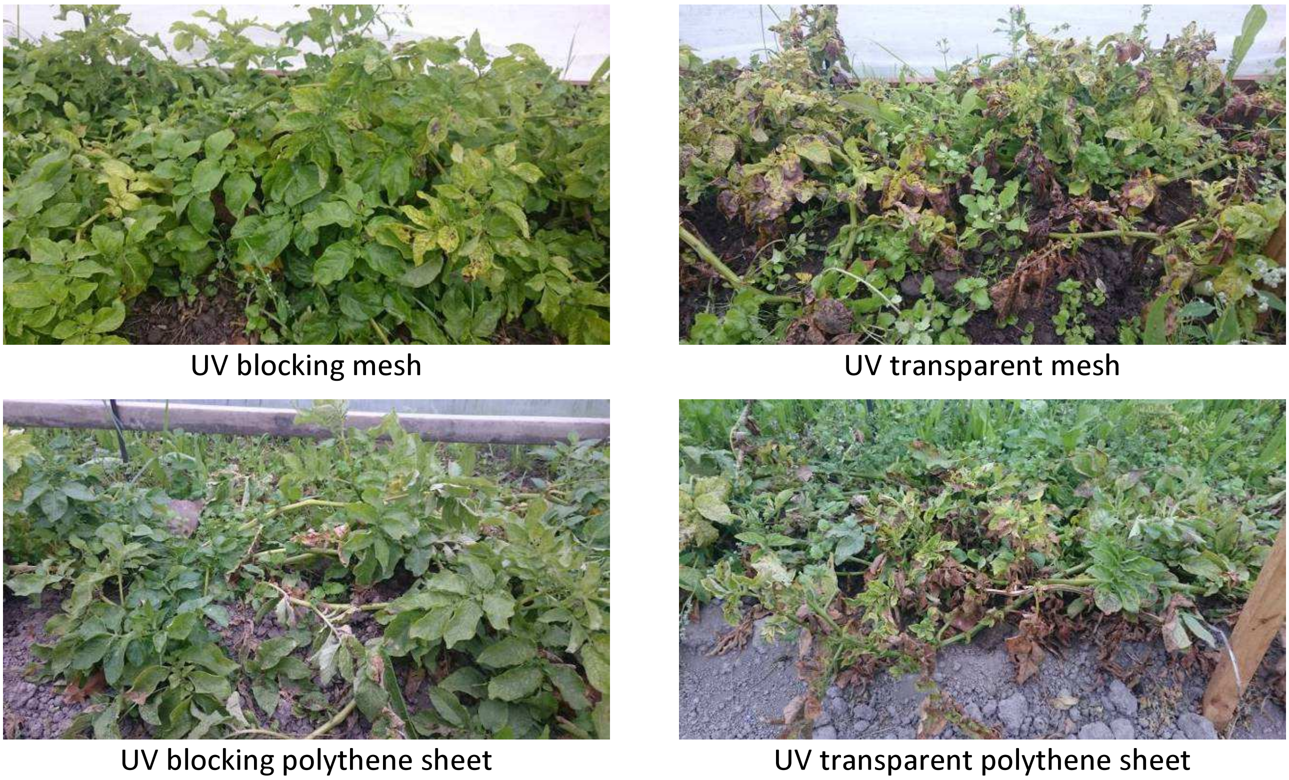

Figure 7. Blight and TPP levels under covers with different UV transparency.

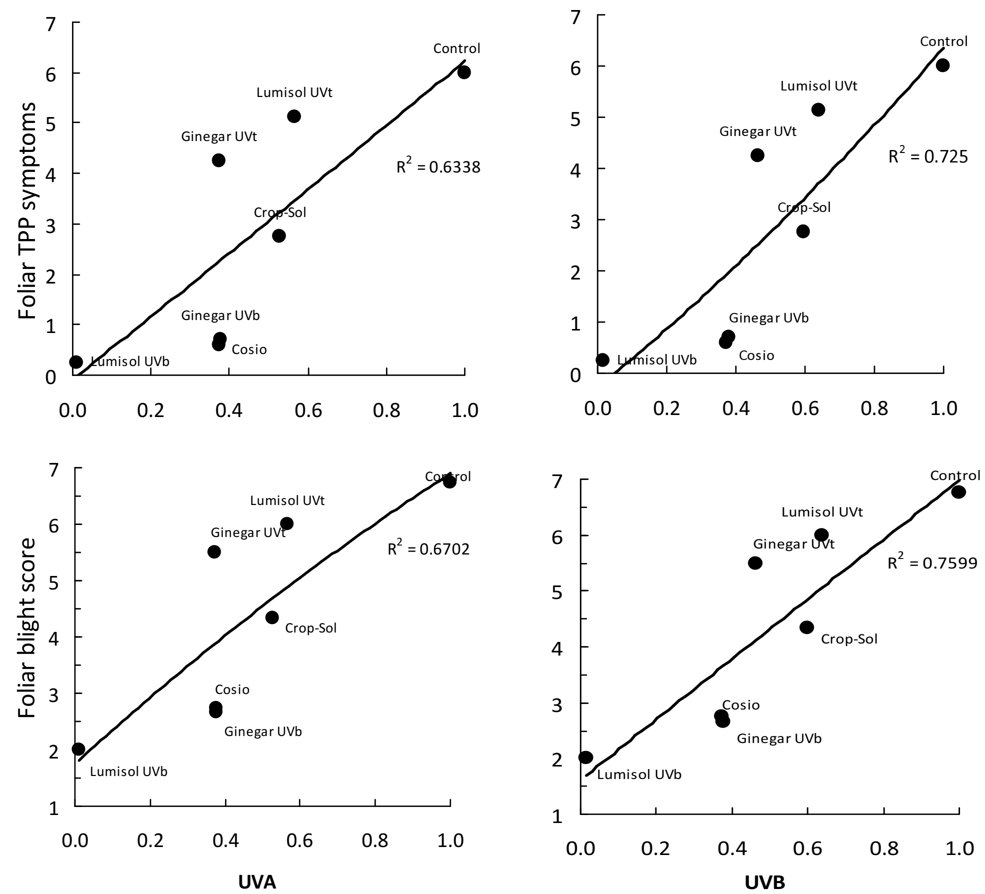

Figure 8. Relationships between UVA and UVB light levels, relative to the uncovered control, with TPP foliar symptom score (0= no symptoms) top charts, and foliar blight score (0= no symptoms) bottom charts. UVb = UV blocking and UVt = UV transparent, see Table 1 for details of the cover types and Figure 9 for mesh transmission spectrum.

Comparing the amount of both UVa and UVb transmitted by the different covers against blight and TPP foliar symptoms showed a clear relationship with lower UV resulting in lower symptoms (Figure 8).

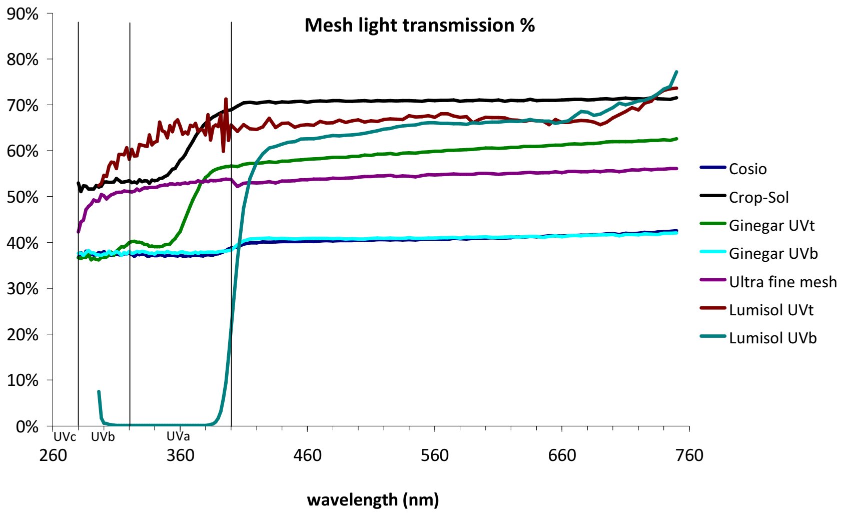

Figure 9. The light transmission spectrums for the covers used in the spectral filter experiment plus ultra fine mesh.

Table 1. Description and properties of mesh crop covers and polythene sheets uses across all experiments.

Mesh type	Description and comments
Cosio Biomesh	A glasshouse quarantine mesh with low light transmission, including UV, from Cosio Industries NZ.
Crop Solutions	A field mesh with high light transmission, and moderate UV blocking from Crop Solutions Ltd. in the UK.
UV blocking mesh	A polytunnel mesh cover from Ginegar Ltd. in Israel with low UV and light transmission.
UV transparent mesh	The same size mesh as the above Ginegar UV blocking mesh but with higher UV and light transmission levels.
Polythene sheets	Visqueen Lumisol polytunnel sheets from in the UK, that differ only in their UV transmissivity, one is UV transparent and the other UV blocking.

There was also a yield and size increase associated with reduced UV, but, with the small number of potato plants per plot, less vigorous growth of the Red King cv., and as the cloches were open at the bottom for ventilation and therefore allowing some TPP and UV light into the cloches, the results should not be over interpreted (Figure 10).

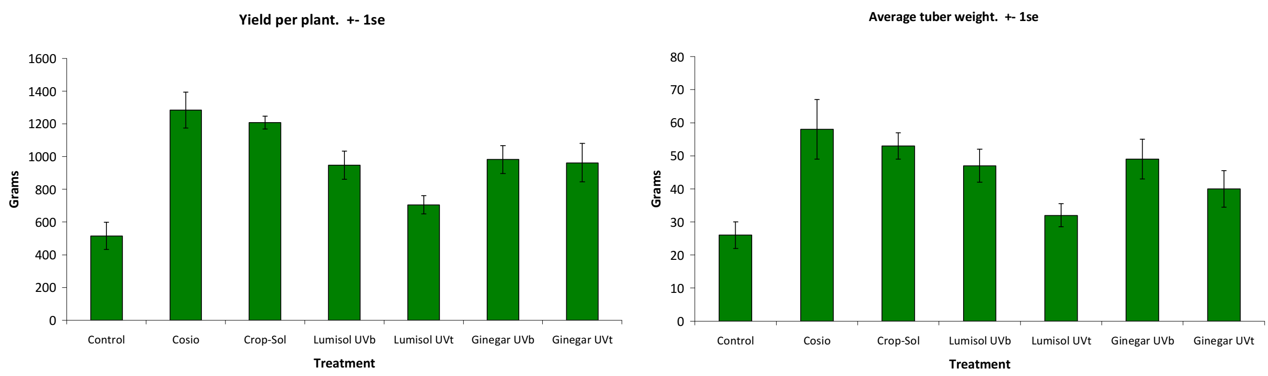

Figure 10. Total yield per plant (left) and average tuber weight (right) for spectral filter experiment. See Table 1 for details of covers used.

3.5. Ultra-fine mesh test

To address the problem of aphids penetrating the mesh, lab tests were conducted to determine the mesh hole size that would keep aphids, both adults and juveniles, out, which was found to be approx. 0.2 mm. Currently no field mesh crop covers currently have hole sizes that small, with the minimum being 0.3 mm. However, glasshouse quarantine screen mesh goes down to 0.15 mm, but due to the cost of the material it was financially impossible to use it in the FAR / PFR field trials. However, Ludvig Svensson donated a 6 x 3 m piece of mesh ECONET with 0.15 × 0.35 mm holes which allowed a field test (not a trial as there was no replication) to study potato growth Figure 11 using cv. Moonlight. The mesh was dug in so there was no point of ingress for insects or light other than through the mesh.

Figure 11. ECONET 1535 field test, showing accelerated potato growth under the mesh.

Despite a complete green bridge around the mesh, no aphids were found under the mesh at harvest, indicating the mesh was aphid proof.

The effect of the mesh on potato foliage and TPP and blight levels is shown in Figure 12 with foliage under the mesh showing a nearly complete absence of blight, with about one blight spot per whole leaf, while the uncovered potatoes had blight on all leaves with entire leaflets dead.

Figure 12. Potato foliage from under the mesh left, uncovered right, at harvest.

The effect of mesh on yield was even more dramatic than the foliage with a 654% increase in yield from the mesh equivalent to 54 t/ha for the mesh and 8 t/ha for the control, with an equally impressive effect on tuber size Figure 13. In Canterbury 60 t/ha is the typical maximum yield, even though the theoretical limit is 90 t/ha. However, this crop was grown in an organic system, and should therefore be compared with yields in previous trials the best of which was 43 t/ha under mesh. This test therefore achieved a 26% increase on previous trials, despite the ground being in its third year of cropping and receiving no nutrients and erratic watering, compared with the previous best yield being grown after two years of pasture and receiving 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 the previous autumn plus frequent irrigation.

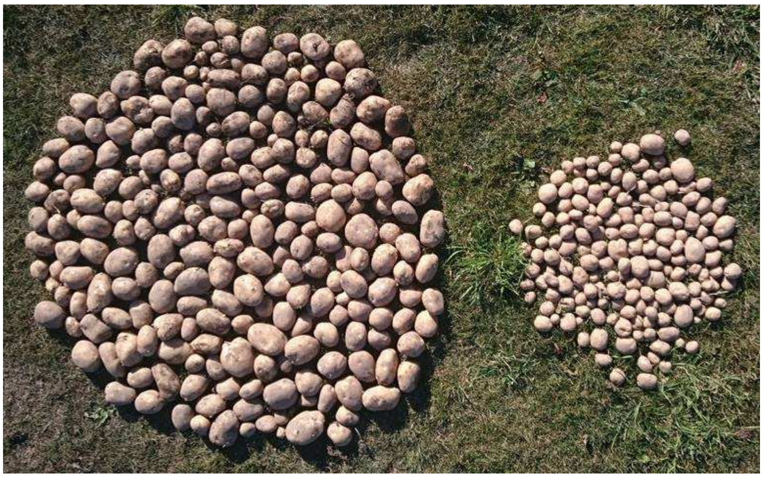

Figure 13. Comparative yield from ECONET 1535 left, compared with control right.

The almost complete suppression of blight in Figure 12 is despite the covers having running condensation on the underside all night and a considerable portion of the day (Figure 14), indicating very high humidities under the mesh, and the leaves touching the mesh were wet. Normally such high RH would cause exceptionally rapid spread of blight to the point of plant death, however, blight levels were almost non-existent.

Figure 14. Condensation under ECONET 1535.

Caution should be exercised as this was not a replicated randomised experiment, rather a single test of one piece of mesh. However, the results are so contrary to expectations, i.e., no blight despite high levels and duration of condensation, and large increase in yield despite poor husbandry, that they are considered to point to potentially important findings and are a second potentially serendipitous discovery in this research project.

The good blight control is believed to be caused by the mesh more effectively blocking UV light that larger holed meshes as finer meshes have a higher proportion of thread to holes so more light travels through the thread than the holes.

The cause of the yield effect is more speculative. The high levels of condensation, along with the large haulm on Moonlight, points to large increases in humidity under the mesh, although this was not directly measured. The potato is 'sappy plant' with a high water requirement but limited root system so may well be under water stress in typical Canterbury hot and windy conditions even with frequent watering. Research has also shown that even moderate shaking of plant foliage can induce significant yield loss, well before wind induced damage to foliage appears. Ultra fine mesh may therefore be reducing water and mechanical movement stress thus leading to greater yields.

Taking all the mesh research together, the use of ultrafine mesh points to three key benefits

- Completely insect proof including aphids;
- High level of blight control;
- Changed microclimate increases yield.

If these results are repeatable this points to mesh crop covers being a single, non-chemical, technology providing a significant improvement in potato cropping.

3.6. Current field trial - three mesh types and industry spray regime

Based on the previous years results, a field trial was established to compare three grades of mesh 0.15, 0.3 and 0.6 mm hole sizes, donated by Crop Solutions, against a 'full monty' spray regime (weekly insecticide and fungicides as used in the FAR field trials, section 3.3) and a null control, with a particular focus on the effects of the 0.15 ultra fine mesh hole size.

The trial is a randomised complete block design with six reps, with 10 x 10 m plots to simulate real crop conditions. The mesh has been dug in, the same as commercial mesh use, with zips sewn into the mesh to allow access for data collection. Weeds are controlled with residual herbicides. A full fertiliser and irrigation regime are in place. The cultivar is Nadine planted on 25 November. A wide range of measurements are being made, including temperature and RH, potato growth, multiple measurements of aphids, TPP and blight, plus a full yield analysis at harvest.

Unfortunately, the mesh manufacturer did not supply mesh of the required specifications with the three hole sizes received being 0.3, 0.4 and 0.7 mm. As more mesh could not be sourced in sufficient time, the trial went ahead with the larger hole sizes, in the hope that 0.3 mm mesh would still show an increased microclimate effect and it would allow economic comparisons between mesh and agrichemical control of TPP and blight.

Due to the incorrect mesh hole sizes the piece of ultra fine mesh (UFM) with the 0.15 x 0.35 mm hole sizes used last year was again planted with potatoes but this time data loggers were installed. However, due to over application of herbicide the potatoes have not grown well and with Nadine having a smaller haulm than moonlight, the condensation that occurred last year has been considerably less this season. With the multiple issues and lack of replication etc., little should be taken from this test this season.

3.6.1. Temperature and RH

Mesh has caused a small increase in temperature and decrease in RH (Figure 15)

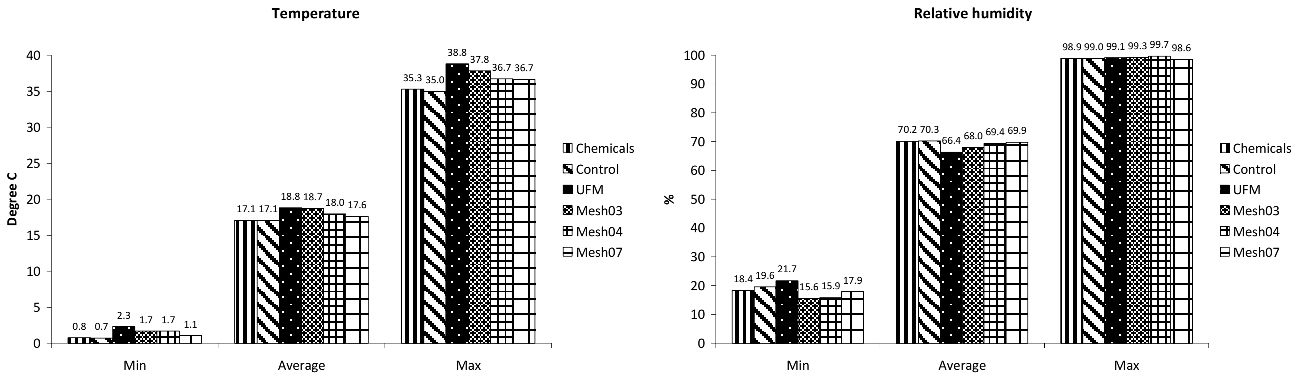

Figure 15. Temperature & RH from 19 Dec 16 to 1 March 17

The smaller the mesh size the larger the increase in temperature, particularly maximum temperature. For RH, the UFM did increase minimum RH but not as much as expected, due to problems noted above, while it decreased average RH, with maximum RH the same across all treatments, as would be expected.

3.6.2. Potato growth

Mesh accelerated growth and increased the length of haulm across four dates (Figure 16) which is taken as an indication of improved growing conditions under the mesh.

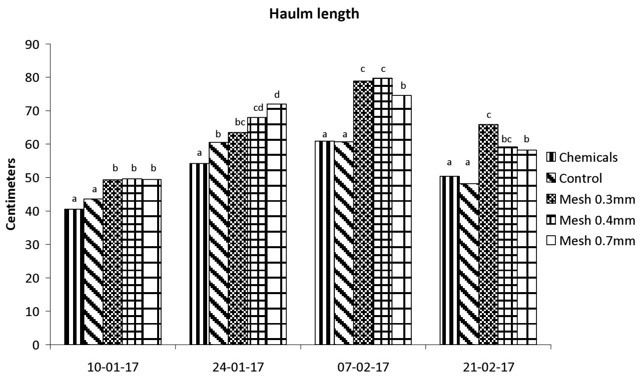

Figure 16. Repeated measure of haulm length.

3.6.3. Aphids under mesh

All mesh treatments had aphid infestations, believed to mainly be the green peach aphid / peach-potato aphid *Myzus persicae*. This was initially thought to be due to cross contamination from people entering the mesh to make data measurements transporting aphids on their clothing, even though precautions were made to avoid this by entering the finest 0.3 mm mesh first, then the 0.4, 0.6, chemical and finally the control plots. However, only four of the six reps were being used for data measurement, so the last two reps had not been entered so a lack of aphids in these plots would indicate cross contamination as the source. However all these mesh plots in the last two reps had similar numbers of aphids, ruling out cross-contamination.

It is not clear how aphids are entering the mesh. As it is dug in, they cannot be getting around the mesh edge. Also, the edges of the mesh were re-sprayed with residual herbicides after digging in, and there is no plant growth within 20 cm of the mesh edges so a green bridge being a source of aphids is considered unlikely. Also considered unlikely is that aphids were present on the bare soil prior to mesh being laid. The current hypothesis is that winged adult aphids are alighting on the mesh, a behaviour that has been observed, then detecting (smelling / tasting) the potatoes underneath, causing the winged aphids to stay on the mesh even though they are too big to get through the holes. While they are on the mesh they produce nymphs which are sufficiently small and soft, that they can penetrate even the 0.3 mm mesh (Figure 5).

As in the FAR field trials (section 3.3), aphid populations increased exponentially (Figure 17), such that on the 15 February Chess was applied to all mesh plots to kill the aphids to stop them killing the potatoes and has been applied weekly since then to ensure aphids are controlled.

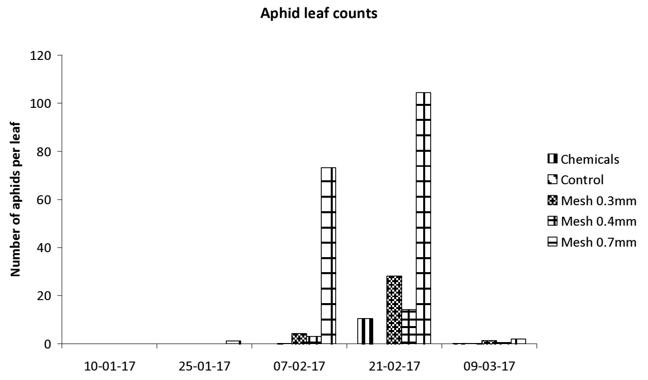

Figure 17. Average number of aphids per leaf, from five leaves. Chess application started 15 February.

There is considerable irony that an insect mesh crop cover is controlling a foliar fungal pathogen but failing to control the key insect pest of potatoes. This ability of potato aphids to circumvent mesh crop covers is believed to be a global first. For example, mesh is successfully used to keep cabbage aphids off broccoli and other brassicas in Europe. However, due to aphids having very rapid, asexual, live reproduction and the nymphs being particularly small, their biology makes them particularly difficult to deal with. As a comparison, root flies, such as carrot and cabbage, are exceptionally well controlled by mesh as even if a female does get under the mesh, she only has a limited number of eggs she can lay before she dies and the length of the life cycle means her offspring wont emerge in time to lay more eggs.

3.6.4. TPP

It has been a poor year for TPP, with Plant & Food Research reporting very low numbers of TPP in their traps for Canterbury and numbers in this trial are also low Figure 18. Differences between treatments due to TPP are therefore likely to be reduced compared with previous trials. In the last sampling two psyllids were found in two mesh plots. This is unexpected, due to both mesh being TPP proof and Chess being applied, so requires further investigation. The larger number of TPP in the sprayed than control plots is not statistically significant.

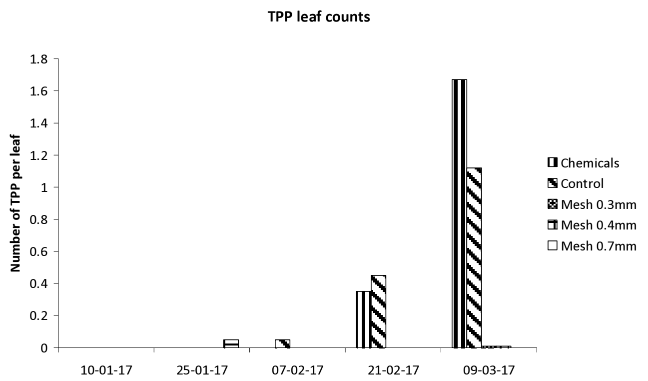

Figure 18. Average number of TPP (nymphs and eggs) per leaf, from five leaves.

Chess is also effective against TPP, so, the use of Chess has to an extent reduced the validity of the TPP comparisons among treatments.

3.6.5. Blight

As for TPP, this has been a poor season for blight, especially post Christmas, when rainfall has been negligible, except for the last four days. No *Phytophthora infestans* or *Alternaria solani* spores have yet been trapped on the vaseline slides, and visual scoring of foliar blight shows only low levels, even in the controls (Figure 19).

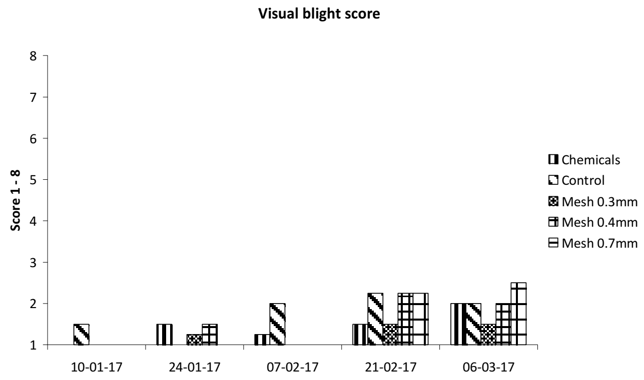

Figure 19. Visual score of blight levels from 1 (no blight) to eight (plant dead).

3.6.6. Yield & economics

As the trial is still in progress yield and economic data are not yet available.

4. Future research

The two main areas for future research are blight and aphids, as TPP is considered to be effectively controlled with mesh, though the UV effect on TPP needs investigation and could be imported for protected solanaceae crops.

4.1. Causal link between UV and blight

To date, all measurements of the effect of mesh on blight are visual foliar symptom assessments. While the reduction in blight has been highly consistent in trials and on-farm, foliar blight looks similar to a range of other potato foliar diseases, e.g., Rhizoctonia, and there are two blight species early blight *Alternaria solani* and late blight *Phytophthora infestans* which are biologically very different, early blight being a true fungi and late blight an oomycete. Research to date therefore has 'only' achieved a correlation between UV levels and foliage symptoms that look like blight, rather than showing causality between UV levels and proven blight infections. If mesh and the UV effect is to be relied upon by the global potato industry, causality must be established. This will require potatoes to be grown in isolation, deliberately inoculated with individual blight spp and then grown under plus and minus UV conditions, or a gradient of UV levels, and then the resulting foliar infections tested to confirm their identification. This work was attempted this season, but met multiple problems, which, have been addressed in the design of future experiments.

4.2. Aphids

A number of prongs of attack are required to address the aphid problem. These are both to understand how and why aphids are circumventing mesh and also to find solutions.

4.2.1. Determine how aphids penetrate mesh

The method by which aphids are penetrating or otherwise getting underneath the mesh needs to be established. The current hypothesis that winged adults are alighting on the mesh and producing nymphs needs testing. This will require behavioural studies in real-world conditions. For example, small pieces of mesh e.g., 1 x 1 meter with potatoes underneath are video recorded to observe if winged adults do alight and produce nymphs.

4.2.2. Determine maximum mesh hole size that is fully aphid proof

A key potential benefit of mesh is for potato seed production is fully eliminating aphids from crops, especially early stage multiplication. However, the current field trial demonstrates that 0.3 mm and above mesh is not aphid proof. The previous trial on ultra fine mesh (UFM) with 0.15 x 0.35 mm hole size did not have aphids penetrate the mesh, but this year, they have, though this is not clear if it is contamination or not. Considering the other possible benefits of UFM, i.e., yield and blight control, determining the maximum mesh hole size that is completely aphid proof is considered vital.

The laboratory experiments trying to determine minimum mesh size have indicated that 0.2 mm is the minimum hole size, but, these are far removed from field conditions. A range of hole sizes, e.g., from 0.1 to 0.3 mm should be field tested, similar to the FAR field trials (section 3.3) where small, e.g., 1 x 1 m, pieces of mesh have potatoes growing under and around them to create a full green bridge. The potatoes outside should be tested for aphids, and or be inoculated with aphids to ensure sufficient aphids are present. Larger holes meshes, e.g., 0.6 could be placed over the finer mesh and surrounding potatoes to create very high aphid populations to thoroughly test the meshes.

4.2.3. Introduced biocontrol agent backup

Even when the maximum aphid proof hole size is determined, under real-farm conditions, mesh will be used for many years, and wear and tare is inevitable and 'damage-holes' will be created. Such damage-holes are possible aphid ingress points, and even one aphid getting under the mesh via such a damage-hole early in the crop could result in outbreaks. Working on the basis of trying to avoid an agrichemical solution, the control of aphids through commercially available biological control agents (BCAs) is well established. However, there is no prior research looking at using commercially available aphid BCAs in potato crops, nor have BCAs been used under mesh before, so the combination of BCA's under mesh on potatoes is entirely novel. Hopefully the considerable experience in other crop / pest combinations will indicate likely successful BCA species to trial.

It is assumed that the total number of aphids penetrating mesh are quite small, e.g., a handful a week per 100 m^2, so if the BCA is used as a preventative measure, i.e., the BCA is put in before aphids are seen on the crop (as is best practice) then
(1) the BCA is likely to benefit from alternative food sources, such as nectar and pollen to sustain it when aphid prey is absent and/or where parasitoids are used the adults are also likely to benefit from such resources,
(2) it needs to be able to actively detect aphids and search them out to be able to control what are assumed to be very small numbers penetrating the mesh, before their populations start expanding.

4.2.4. Aphid on mesh searching behaviour

As per the wear and tare issues (section 4.2.3) it needs to be determined if the winged adults alighting on the mesh, and/or the nymphs they are hypothesised to produced while on the mesh, are actively seeking a way through the mesh, and are therefore finding damage-holes in the mesh to gain entry. The techniques from the experiment looking at how aphids penetrate mesh (section 4.2.1) could be used to study their searching behaviour while on the mesh, to see if they do locate damage-holes and use them to penetrate the mesh.

4.2.5. Natural biocontrol agents

Some organic growers already managing aphids under mesh by not sealing the mesh all the way round, but, leaving part of the sheets open, e.g., at the ends, which allows BCA's that are naturally present in the field, to be able to enter the mesh and control the aphids. While simple and cheap, that approach needs to be researched to determine how effective it is. Monitoring of actual farm crops is considered to be the best approach as commercial mesh sheets can be as large as 40 x 200m which cannot be replicated in research plots because sheet size will effect aphid and BCA movement.

4.3. Yield / growth enhancement from mesh

The 2015-16 ultra fine mesh test coupled with the enhanced growth seen in other trials indicates that there is a direct positive benefit on potato growth and yield from mesh, in the absence of pests & disease. For the regular mesh, this is likely to be in part a response to the increase in temperature, which while small, equates to a significant number of growing degree days when compared with the total required by potatoes.

In addition, previous research has show that even moderate movement of plant foliage can have considerable impact on crop yield, and observations of potatoes under mesh on windy days clearly shows reduced haulm movement under mesh, which may be contributing to improved growth. There is also the potential for mesh to protect haulm from damage in more extreme wind. The extra-ordinary yield result from the ultra fine mesh test indicates that more extreme under-sheet microclimate modification could result in dramatic improvement in yield, as well as maximising other mesh benefits such as controlling blight and pests.

4.4. Other potato pests

Mesh is expected to be effective against other potato insect pests, e.g., potato tuber moth, green potato bug, potato leafhopper, and overseas, the likes of Colorado beetles. However, this should be positively confirmed and tested for unexpected results and consequences.

4.5. Other pest outbreaks due to exclusion of natural biocontrol agents

As with aphids, there are a number of other potato pests that are a similar size to aphid nymphs, e.g., thrips and mites, that can also penetrate the smallest mesh sizes. Future experiments and on-farm use of mesh should include wider pest insect monitoring to determine if pests, other than aphids, also become problematic under mesh.

4.5.1. TPP and UV light

The same as for the control of blight through reduced UV light levels, the spectral filter experiment (section 3.4) 'only' established a correlation between foliar TPP symptoms and UV levels. While this effect is somewhat incidental for potato production, as mesh is an effective means of TPP control, this finding could have significant implications for production of solanaceae crops grown under protection, e.g., tomatoes, peppers etc. For example a UV blocking plastic on polytunnels could control TPP populations, or UV light could be a TPP attractant to trap / kill them, e.g., as per commercial UV fly traps for food premises. Fundamental studies of TPP's response to UV light therefore needs to be established and then this used to guide how this can be used for TPP management in protected cropping.

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