An investigation of low cost protected cropping options for vegetable growers

Contents

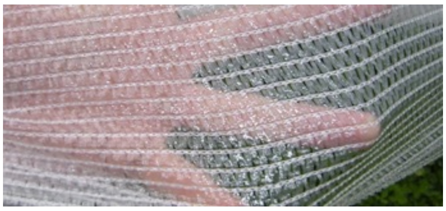
1. Netting materials and trial summary

1.1. Netting materials

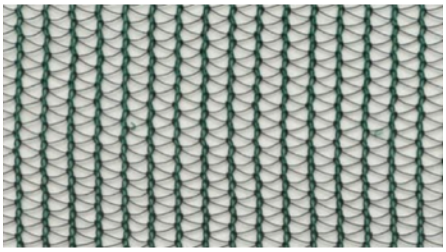
The trials reported in this document have all tested one or more netting materials and / or spunbonded polypropylene (fleece) on temperatures, RH, yield and quality of different crops.

Materials included;

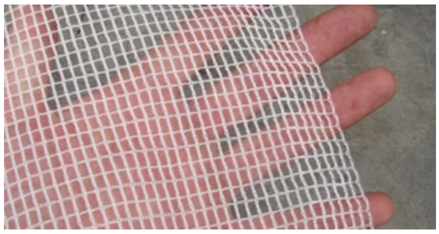
Insulnet Semi-transparent, knitted material designed to exclude larger pests and provide some protection from rain, hail and light frosts. Supplied by Redpath Australia. Mesh size approx. 4 x 2mm, 105g/m^2, low cost option.



Shade cloth Long lasting, knitted HDPE filament shade material, rated for a minimum 10 year life. Used as a 'crop top' cover on a frame. Available in colours including black, green, red and white and beige and shade density from 30 to 80%. Many suppliers, including NetPro.

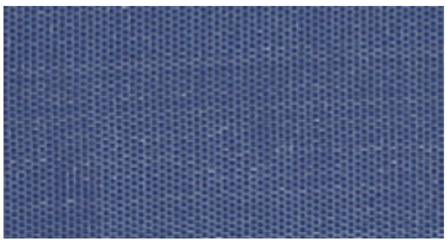


Vent Net White, open strand knitted fabric used for screening the sides of greenhouses and other structures. Prevents entry of birds and large insects, reduces impact of wind or strong rain. Supplied by Redpath Australia. Mesh size approx. 6 x 4mm



VegeNet Knitted white high density polyethylene net designed to exclude larger pests and provide some protection from wind and rain. Mesh size approx. 1 x 3mm, shading 10%, weight 45g/m^2. Supplied by NetPro Pty Ltd.

Insect Net Translucent woven material made from high density polyethylene. Long lasting material used to construct insect-proof net houses. Mesh size approx. 0.5 x 0.9mm, shading 27%, weight 125g/m^2. Supplied by NetPro Pty Ltd.



Aphid Net Translucent woven material made from high

density polyethylene. Designed to exclude most insects and last 8-10 years. Mesh size 0.6 x 0.6mm, shading 14%, weight 45g/m^2. Supplied by Crop Solutions UK.

GroShield Spunbonded polypropylene 'fleece' used primarily for frost protection but also insect exclusion and reduction of evaporation. Inexpensive but single use only as tears easily. Cohesive barrier (no holes), shading approximately 10-15%, range of thickness/weights from 18-50g/m^2. Supplied by NetPro Pty Ltd.

Agryl Spunbonded polypropylene 'fleece' similar to Groshield but with (claimed) stronger tear strength. Cohesive barrier, shading approximately 19-25%, range of thickness/weights from 17-30g/m^2. Manufacturer Fiberweb, Germany, supplied by Crop Solutions UK.

1.2. Summary of trials conducted and results

	Netting / structure	Location	Season	Crop	Result compared to uncovered control
PERMANENT STRUCTURES	Hail net	Tolga, Qld	Summer	Lettuce	Lower maximum temperatures under hail net.
	Hail net, Insect net	Stanthorpe, Qld	Summer	Babyleaf spinach	Higher temperatures under Insect net, hail net similar. Yield and shelf life unaffected.
	Red, white shade netting	Bairnsdale, Vic	Summer	Babyleaf spinach	Slight (~1°C) increase in maximum temperature under red net. Yield unaffected. Darker leaves under red netting, shelf life extended under both nettings.
	White shade netting	Carnarvon, WA	Summer	Capsicum	Temperature similar, wind speed halved, structure destroyed by cyclone.
	Green shade netting	Adelaide Hills, SA	Summer	N/A	Temperature significantly reduced under 70% shade.
	Cravo® house	Bundaberg, Qld	Spring	Capsicum	Temperatures elevated in Cravo® below 35°C, decreased in Cravo® above 35°C. Plant growth, vigour and health increased, yield and quality improved. Rain and hail damage was prevented by structure.
FLOATING ROW COVERS ON LEAFY VEGETABLES	Insulnet	Camden, NSW	Summer	Direct seeded spinach	Temperatures similar, RH higher, yield similar.
	VegeNet	Werribee, Vic	Summer	Baby cos lettuce	Larger lettuces, higher yield under net, fewer insects, shelf life unaffected.
	VegeNet, fleece, Aphid Net	Bairnsdale, Vic	Summer	Direct seeded lettuce	Higher daily maximum temperature under fleece and aphid net, slightly cooler under VegeNet, insect populations reduced, no differences in germination rate or yield.
	Insulnet, VegeNet, fleece	Robinvale, Vic	Autumn	Direct seeded lettuce	Warmer and more humid under covers, especially fleece. Slight reduction in yield under fleece, otherwise unaffected.
	VegeNet, Insect Net	Camden, NSW	Autumn	Direct seeded spinach	Higher daily maximum temperature under nets, higher overnight minimum under Insect net, insect populations reduced 60%, weed growth favoured under nets so yield reduced.
	VegeNet, Insect Net, fleece	Camden, NSW	Autumn	Direct seeded spinach	Higher daily maximum temperature and higher overnight minimums under nets, insect populations reduced 80%, weed growth favoured under nets so yield reduced.
	Fleeces	Werribee, Vic	Winter	Cos lettuce	All fleeces increased air and soil temperatures by 2-3°C and 2°C respectively. RH increased, insect populations decreased. Germination and yield increased, harvest advanced by approx. 1-2 weeks.
	Fleeces	Camden, NSW	Winter	Direct seeded lettuce	All fleeces increased air and soil temperatures. RH increased, insect

					populations decreased. Germination and yield increased, harvest advanced by minimum 2 weeks.
FLOATING ROW COVERS ON FRUITING VEGETABLES	VegeNet	Silverdale, NSW	Summer	Capsicum	Daily maximum slightly increased, higher RH. Insect damage reduced, yield similar but marketable fruit increased by 37%.
	VegeNet (3 timings)	Bundaberg, Qld	Summer	Capsicum	Temperatures reduced at >35°C, RH increased. Fruit fly catches reduced. Yield higher, more marketable fruit and advanced maturity (no. red fruit) in plants netted early in development. Little effect when plants netted 3 weeks prior harvest.
	Aphid Net, VegeNet, Vent Net	Silverdale, NSW	Summer	Chilli	Temperatures reduced at >25°C, temperatures increased at <20°C, higher RH. Aphids increased under aphid net, yield and quality unaffected overall.
	VegeNet	Bundaberg, Qld	Summer	Chilli	High temperatures reduced, RH reduced. Yield slightly reduced under netting due to increased rots, but crop damaged by heavy rain and waterlogging, trial abandoned early.
	VegeNet, Insect Net	Bundaberg, Qld	Autumn	Capsicum	High temperatures reduced by Insect Net, VegeNet similar to uncovered. Yield similar but marketable fruit increased and maturity (no. red fruit) advanced.
	VegeNet, fleece	Bundaberg, Qld	Winter-spring	Capsicum	Temperature and RH increased under fleece. Yield and quality increased under 18g/m^2 fleece, heavy weight fleece not durable.
	VegeNet, Aphid Net	Darwin, NT	Autumn	Eggplant	No results as yet – trial is ongoing.

2. Permanent netting or crop covers

2.1. Introduction

More variable weather, and particularly an increased frequency of heatwaves, are a key challenge facing Australian vegetable growers. Increases in average temperatures have already occurred, with the Bureau of Meteorology reporting that 2015-16 summer temperatures were 'very much above average' across much of coastal northern Australia, almost all of Victoria, all of Tasmania and much of south-east Australia.

Permanent or semi-permanent shade structures have been identified as the best way to protect vegetable crops against high temperature extremes. According to Kittas et al[1] rising air temperatures and light intensity have greatly increased the area of crops being grown under shading materials around the world. Shade cloth does not necessarily reduce air temperature around the crop; 34 to 50% shading in a structure with open sides did not affect ambient air temperatures in Greece as there was a high rate of airflow[1]. However, by reducing direct radiation, shading can reduce average leaf and soil temperatures by up to 3°C[2].

The major effects of shade net are to protect crops from sunburn and reduce moisture stress. Capsicums grown under shade are taller and have fewer, but larger leaves[2]. Despite increased leaf area, soil water content is increased, and so irrigation requirements are reduced[3]. Disorders such as blossom end rot and skin cracking are reduced by shading, as the plant is less stressed by extremes in temperature and radiation[4].

Netting not only changes light intensity, but also affects the spread of wavelengths reaching the plant. The colour of the net can influence accumulation of chlorophyll in leafy vegetables, and fruit colour in fruiting vegetables[5]. Red nets can increase leaf development, so can potentially have a positive impact on leaf crops such as spinach[6]. Yield of tomatoes is higher under red and white nets than other colour nets or the uncovered field, but lycopene

[1] Kittas C et al. 2009. Influence of shading screens on microclimate, growth and productivity of tomato. ActaHort. 807:97-102.
[2] Diaz-Perez JC. 2013. Bell pepper (*Capsicum annuum* L.) crop as affected by shade level: Microenvironment, plant growth, leaf gas exchange and leaf mineral concentration. HortScience 48:175-182.
[3] Moller M, Assouline S. 2007. Effects of a shading screen on microclimate and crop water requirements. Irrig. Sci. 25:171-181.
[4] Lorenzo P et al. 2003. Efect on microclimate, water use efficiency and yield of a tomato crop grown under different salinity levels of the nutrient solution. ActaHort. 609:181-186.
[5] Bergquist SAM et al. 2007. Ascorbic acid, carotenoids and visual quality of baby spinach as affected by shade netting and postharvest storage. J. Agric. Food Chem. 55:8444-8451.
[6] Shahak Y. 2014. Photoselective netting: an overview of the concept, R&D and practical implementation in agriculture. ActaHort. 1015:155-162.

content may be increased under black and blue nets[7]. Capsicums were also most productive under white nets, although red nets resulted in higher levels of anti-oxidants[8].

Shading has been widely reported to increase productivity of a range of crops. However, the shading intensity needs to be suitable for both the crop being grown and the external environment. For example, in Egypt 40%[9] to 35%[10] shading maximised tomato production. Increasing shading to 51% eliminated sun-scald and increased marketable fruit compared to outside production. However greater than 51% shading reduced light below optimal levels and therefore decreased productivity. Similar results were reported from Israel for production of capsicums under shade[11]. Marketable yield was maximized under 26% shade, although results were not significantly different to 12% shade when planting density was increased. Increasing shading to 47% increased fruit size but reduced the average number of fruit per plant. In contrast, lower light levels in England mean that 23% shade is optimal for production of tomatoes[12].

It is clear that the same level of shading is not necessarily appropriate for all crops, or for use at different times of year. Retractable roof greenhouses are a relatively new technology designed to optimise shading under different environmental conditions. The sensor systems in retractable roof houses manage ventilation and shading to keep plants within an optimal environment. During cool temperatures the roof may be closed and shade curtains pulled back to warm the plants. Under more intense heat and radiation the roof and sides may be opened to allow ventilation, and reflective curtains pulled across to provide shade. Faster production cycles, major reductions in chemical use and 50% cuts in irrigation have all been reported as benefits from such systems[13].

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[7] Ilic ZS et al. 2012. Effects of modification of light intensity by color shade nets on yield and quality of tomato fruits. Scientia Hort. 139:90-95.
[8] Mashabela MN et al. 2015. Bioactive compounds and fruit quality of green sweet pepper grown under different colored shade netting during postharvest storage. J. Food Sci. 80:H2612-H2618.
[9] El-Aidy F, El-Afry M. 1983. Influence of shade on growth and yield of tomatoes cultivated during the summer season in Egypt. Plasticulture. 47:2-6.
[10] El-Gizawy et al. 1992. Effect of different shading levels on tomato plants 2. Yield and quality. ActaHort. 323:349-354.
[11] Rylski I, Spigelman M. 1986. Effect of shading on plant development, yield and fruit quality of sweet pepper grown under conditions of high temperature and radiation. Scientia Hort. 29:31-35.
[12] Cockshull KE, Graves CJ, Cave CRJ. 1992. The influence of shading on yield of greenhouse tomatoes. J. Hort. Sci. Biotechnol. 67:11-24.
[13] Vollebregt R. 2004. The potential of retractable roof greenhouses to dominate greenhouse designs in the future. ActaHort. 633:43-49.

Figure 1. A retractable roof Cravo® house used to grow vegetable seedlings in Gatton, Qld.

A number of trials have examined use of netting in regions where high levels of solar radiation are likely to be an issue, at least during summer months;

- Tolga
- Stanthorpe
- Bairnsdale
- Carnarvon
- Adelaide Hills.

In addition, one trial examined yield and fruit quality of capsicums grown under a Cravo® retractable roof greenhouse in Bundaberg.

2.2. Method

2.2.1. Tolga, Queensland

The trial was conducted at a lettuce production facility at Tolga, in the Atherton Tablelands. This facility produces hydroponic lettuce for local consumption. The major production constraints are high temperatures and extreme weather events (particularly heavy rain and hail) in this region. The grower has installed two potential solutions to these challenges:

- A fully enclosed hail net house, 2.7m high and 10,000m^2, which provides some protection from the weather as well as shading for the crop
- A solo weave plastic dome type greenhouse, 6m high with extensive roof venting and roll up sides

Temperature and RH data-loggers (Hobo U23 Pro v2) were installed at the start of November 2014 to monitor temperatures.

Figure 2. Net house and greenhouse located at Tolga on the Atherton Tablelands

2.2.2. Stanthorpe, Queensland

The Stanthorpe area is highly productive, but can experience extremes of climate. It holds the record for the lowest temperature recorded in Queensland (-10.6°C) and occasionally receives sleet and even light snowfalls during winter. In summer, severe storms, including hailstorms, are a major production issue. The region usually experiences at least one major hail event between November and February each year. A number of growers have invested in hail netting as a result, including for vegetable production.

Two trials have been conducted at the Stanthorpe site. These have examined growth of baby spinach under a large hail net structure, under a floating cover (Crop Solutions UK Insect Net, 0.8mm mesh 70g/m^2) and in an open field (Figure 3).

Figure 3. Spinach growing under hail netting (left) and under a floating row cover (centre) and installation of a data logger in the open field protected by a simple PVC pipe cover

The first trial was conducted during December 2014 to January 2015. Temperature, humidity, insect populations, yield and shelf life were all recorded. Temperature and humidity were logged using Hobo U-23 external data loggers. These were protected from the elements mounted inside a vented piece of PVC pipe, open at the base.

At commercial maturity the covers were removed and twelve samples were taken of insects under the floating covers and compared to twelve samples collected from the adjacent open area. Each sample was collected using a blower-vac to suction an area approximately $2.6m^2$ for 40 seconds.

Yield was sampled from ten randomly selected positions within each treatment block. Each sampling area consisted of a 30cm x 30cm square. Spinach was harvested using a pair of scissors to trim leaves to within 10mm of the ground. Samples were weighed and then stored at $5^{\circ}C$. These were examined each day to determine the number of days until they were no longer commercially acceptable quality.

2.2.3. Bairnsdale, Victoria

The Bairnsdale region grows large quantities of babyleaf crops including rocket, spinach and lettuce, as well as more traditional lettuce varieties such as cos and oakleaf. However, high temperatures and low humidity during the summer months make it difficult to germinate seeds – especially lettuce – as well as causing sunburn, increasing water use and reducing quality of other crops.

Figure 4. White and red shade protection netting at property in Bairnsdale, and temperature + RH datalogger mounted inside a short piece of PVC pipe and placed in the seeded bed.

This trial was conducted during the summer of 2014-2015 at a commercial vegetable farm. Babyleaf spinach was planted under red and white shade netting as well as in the open field. Temperature and humidity loggers (Hobo UX100-003) were installed in the outdoor area as well as under the red and white netting. The dataloggers were protected by a radiation screen constructed from a short piece of PVC pipe and placed 20cm above the soil surface.

Comparative measurements of light intensity were taken at the time of installation using a handheld meter. Average values were calculated from a sequence of five spot measurements taken 60 seconds apart. These indicated that the white and red hail netting both provided approximately 30% shading.

Shortly before the crops reached commercial maturity, samples were taken for yield and shelf life. Five 30 x 30cm sections were harvested from each of the trial areas. Average yield was calculated for each treatment.

Three subsamples of fresh, unwashed leaves were taken from the five harvested samples from each plot area. These leaves were visually assessed then placed in separate plastic bags and stored at 5°C. A random subsample of these leaves was reassessed daily from seven days after harvest. Figures 8 and 9 illustrate a composite of typical leaves at each assessment.

Samples were considered unacceptable when >10% of the sample had signs of yellowing, leaf deterioration, or rots.

2.2.4. Carnarvon WA

Carnarvon has a hot, dry climate. Only one capsicum crop is produced each year, between February and October – December. While tomatoes and other crops are produced in the open field, capsicums are generally grown under shade netting; production is not economically viable without this protection.

Data-loggers were installed inside and outside a large, white shade house being used to grow capsicums. This was typical of structures in the area. It was several years old and quite coated with dust, which likely reduced light transmittance. Comparative measurements of light intensity, temperatures and wind were taken at the time of installation.

Figure 5. Capsicum crop grown under shade netting in Carnarvon

2.2.5. Adelaide Hills

A non-crop based assessment was conducted over the summer of 2014–2015 at Meadows, an area in the Adelaide hills. This area is adjacent to the important viticulture and horticulture region of McLaren Vale. Although only small quantities of vegetables are currently grown in this area, there is strong potential for production if the climatic constraints of high summer temperatures and limited irrigation water availability can be addressed.

Loggers were installed under a 70% shade canopy and in an adjacent uncovered area. Temperatures were monitored from 22 January to 16 February, the period when highest temperatures could be expected.

2.2.6. Bundaberg, Queensland – Cravo® house

Temperature, humidity and yield were recorded from a capsicum crop grown in the Young Sang and Co. retractable roof (Cravo®) greenhouse. This was the first crop produced inside the 4.3ha house. Temperature and humidity were monitored using Hobo outdoor data loggers (U23-100). Yield and quality were assessed when the capsicum 'king fruit' in the Cravo® house reached maturity and turned red. Data was compared to an adjacent capsicum crop planted in the field that was at a similar maturity stage. The planting dates were not the same, with the seedlings in the Cravo® house planted 1−2 weeks after the field grown crop.

Figure 6. The retractable roof Cravo® house installed by Young Sang & Co. in Bundaberg.

2.3. Results

2.3.1. Tolga, Queensland

Temperatures during the daily peak were approximately 5-7°C cooler under the hail netting compared to inside the full protected cropping structure (greenhouse). While humidity remained slightly higher inside the house during the cooler evenings, these differences were relatively minor (Figure 7).

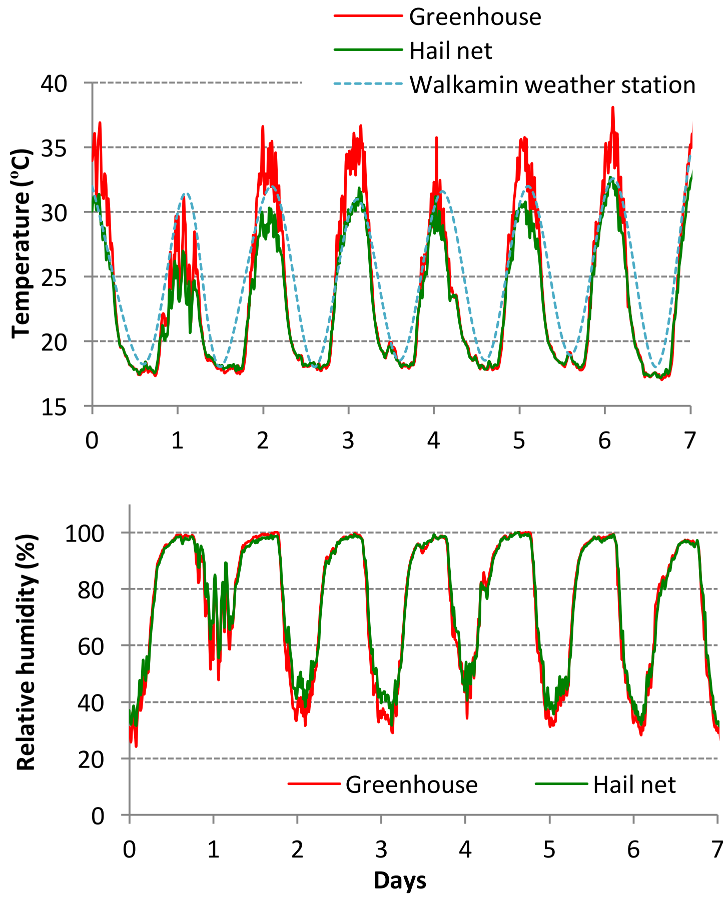

Figure 7. Temperature (top) and humidity (below) recorded at a hydroponic lettuce farm in Tolga, North Queensland during November 2014.

Data collection was limited by logger malfunction. This meant any yield data collected would have had limited usefulness.

2.3.2. Stanthorpe, Queensland

In general, temperature and humidity under the floating row cover and the hail net structures were similar to the open field. Exceptions were noted during hot weather, when daily maximum temperatures were higher under the floating row cover than the open area (Figure 8).

Under mild conditions, diurnal fluctuations in temperature were buffered by the hail net and floating cover, compared to the fluctuations in the open field (Figure 9). Similar results were found for relative humidity; in the first of these periods humidity was slightly lower in the open area, whereas in the second period RH in the open field was higher at night and lower during the day compared to the protected areas.

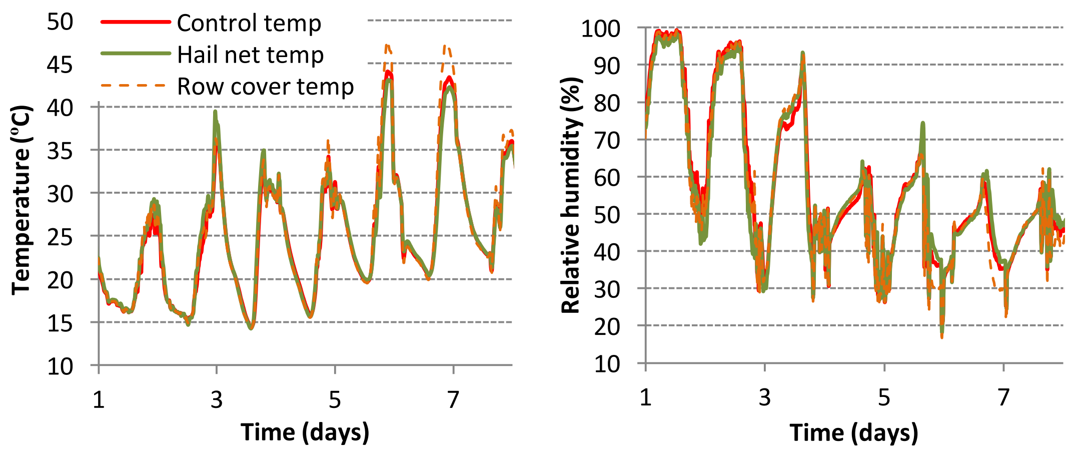

Figure 8. Temperature (left) and humidity (right) in an open field, under a floating row cover and under hail net in Stanthorpe, Qld from 5/1/2015 to 12/1/2015

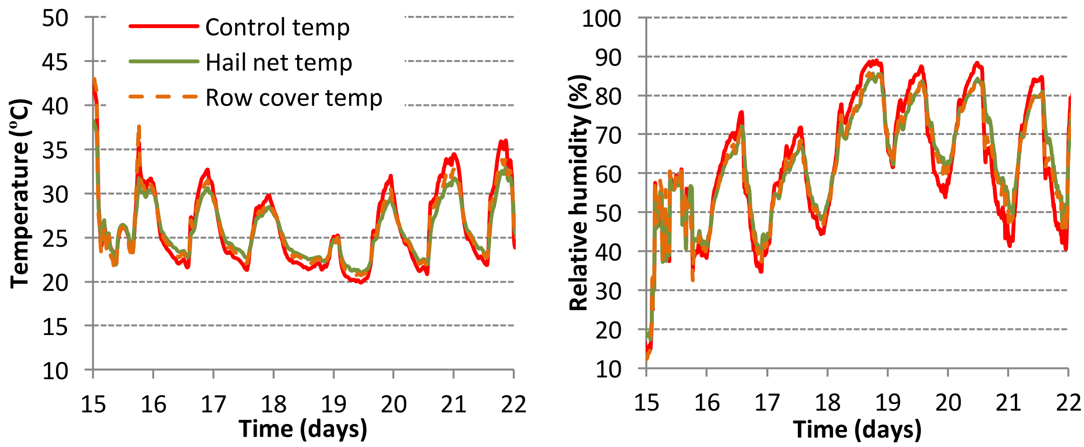

Figure 9. Temperature (left) and humidity (right) in an open field, under a floating row cover and under hail net in Stanthorpe, Qld from 20/1/2015 to 27/1/2015

These apparently contradictory results may be due to the impact of wind as well as direct sunshine, soil moisture and irrigation timing. The effect of netting on temperature and relative humidity is not straightforward, but can vary with other environmental factors.

The floating cover had a major effect on the numbers of potential contaminants in the crop. Large numbers of Rutherglen bugs were found in the open field, whereas almost none were under the floating cover. As Rutherglen bugs are a major contamination problem for baby spinach production, this represents a very positive result for the use of the netting material. The floating cover also mostly excluded beet webworm, although it was less effective against lady beetles. Although lady beetles are also a contamination issue, they may be more easily detected during packing.

Table 1.Total insects found under floating row covers compared to the adjacent field (sample size 2.6 m^2, n=12)

	Rutherglen bug	Moth /caterpillar	Beet webworm	Lady beetle
Floating cover	4	0	1	7
Open field	297	1	7	10

Yield and shelf life of spinach grown under the floating row cover was not significantly different to that grown in the open field (Figure 10).

Samples of 30 leaves were weighed to assess the relative sizes of leaves. This indicated that spinach leaves grown under the netting were approximately 10% smaller on average than those grown outside. Although yield from under the hail netting appeared to be slightly reduced, these results suggest the crop was simply slightly less mature at harvest. This limits any inference with regard to effects of growing method on total yield.

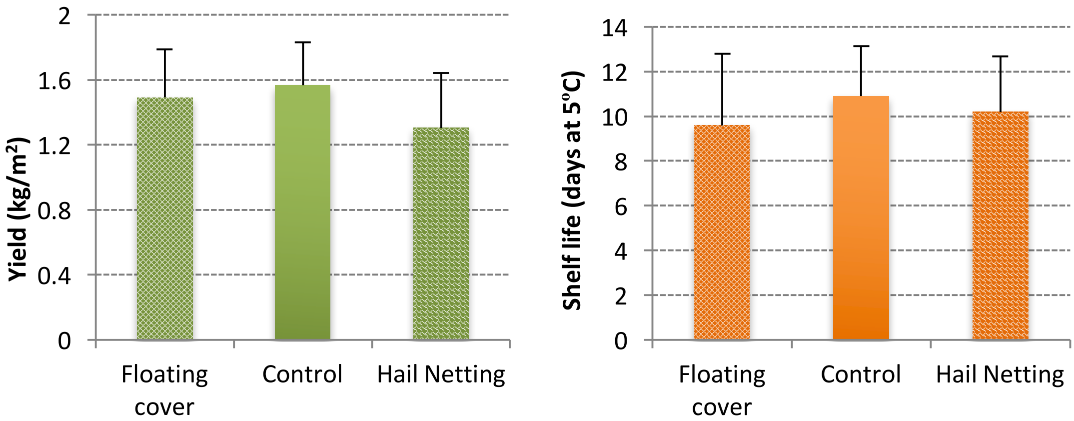

Figure 10 . Yield and shelf life of baby spinach grown under a floating net cover, under hail netting, or in the open (control). Bars indicate the standard deviation of each mean value (n=10)

Part of the reason for selecting the Stanthorpe site was because the area is prone to hailstorms during summer. While a number of hailstorms did affect the region during the trial, none impacted on the specific trial crops. The area also experienced fairly moderate temperatures during the trial period, so little information could be gathered about the impact of hail netting structures or floating covers on mitigating extreme weather events.

The most promising result is the large reduction in insect contamination of the crop by floating covers, without negatively affecting yield or quality.

2.3.3. Bairnsdale, Victoria

Although initial readings indicated that it was significantly cooler under the shade materials (Table 2), analysis of the temperature data indicated that overall temperatures were decreased by less than 1°C under the netting (Figure 11). Moreover, at higher temperatures it was approximately 1°C warmer under the red netting than it was in the uncovered field. These small differences were not statistically significantly different.

The netting did slightly increase average humidity. Although plants tended to be slightly taller when grown under the shade netting, differences in yield between the plots were not statistically significant (p=0.069).

Table 2. Differences between shaded and unshaded areas in Bairnsdale based on environmental measurements at setup.

	Air temperature (°C)	Relative humidity (%)	Soil surface temperature (°C)	Light intensity (PAR)* (µmol.m^{-2}.s^{-1})	Plant height (mm)	Leaf length (mm)	Yield**(g/m^2)
Unshaded	38.0	38.4	31.4	1750	68	52	656
White shade	30.3	42.2	29.2	1190	74	47	489
Red shade	35.5	42.2	31.8	1242	82	48	672

* Photosynthetically active radiation

** Yield is comparative between the assessment plots but does not necessarily represent full commercial yield as the assessments were conducted prior to harvest.

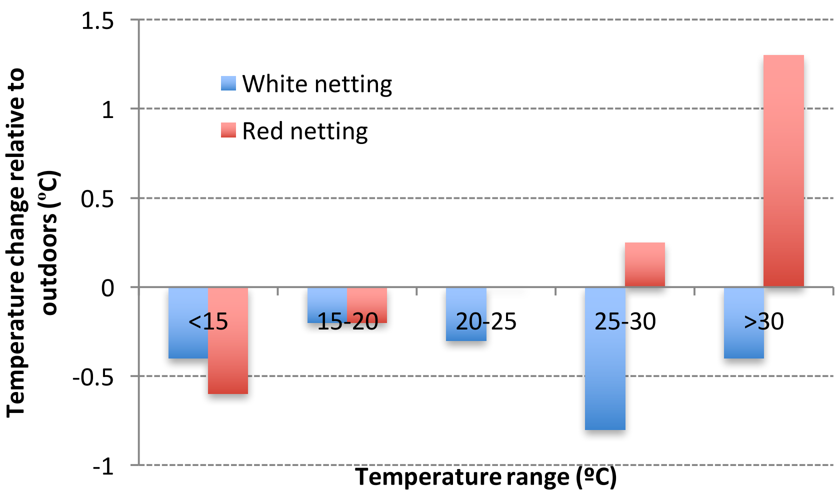

Figure 11. Change in temperature under white or red netting compared to the open field

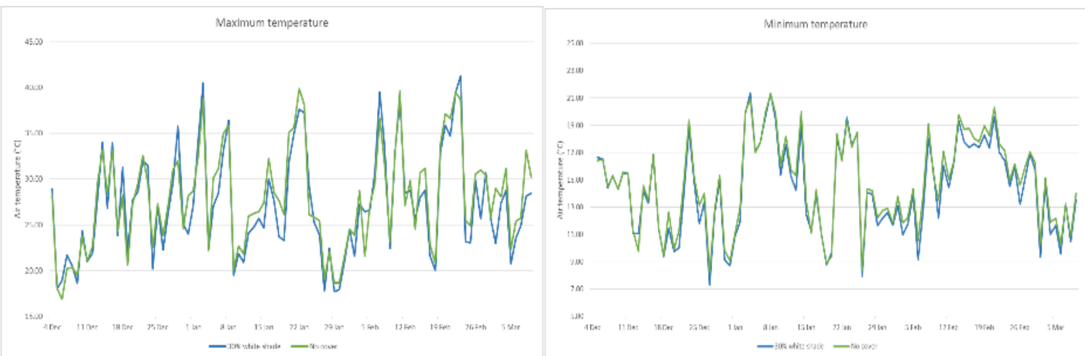

Figure 12. Daily maximum (left) and minimum (right) temperatures in an uncovered field compared to the adjacent area covered by white (top) or red (below) netting.

All three areas produced high quality leaves. The main difference between the samples which was immediately noticeable was the darker green colour of leaves grown under red netting.

All samples remained high quality until day 20. At day 21 initial leaf breakdown (<5% of sample) was evident in the product harvested from the open field (no cover). By day 23, these symptoms had increased to around 10% of leaves. At this point the product is expected to fail consumer acceptance.

Some leaf damage (<5% of leaves) was identified in the red shade product. Some of these pre-existing leaf marks became more evident by day 25. The product harvested from under the white shade was also still good quality at day 25. Initial signs of leaf breakdown in the white shade product only became evident at day 28.

Figure 13. Spinach leaves grown in the open field or under red or white netting and stored for up to 28 days at 5 °C

Estimated average shelf life was:

- Open field 23 days
- Red shade 28 days
- White shade 30 days

The 2014–15 summer was relatively mild in Bairnsdale. No major storms, hailstorms or extreme heat or cold or intense wind events occurred during the trial period. However, the results suggest that even under mild, 'normal' growing conditions light shading may slightly extend shelf life of baby spinach.

2.3.4. Carnarvon WA

Unfortunately the trials in Carnarvon were cut short by a cyclone. The loggers were not recovered and the crop was considered a total loss. The only data recorded was therefore the original spot measurements taken at installation.

Table 3. Differences between shaded and unshaded areas in Carnarvon

	Air temperature (°C)	**Relative humidity (%)**	**Soil surface temperature (°C)**	**Light intensity (PAR)* (µmol.m^{-2}.s^{-1})**	**Wind-speed (km.h^{-1})**
Unshaded	31.3	33.6	46.1	1814	7.7
Shaded	32.1	33.4	51.2	1370	3.3

* Photosynthetically active radiation

Although the effects of shade cloth on temperature and RH were minimal, it cut PAR by around 30%. It also halved wind-speed, which would likely be one of the major benefits of this system.

2.3.5. Adelaide Hills

Air temperatures were significantly reduced under the shade, particularly as temperatures became more extreme (Figure 14). At over 30°C, temperatures under the netting were up to 10°C lower than those outside. The average reduction in temperature at 35°C and higher was nearly 14%, which represents a significant potential improvement for most vegetable crops (Figure 15).

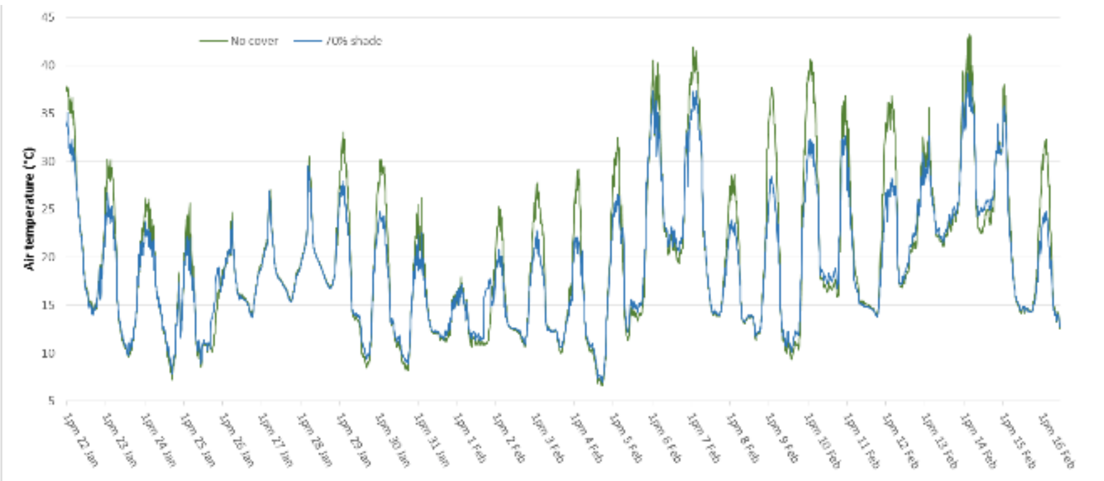

Figure 14. Temperatures recorded in the open field and under 70% shade netting during January – February 2015 in the Adelaide hills

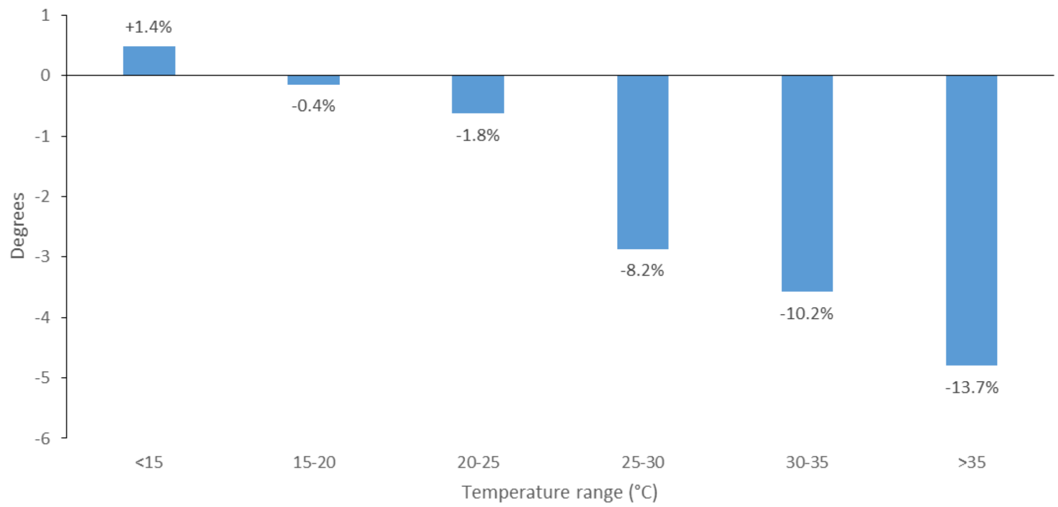

Figure 15. Impact of 70% shade on air temperature at different temperature ranges

These results indicate that shade netting could allow vegetable production during summer in a region previously considered too hot and dry for this to be viable. In this, the region resembles Carnarvon in WA, where production of capsicums and other vegetables is entirely conducted under shade netting and with drip irrigation.

2.3.6. Bundaberg, Queensland – Cravo® house

A major storm occurred in the region on 28 October 2015. Hail completely destroyed some of the outside capsicum crops, and caused significant damage to others which were already in fruit. The crop inside the house was generally untouched, although some slight damage did occur due to water ingress through the roof – it was estimated that the area received up to 150mm of rainfall, considered a 1 in 200 years rainfall event.

The storm coincided with a field day held at the greenhouse, and was effectively a major demonstration of the potential benefits of such a system. Daniel Scavo (GM, Young Sang) was quoted as saying "*You can't control the weather, but you can control the greenhouse roof*", in praise of the system.

The nearby outside capsicum crop used to assess differences in this trial had only just started to set fruit when the storm hit.

The plants inside and outside the Cravo house appeared very different, even though they had been planted at similar times. The plants inside the house had grown over a metre tall, with lush growth and very large leaves (Figure 16). Those outside the house were short, with windblown, often damaged leaves and a sprawling growth habit.

Figure 16. Capsicum crop inside the retractable roof greenhouse.

Figure 17. Field grown capsicums at a nearby field, planted 1–2 weeks prior to those inside the greenhouse.

The Cravo house provided a slightly warmer environment than the open field at air temperatures below 34°C. At higher ambient temperatures the crop was slightly cooler inside the house.

Soil temperature showed a similar pattern, although the change-over occurred at 24°C. Thus, when field soil temperatures fell below 24°C, the environment inside the Cravo house was slightly warmer. However, these differences were very small, so do not explain the large differences observed in plant growth and health.

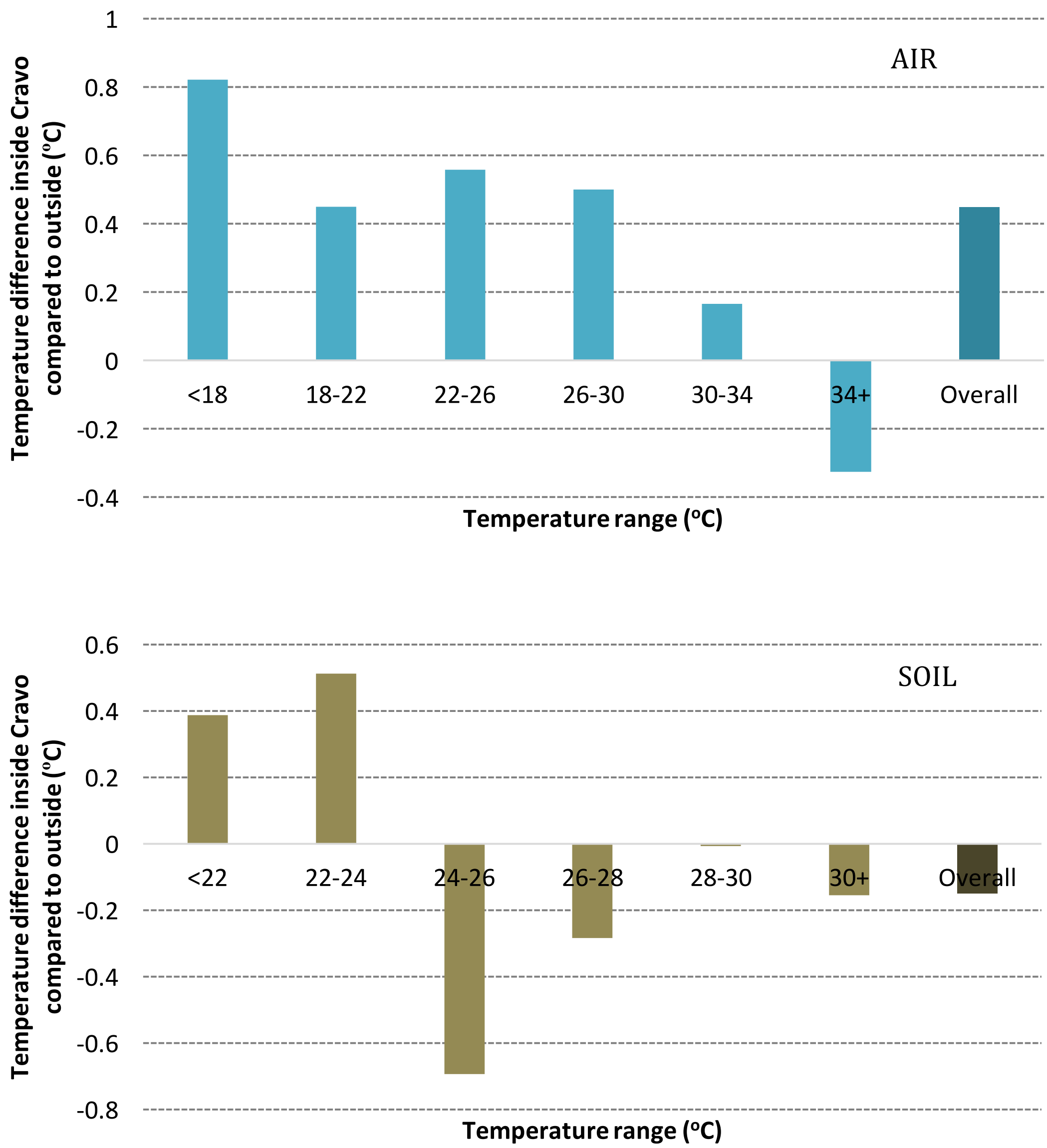

Figure 18. Air (top) and soil (below) temperatures inside the Cravo® house relative to those in a nearby capsicum crop. Below 34°C air temperature or 24°C soil temperature, the greenhouse structure provided a warmer environment for the field. However, when outdoor air temperature exceeded 34°C or soil temperatures were above 24°C, the greenhouse cooled the crop.

Large differences in yield and quality were expected between capsicums grown inside the greenhouse and field grown plants. Significant differences were found in total yield, average fruit weight and total weight of marketable size (>120g) fruit.

Table 4. Yield and quality of fruit grown inside the Cravo house compared to field grown fruit from plants of the same age. Letters indicate means that are significantly different (p<0.05, n=18).

	Total yield of fruit (g)		Total yield of fruit ≥120g		No. of Excellent fruit/plant		No. of OK to poor fruit/plant	
Field grown	1,352	a	1,085	a	3.2	a	1.3	a
Cravo house	1,692	b	1,418	b	4.2	a	0.6	a

All of the field grown capsicums were still green, whereas 26% of those inside the Cravo house were at least 50% coloured. Fruit set was extremely variable both inside and outside the house. As a result, although the number of grade 1 (excellent) fruit was higher and the number of fruit graded as "OK" or worse was halved for plants inside the Cravo house, differences were not statistically significant.

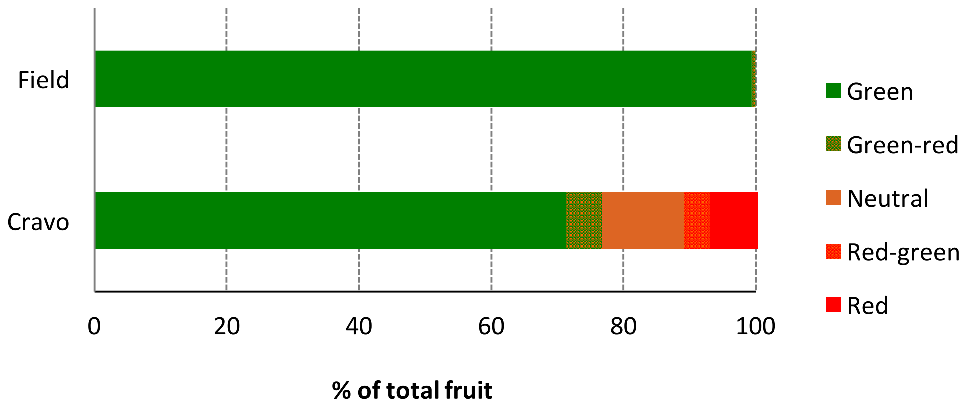

Figure 19. Percentage of the crop classified as green, mostly green, 50/50, mostly red or red from plants grown inside the Cravo retractable roof greenhouse compared with plants of the same age growing outside.

Given the health of the plants, it had been expected that differences in yield and quality would be far greater than was recorded in this trial. Although fruit set was good initially, few fruit had developed around the centres of the plants. However, the plants were flowering well at the time of evaluation, suggesting that total yield during the crop cycle could increase significantly from the figures recorded here.

As this is the first crop inside the Cravo® house, the grower is still working to optimise plant selection, nutrition and growing conditions. For example, the plants growing inside were the same variety as those in the field, which may not be the best for a protected environment. It appeared that excess nitrogen was applied during mid growth- resulting in overabundant foliage production at the expense of flowering and fruit set. The large leaves on the plants inside the house also suggest that the plants were too strongly shaded during development. It is also possible that keeping the sides of the house fully closed for an extended period during adverse weather in November may have excessively increased humidity and affected fruit set.

2.4. Conclusions

2.4.1. Effects on temperature and humidity

The results generally confirm previous published results that shade netting has minimal impact on temperatures when used only as a top over the crop. However, adding sides to the structure reduces air-flow, so can increase air temperatures even if light intensity is reduced. The red netting slightly increased maximum temperatures compared to uncovered areas, which again is consistent with published results showing higher temperatures under red netting late in the day, presumably due to increased long wavelength radiation[7].

The exception to this result was the trial from Adelaide. In this case heavy shading of 70% was tested. The result was a significant decrease in peak daytime temperatures. This site was relatively protected from wind, being located in a slight valley. This may account for the increased variation between the areas under and outside the shading compared to more exposed sites.

Humidity was also relatively unaffected by shading. Despite this, irrigation requirements under shading are likely to be significantly reduced. Adding sides to a net house reduces air movement, with the result that increased relative humidity was recorded at Tolga when comparing the net structure to a more enclosed greenhouse system.

2.4.2. Effects on yield

The trials in both Stanthorpe, QLD and Bairnsdale, VIC found no yield benefit when baby spinach was grown under white hail netting. Results were improved in the Bairnsdale trial when red netting was used. It was also notable that baby spinach grown under red netting was taller and darker green than the uncovered control. This is similar to the results reported by Bergquist[5], who also found that chlorophyll and carotenoids were increased when spinach was grown under shade netting. Darker green leaves are likely to be perceived as fresher by consumers, so are an important quality attribute. The slight improvement in shelf life that was found for spinach grown under both white and red netting is also an important positive result.

2.4.3. Protection from weather

These trials were conducted to assess how well shading could protect plants from extremes of weather and climate. Three extreme weather events occurred during the experimental periods: the cyclone in Carnarvon, a hailstorm in Stanthorpe and heavy rain in Bundaberg.

The netting in Stanthorpe completely protected the crop underneath from hail. We could easily have ended up comparing total crop loss outside the net to normal yield inside the protective structure. However, this was a highly localized storm, and in this case the adjoining control area was untouched.

Similarly, in Bundaberg, some of the capsicum crops adjacent to the Cravo® house were completely destroyed by the heavy rain during November 2015. The crop inside the structure suffered some damage, but was generally in good condition. The crop used to assess yield was approximately 2km from the Cravo® house. Although these plants were in poor condition, yield was still relatively good. However, these plants would be picked over only once or twice before the crop was ploughed in. In contrast, the Cravo® house plants were expected to continue to yield for several months. Although total yield was not assessed, it seems probable that the Cravo® house capsicums would easily overtake that from field grown crops as the season progressed.

Results would also have been improved by better nutrient and shade management of the capsicums inside the Cravo® house: this being the first crop, management was not optimal and resulted in excess leaf growth at the expense of fruit production.

Improved productivity under shading systems has been widely reported in the literature for crops such as tomatoes and capsicums, although yield of leafy vegetables such as baby spinach generally appear to be less affected. In these trials we found only moderate or no increases in productivity. However, the results do support the effectiveness of shading systems to protect crops during extreme weather events. The cost of shading must therefore be primarily balanced by the probability of total crop loss. Effects on productivity are likely to be less important, with the possible exception of systems such as the Cravo® retractable roof greenhouse.

3. Netting for summer production of leafy vegetables

3.1. Introduction

Floating covers are lightweight, permeable materials that can be laid directly over the crop without a supporting structure. Floating covers include various types of woven netting, as well as ‘fleeces’, spun-bonded materials made out of polypropylene.

Netting is primarily designed to exclude pests. Insect proof nets can reduce insecticide use, and provide an effective barrier against vectors of plant pathogens[14]. A wide range of netting materials are available, which vary considerably in light transmission, weight and mesh size. While smaller mesh sizes can help exclude more pests, they may also make control more difficult if the pest does penetrate the barrier.

For example, although fine netting can delay outbreaks of aphids, once established the aphid population can increase rapidly in the absence of predators and parasitoids[15]. One answer has been to treat the net with a long lasting insecticide, such as the pyrethroid alphacypermethrin[16]. However, this would be considered ‘off label’ use in Australia, particularly where crop contact is likely, so is not necessarily an option in Australia in the short term.

Nets also modify the microclimate around the plant. Small mesh sizes reduce ventilation, which can increase plant disease[17], but also potentially minimise moisture loss from plants and soil. Consistent soil moisture reduces irrigation requirements and may increase germination, especially for small seeds.

Although netting reduces light levels, light is more diffuse, so total photosynthesis is not necessarily affected. In addition, damage due to sunburn or heat stress may be avoided. Plant health, crop quality and yield may therefore benefit from use of nets[18]. For example, growing tomatoes under floating row covers increased total yield, marketable yield, fruit size and fruit firmness[19].

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3.2. Method

3.2.1. Robinvale, Victoria

Trials were conducted comparing the effects of Insulnet, VegeNet and Groshield on growth of direct seeded lettuce during March – April 2015. Temperature and humidity were recorded using Hobo data-loggers. Lettuces were harvested at commercial maturity, weighed and assessed for quality attributes. A random subsample of these lettuces was reassessed 7, 14 and 21 days after harvest.

Figure 20. Insulnet applied to a seeded lettuce crop in Robinvale, Victoria

3.2.2. Camden, NSW

Trial 1

Dates: 12 November to 5 December 2014

Material tested: Insulnet

Two x 50m long sections of Insulnet (Redpath, Australia) were placed over spinach plants immediately after seeding. Each piece was wide enough to cover two beds. The edges of the material were weighed down with sandbags. Adjacent beds were left uncovered.

Temperature was recorded using Hobo temperature and relative humidity (RH) dataloggers placed inside protective shields constructed of pieces of PVC pipe. Environmental conditions were also recorded using a weather station located within 1 km of the cropping area.

Figure 21. Insulnet installed over a double bed of baby spinach (left) and temperature + RH data logger inside a protective piece of PVC pipe

At commercial maturity, randomly selected 1m^2 sections of the crop under the net and in the open field were harvested (n=5). Plants were cut approximately 10mm above soil level and weighed to determine average yield/m^2.

Trial 2

Dates: 5 March to 1 April 2015

Materials tested: VegeNet and Insect Net

Three replicated 20m long sections of each type of floating cover material were placed over beds three days after seeding with baby spinach, as shown in Figure 22. The edges were secured using sandbags. Buffer areas at least 2m long were included between treatment blocks. A Hobo U23 external temperature and humidity data logger was mounted under each type of material as well as in the uncovered control area. In this case loggers were not placed in any type of protective shield but left exposed.

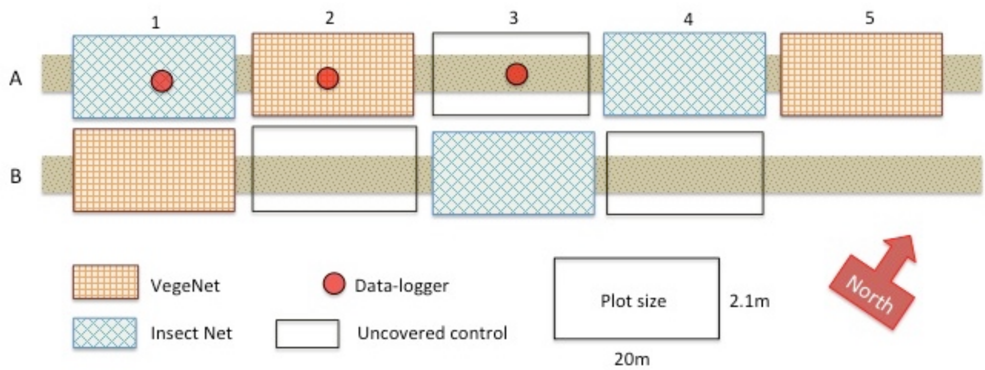

Figure 22. Trial 2 layout

Figure 23. Hobo data logger installed in the open, uncovered area of the bed and under a floating row cover

At commercial maturity each cover was removed and a blower-vac was used to sample insects from the central area of the crop. Each sample was taken over a timed 20-second period, with the operator slowly walking along the treatment block during the vacuuming procedure. Each sample was bagged for later examination of the type and numbers of insects present.

A 30cm x 30cm template was used to harvest three randomly selected sections from each treatment block (total n=9). Spinach was harvested as previously, with plants cut approximately 10mm from the ground level. Samples were returned to the lab, weighed, sorted, and segregated into units for evaluation of storage quality at 4, 7 and 10°C. Quality was assessed subjectively from excellent (4) to very poor (0) with OK (2) the limit of acceptability.

Trial 3

Dates: 16 April to 27 May 2015

Materials tested: VegeNet, Insect Net, Fleece (Agryl 22g/m^2)

Methods used were the same as those in Trial 2, with three replicated blocks of each type of material along with sections of uncovered control randomly allocated along two beds of baby spinach. Materials were applied a few days after seeding and secured with sandbags (Figure 24). A Hobo U23 data logger was mounted within each treatment type, as in the previous trial.

Figure 24. Installing three different types of floating cover on newly seeded beds of baby spinach

Insect number and presence, yield and storage quality were assessed as previously.

3.2.3. Werribee and Bairnsdale, Victoria

Trial 1

Dates: 14 December to 16 January 2016

Materials tested: VegeNet

Previous winter trials examining the use of netting or fleece on lettuce crops resulted in increased yield, but also in lettuces that were lighter and softer. This was thought to potentially reduce shelf life. This trial therefore examined the effect of removing the netting materials approximately one week before harvest, allowing plants to 'harden up'.

Baby cos lettuce was direct seeded at a commercial vegetable farm in Werribee in December 2015. Six sections of VegeNet were placed over the seedlings one week after planting, with netting removed either five days before harvest or at the time of harvest. Control plots were left uncovered (Figure 25).

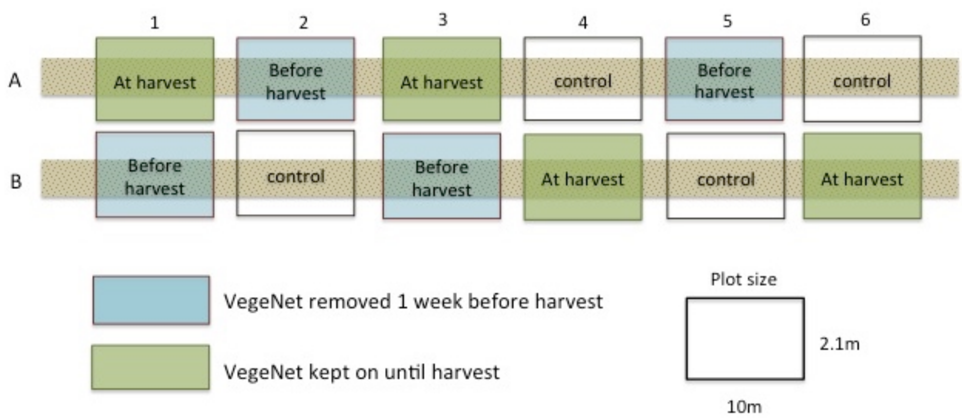

Figure 25. Trial plan for VegeNet application in Werribee

At commercial maturity, a hand-held blower-vac was run along each treatment block to collect insects present in the crop. In addition, ten lettuces were randomly harvested from the central rows of each plot. Plants were cut at the base and placed in a plastic bag. Lettuce heads were weighed, and the number of insects on each head was recorded. Lettuces were given a shelf-life score of 1-5 (1= perfect, 5=very poor) following 7 days storage at 5ºC.

Trial 2

Dates: 13 January to 23 February 2016

Materials tested: VegeNet, Groshield fleece (18g/m^2), Aphid Net

This trial aimed to test whether germination of direct seeded lettuce during summer could be enhanced using netting materials, due to more even soil moisture levels. Babyleaf lettuce (Var. Celtic) was sown in a silty clay loam on a commercial vegetable farm in Bairnsdale in February 2016. Sections of netting were placed over the beds immediately after seeding.

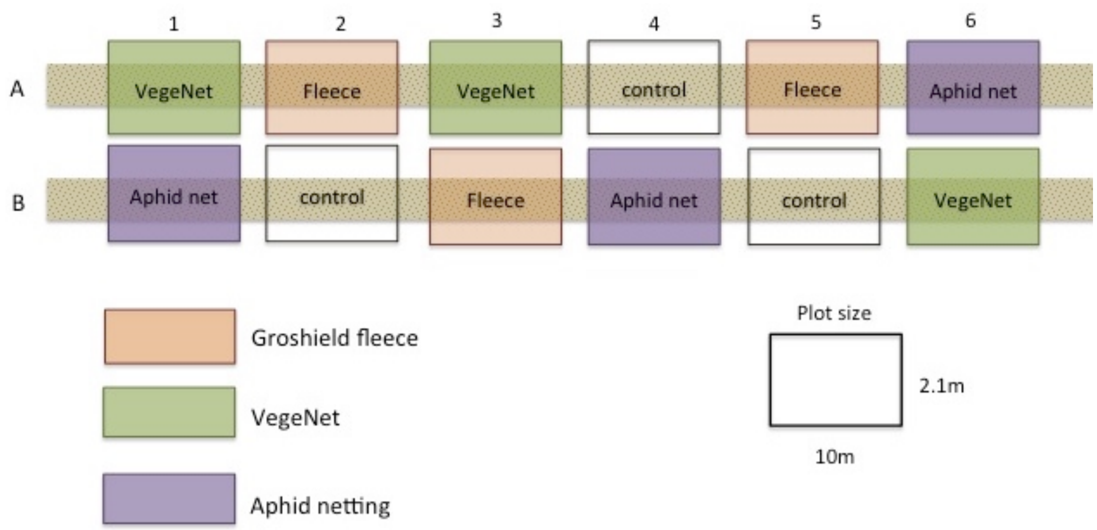

Figure 26. Trial plan for floating row covers on direct sown lettuce in Bairnsdale

At commercial maturity, a hand-held blower-vac was run along each treatment block to collect insects present in the crop. A 30cm x 30cm template was used to cut three sections from each treatment block, and the total number of seedlings was counted.

3.3. Results

3.3.1. Robinvale, Victoria

All of the floating row covers produced a warmer and more humid growing environment compared to the open field. Temperature in the open field barely exceeded 25°C and humidity stayed between 20 and 50% RH. In contrast, temperatures under the floating covers reached well over 30°C and even 35°C, while night time RH ranged up to 85-95%. The Groshield was the warmest and also most humid of all the materials, consistent with lower airflow through this material. This material increased minimum night temperatures by up to 2°C relative to the uncovered control.

Average fresh weights of lettuces grown under the Vegenet and Insulnet materials were the same as those grown in the open field, while those grown under the Groshield were approximately 30% smaller. No quality differences were observed between the lettuces, either at harvest or following postharvest storage (Figure 27).

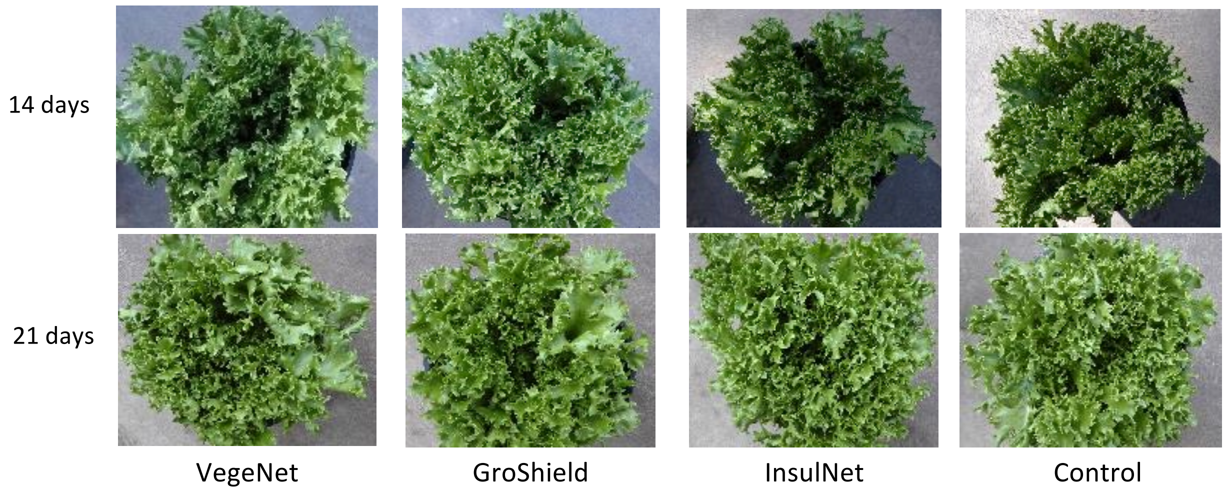

Figure 27. Whole lettuces grown under different types of floating row cover or left uncovered follwoing 14 or 21 days of storage at 5°C

3.3.2. Camden, NSW

Trial 1

Temperatures under the Insulnet cover were similar to those recorded in the open field. However, humidity stayed higher under the floating cover, with overnight values regularly approaching or reaching 100%RH. No desiccated plants were observed underneath the netting. However a number of dead areas occurred in the uncovered adjacent beds, where irrigation had not been sufficient to counteract hot summer temperatures.

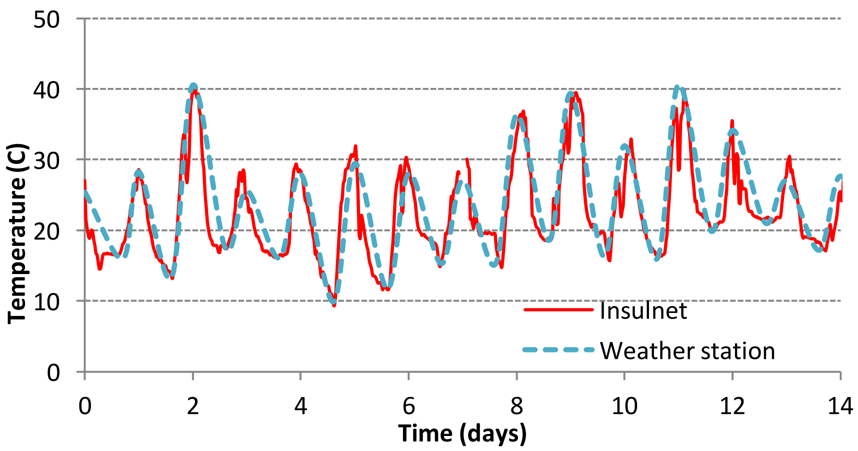

Figure 28. Temperatures recorded under Insulnet and at a nearby weather station during November 2014

Unfortunately, patchy establishment of the crop meant that yield was generally low. Yield appeared to be lower under the Insulnet cover than the open areas, although high variability meant that these differences were not significantly different (Figure 29).

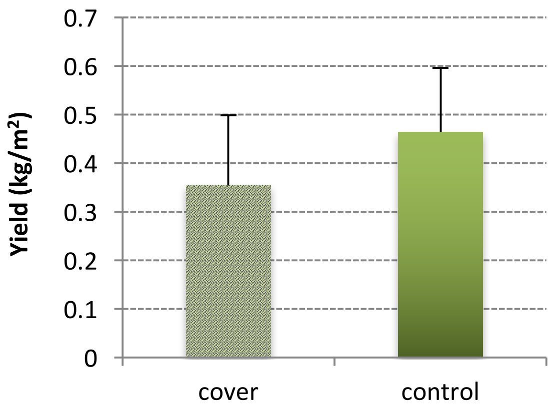

Figure 29. Yield of spinach grown under a floating row cover of Insulnet and in the open field (control), bars indicate the standard deviation of each mean value (n=5) (left) and patchy growth in the spinach crop.

Trial 2

Temperatures under the Insect Net and VegeNet were generally very similar to those in the uncovered control. However, the Insect Net did slightly mitigate against cold night temperatures, with both netting types slightly increasing daytime maximums (Figure 30). Relative humidity was slightly higher under the Insect Net but, as with temperature, such effects were marginal.

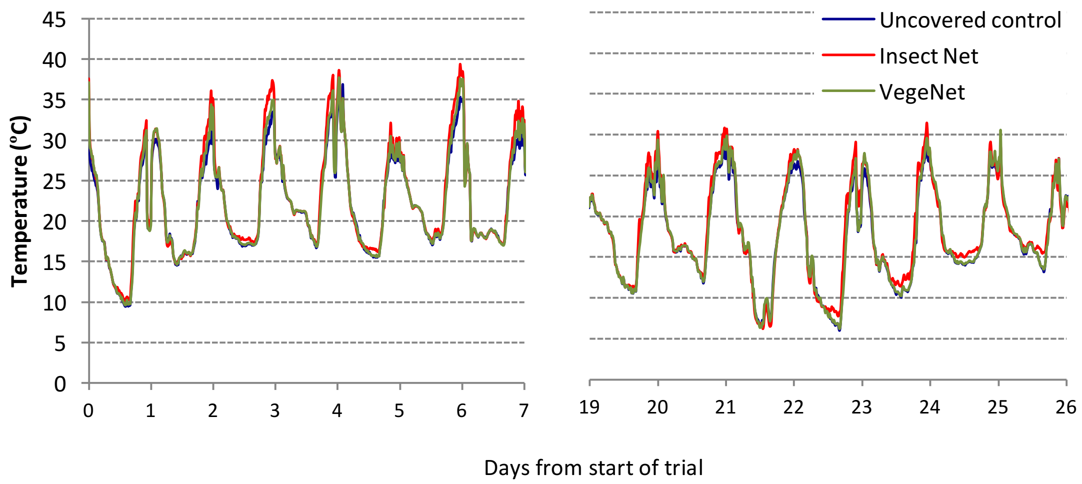

Figure 30. Temperatures during the first and last weeks of trial 2 in uncovered control plots, under Insect Net and under VegeNet floating covers

Although insects were found under both of the floating cover types, numbers were significantly reduced compared to the uncovered controls (Table 5). The ends of the nets were not very securely fastened for the trials, partly because the nets were loosened to allow for growth of the crop underneath. Had the nets been more securely fastened, results may have been improved.

Table 5. Total insects collected from the uncovered control, Insect Net and VegeNet covered crop

	Weevil	Moth	Caterpillars	Rutherglen bug	Flea beetle	Wasp / parasitoids	Thrips	Flies	Leafhoppers	Aphids	Beetles	**TOTAL**
Uncovered control	6	1	6	6	1	3	1	140	6	7	5	**182**
VegeNet	4	-	6	4	-	3	1	55	1	1	-	**75**
Insect Net	1	1	3	2	3	4	-	58	-	1	-	**73**

One potential issue noted with baby spinach growing underneath the VegeNet was that the cotyledons were narrow enough to poke through the mesh. The Insect Net mesh was too fine to allow this. When this was observed the nets were loosened and the cotyledons detached. However, this may have been unnecessary, as it was later observed that the cotyledons would naturally detach as the larger true leaves expanded under the netting.

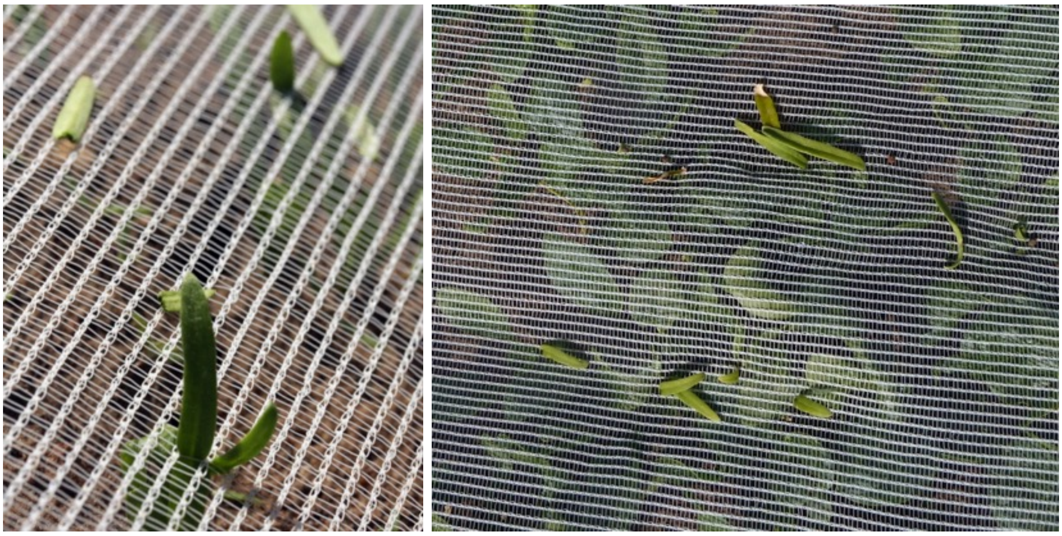

Figure 31. The spinach cotyledons could poke through VegeNet but tended to naturally detach as the plants grew

Yield results for this trial were severely affected by weeds. Although the grower had applied a pre-emergent herbicide before seeding, heavy rain the following day had clearly reduced its effectiveness. Moreover, weeds appeared to be favoured by the netting, especially the Insect Net. Yield of spinach as a percentage of total yield of vegetation was 91% in the uncovered control compared to 62% under VegeNet and only 29% under Insect Net.

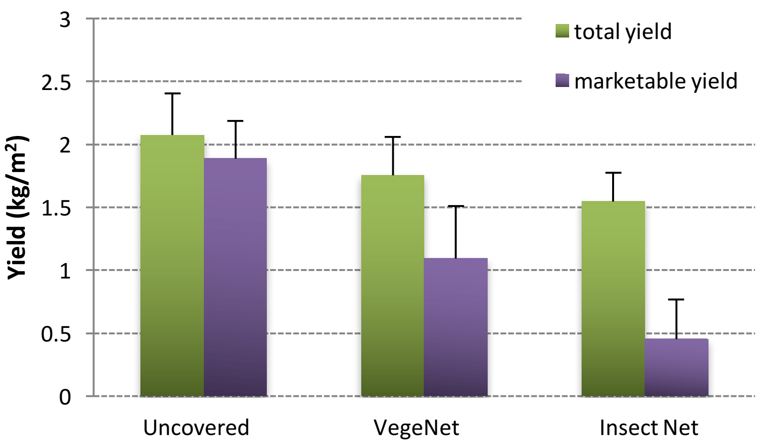

Figure 32. Total average yield of vegetation and actual marketable yield of spinach of crop grown in an uncovered bed (control), under VegeNet and under Insect Net. Bars indicate the standard deviation of each mean value.

Quality was also negatively affected by the netting materials, particularly the Insect Net. After 12 days of storage at 4, 7 or 10°C, the spinach grown uncovered in the open field remained acceptable at all storage temperatures. However, spinach grown under either type of netting and stored at 7 or 10°C was no longer marketable or consumable.

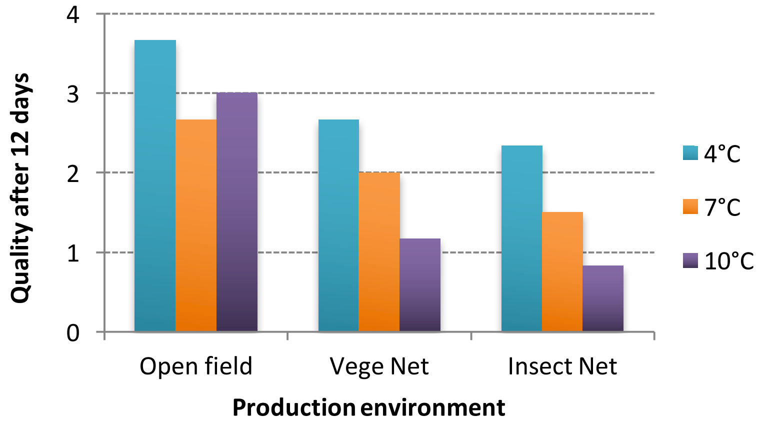

Figure 33. Average quality of spinach grown in the open, under VegeNet or under Insect Net after 12 days storage at 4, 7 or 12 °C (n=3). Quality subjectively assessed from Excellent (4) to very poor (0).

Trial 3

During the period of Trial 3, temperatures decreased and growing time increased. As the nights got cooler, differences in temperature between the different types of floating cover increased. Night minimum temperatures were up to 5°C higher under the Agryl than under the control or VegeNet. This material also increased daytime maximum temperatures, but as ambient temperatures were generally below 25°C this could have had a positive, rather than a negative effect on growth.

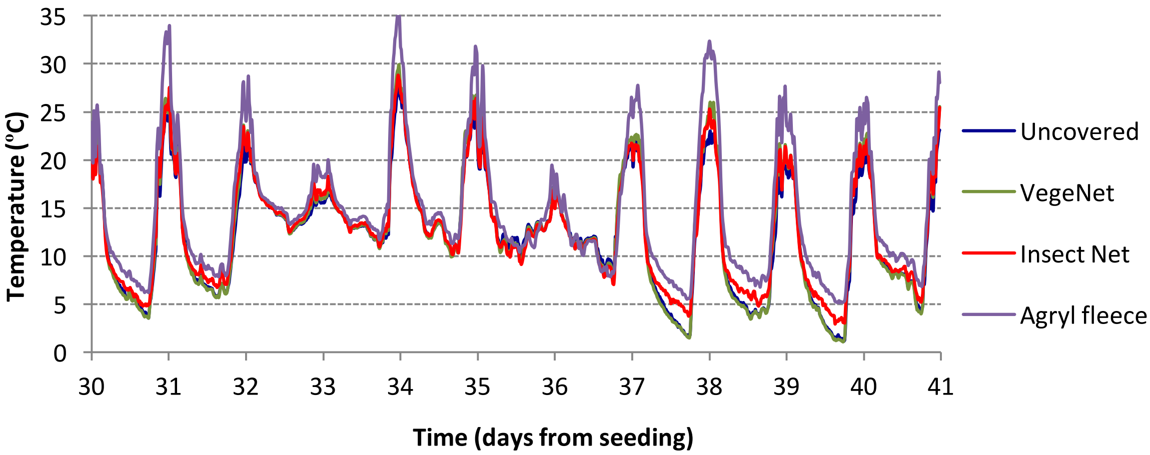

Figure 34. Temperatures during the later stages of crop growth of spinach in an uncovered control compared to under VegeNet, Insect Net and Agryl fleece

In this trial, the netting materials had been secured at the end of each block using a metal pin. There was also less pest pressure at this time compared to that in the previous trial. These factors may have helped to reduce the number of insects getting underneath, all three floating covers proving effective at reducing the numbers of insects in the crop (Figure 35).

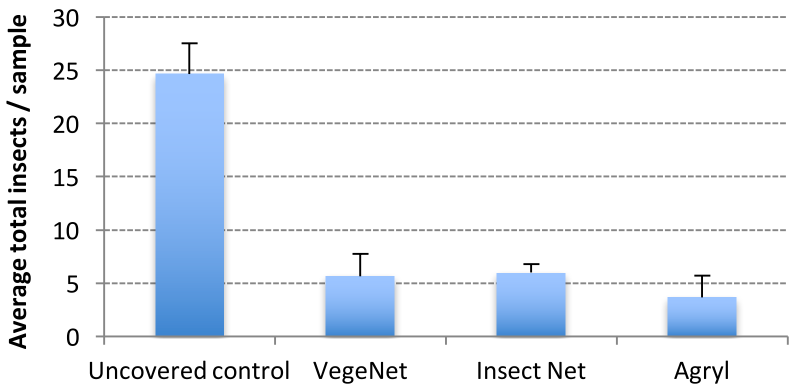

Figure 35. Average number of insects per sample (n=3) from the uncovered control compared to samples taken from under floating covers of VegeNet, Insect Net and Agryl fleece. Bars indicate the standard deviation of each mean value.

Again, growth during this trial was somewhat patchy. This was due to uneven spreading of fertiliser at planting. Also, heavy rain during the trial period leached nutrients from the sandy loam soil, with the result that plants had almost run out of fertiliser near the end of the cropping cycle. As in the previous trial, growth was also affected by weeds – particularly under the floating covers, which again had increased weed growth relative to the uncovered areas (Figure 36).

In this trial, samples from the uncovered areas contained 3.5% weed material compared to 8.8, 12.6 and 15.3% in the VegeNet, Insect Net and Agryl fleece treatments respectively.

Figure 36. Crop growth in the uncovered control (left) compared to that under fleece (centre) and Insect Net (right)

The favouring of weed growth under floating covers is an issue that will clearly need to be addressed if this method is to be used commercially. The soil under the covers was observed to be much damper than that in the uncovered areas. This was particularly the case with soil under the fleece and Insect Net. Increased soil moisture is likely to favour weeds. Reducing irrigation frequency could possibly address this issue, as well as reduce production costs.

All three floating covers reduced yield. However, as may be observed from the large error bars shown in Figure 37, results were highly variable. Spinach growing adjacent to the data logger position under the Agryl was the highest observed anywhere else in the crop (2.1kg/m^2). It was also almost entirely (97%) weed free. At this point the material was held slightly above the crop rather than resting on it, which may help explain this result.

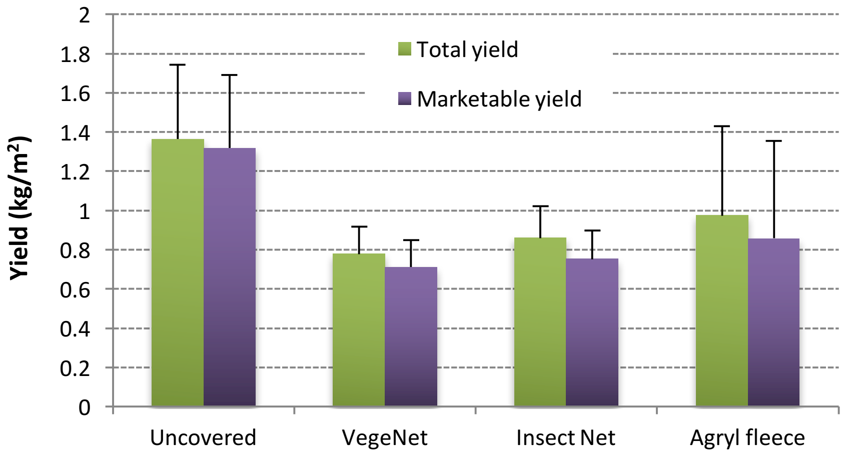

Figure 37. Total vegetative yield compared to marketable yield of spinach from the uncovered control compared to that grown underneath floating covers of VegeNet, Insect Net and Agryl fleece. Bars indicate the standard deviation of each mean value.

Although the results are not positive overall in terms of application of floating covers, they do suggest a number of refinements to the application method. The warming effect of the Agryl fleece certainly deserves further investigation for winter production. However, results may be improved if the material is slightly raised off the crop and, perhaps, irrigation frequency is reduced.

3.3.3. Werribee and Bairnsdale, Victoria

Trial 1

Lettuces covered with VegeNet were at least 29% larger than uncovered plants. This is likely due to the advanced maturity of netted plants, which appeared to be one week advanced compared to those grown in the open. Despite this faster growth under the nets, shelf life was unaffected by the netting treatments.

The results of vacuuming the crop indicated that although numbers of flies, leafhoppers and beetles were reduced in the covered crop compared to that left open, the number of Rutherglen bug was similar or increased. Although the VegeNet acted as a visual barrier, the ends of the netting were not secured, allowing Rutherglen bugs to penetrate underneath. Moreover, by excluding natural enemies, these insects may have been advantaged underneath the netting.

Despite the presence of insects under the net, the number of insects found actually on the lettuce after harvest was significantly reduced by VegeNet. This difference disappeared when the nets were removed five days before harvest.

Table 6. Effect of early removal or continuous cover of VegeNet on yield, quality and insect infestation of baby cos lettuce

	Head weight (g)	Quality (1-5)	Insects/head
Uncovered	196 c	2.2	2.4 b
Uncovered 5 days	272 a	2.5	2.0 b
Covered to harvest	256 b	2.8	1.1a
		n.s.	

Figure 38. VegeNet covers on baby cos lettuce in Werribee, and blower vac used to sample for presence of insects.

These results suggest that VegeNet improved yield without negatively impacting quality and shelf-life of baby cos lettuce. In this case yield was further increased slightly when the netting was removed several days prior to harvest. However, the potential benefits of any such removal may be counterbalanced by increased insect contamination of the crop.

Trial 2

Air temperatures reached over 40ºC a number of times through the trial, which had the potential to stress germinating seedlings. Extremes in temperature were increased under the fleece, and to a lesser extent under AphidNet, whereas temperature under VegeNet was similar or slightly cooler to the control (Figure 39).

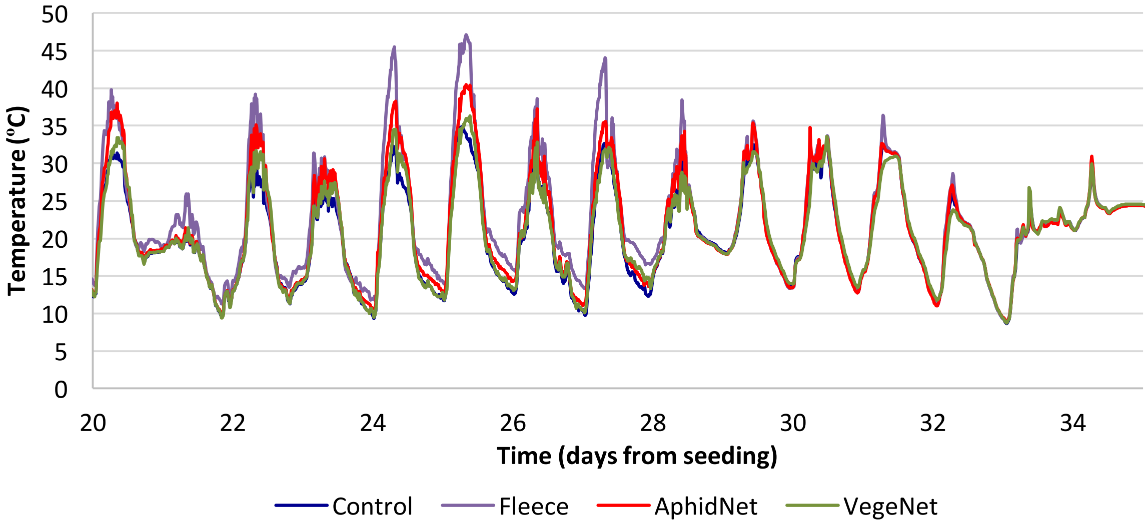

Figure 39. Air temperature in uncovered area (control) or under Groshield fleece, AphidNet or VegeNet.

Seedlings were kept very well irrigated during the trial, and were grown in a soil with a high water holding capacity. Therefore despite high temperatures which had the potential to quickly dry the soil and stress seedlings, seedling germination was very good in both netted and uncovered plots. There were therefore no differences between treatments in the number of seedlings that germinated (Table 7).

There were no significant differences between insect numbers in any treatment, although there was a trend towards fewer insects under netted treatments (Table 7). Insects were able to enter the crop because the ends of the netting were not secured, thereby allowing insects to enter.

Table 7. Establishment and insect levels in direct-seeded baby-leaf lettuce grown under floating row covers

Treatment	Insects/plot	Seedlings/m^2
Control (un-netted)	7.3	267
AphidNet	3.3	270
VegeNet	5.0	289
Fleece	2.3	264
	ns	ns

Figure 40. Floating row covers on direct-seeded lettuce in Bairnsdale, at planting (left) and harvest (right)

In this trial the crop was well managed, planted in fertile soil and provided with frequent irrigation. Despite high temperatures during the trial, floating row covers did not enhance germination. Row covers are more likely to increase summer germination of small seeded crops (such as lettuce) if the soil does not retain moisture well and/or the crop is infrequently irrigated.

3.4. Conclusions

It had been expected that the netting materials could provide some shade, reduce sunburn and maintain more even soil moisture. They could also reduce insect contamination in the crop. However, in these trials a number of issues were observed with use of floating row covers to produce leafy vegetable crops during summer.

While insect numbers were certainly reduced under the netting, insects were not prevented from entering the crop due to the ends being left open. The number of Rutherglen bugs was actually increased in one case, possibly due to these insects being protected from natural enemies by the netting. If prevention of insect contamination is a key objective, then nets must be securely fastened and left that way until harvest.

Weeds are often an issue in babyleaf crops, so thorough application of pre-emergent herbicides is essential. Where herbicide application was less than optimal, VegeNet and Insect Net increased weed growth. The warmer, moister environment under row covers can increase weed seed germination and growth rates, as well as making control with herbicide or hand weeding more difficult[20]. It is clear that effective weed control in beds prior to planting is essential if row covers are to be used.

[20] Bonanno AR. 1996. Weed management in plasticulture. HortTechnol. 6:186-189.

One of the key benefits of netting materials on vegetable beds is that soil moisture is retained, reducing irrigation requirements[21]. It is possible that irrigation requirements were reduced by using floating row covers, however this was not assessed in the current work. Positive effects of netting on seed germination were observed in trials conducted during winter. However, the results demonstrate that floating row covers are only likely to be of benefit for this purpose if other crop production factors are suboptimal. That is, if crops are being grown in sandy soil and/or irrigation is infrequent or uneven.

None of these trials resulted in significant increases in yield or quality when leafy vegetables were grown under netting. While these materials can provide some protection from insects, wind and strong sunlight, none of these factors was a major issue during the trials, and in fact the negative impacts of nets were more significant. Use of netting materials during summer for leafy vegetable crops is therefore not supported by these results.

[21] Hegazi HH, Sayed MA. 2001. Strawberry water use efficiency for different row-cover types and their economic assessment at newly reclaimed sandy soils. Alex. J. Agric. Res. 46:113-125.

4. Netting for winter production of leafy vegetables

4.1. Introduction

The main purpose of using floating row covers in summer is to protect plants from strong sunlight, dehydration and insects. In winter, the purpose is often quite different. Frost cloths, or fleece, are used to mitigate the effects of low temperatures. The slight warming these materials provide can protect plants from mild frosts, as well as provide a better growing environment for plants grown during winter months.

4.2. Method

4.2.1. Werribee, Victoria

The trial was setup at a commercial vegetable farm using beds planted two days previously with cos lettuce seedlings (Figure 41). Sections of 10m long Groshield (18g/m^2 and 30g/m^2) and fleece (50g/m^2, Elders) were laid out randomly on two seedbeds (Figure 42). The edges of the fleece material were secured using shovels of soil at regular intervals along the sides.

Figure 41. Initial trial setup in Werribee

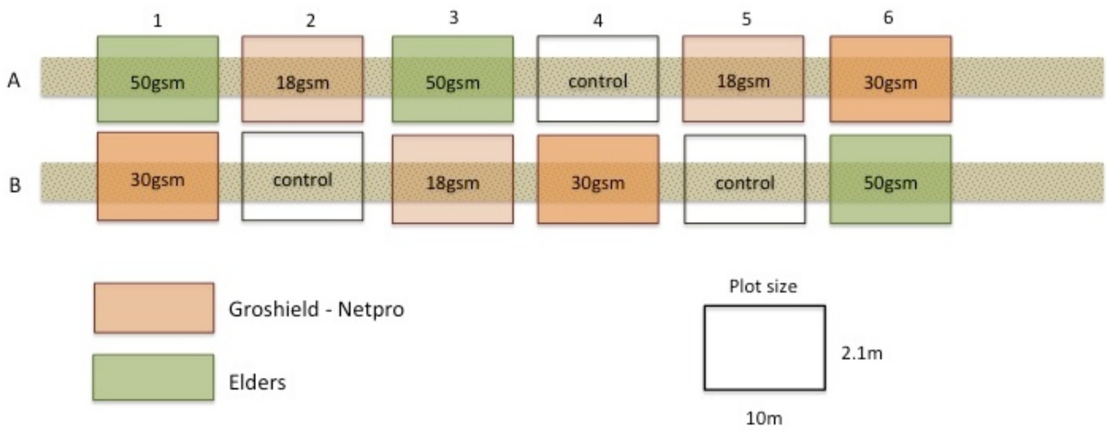

Figure 42. Trial plan in Werribee

Air temperature and relative humidity were monitored using Hobo UX100 outdoor loggers. These were fixed to short posts placed into the centres of each treatment area. Soil temperature was also monitored, using i-buttons inserted into tubes backfilled with perlite. The tubes were buried in the ground to a depth of approximately 6cm, this being the main zone of root development.

Figure 43. Installation of temperature loggers: A Hobo UX100 was used to monitor air temperature and RH, while an i-button buried inside a small tube monitored soil temperature (only lid visible at left, i-button at base of tube at right).

At commercial maturity, a hand-held blower-vac was used to collect insects present on 24 heads of lettuce. Ten lettuces were then randomly harvested from the central rows of each plot. Plants were cut at the base and placed in a plastic bag. Lettuce were weighed and assessed in terms of overall quality.

4.2.2. Camden, NSW

The trial was setup at a commercial vegetable farm using beds freshly seeded with oakleaf lettuce at a high density suitable for babyleaf production. Sections of 10m long Groshield (18g/m^2 and 30g/m^2), Agryl (19g/m^2, 22g/m^2 and 30g/m^2) and fleece (50g/m^2, Elders) were laid out randomly on two seedbeds (Figure 44). An additional two sections of Groshield (30g/m^2) were also used which were lifted off the crop using inverted pots; this was trialed because of the observation during the summer trials that growth was improved where the material was lifted off the crop (Figure 45).

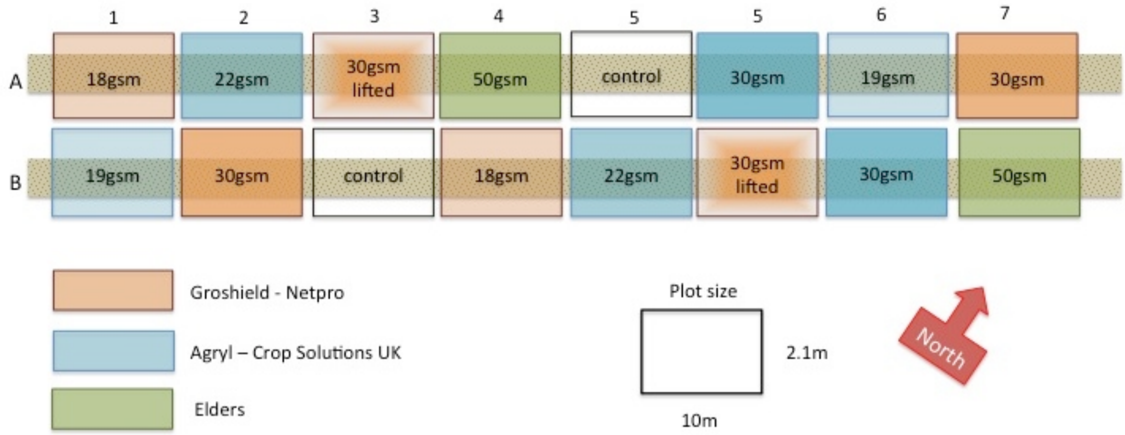

Figure 44. Trial plan in Camden

Figure 45. Initial trial setup in Camden showing sections of different types of fleece (left), and fleece lifted slightly off the crop using inverted plant pots (right).

Two harvests were conducted, at eight and ten weeks after seeding. The first was when the larger plants were just reaching commercial maturity. The covers were removed, and a hand-held blower-vac was run along each treatment block to collect insects present.

A 30cm x 30cm template was then used to harvest three randomly selected sections from each treatment block (total = 48 samples). Lettuce was harvested as previously described for spinach, with plants cut approximately 10mm from the ground level. Samples were returned to the lab, weighed, sorted, and segregated into units for evaluation of storage quality at 4, 7 and 10°C. Quality was assessed subjectively from excellent (4) to very poor (0) with OK (2) the limit of acceptability.

The second harvest was conducted two weeks after the first, when the uncovered control plants had reached commercial maturity. Another set of samples was cut from each treatment block, using areas not previously assessed. These samples were assessed in terms of yield only.

All data was analysed using CoStat statistical software. Means were separated using the Student-Newman-Keuls test for statistically significant differences at a confidence level of p=0.05.

4.3. Results

4.3.1. Temperatures

Ambient temperatures

Ambient temperatures, as measured at the nearest Bureau of Meteorology weather station, show large and significant differences between the two trial sites.

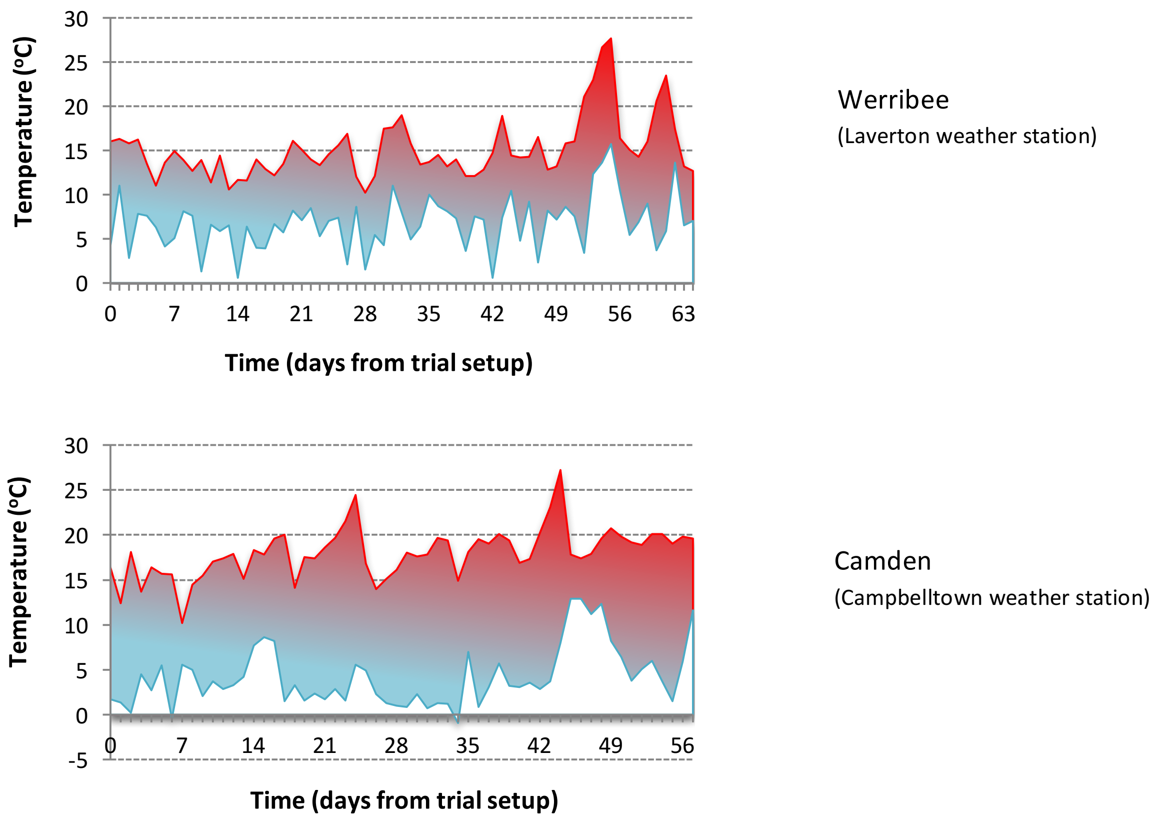

Figure 46. Daily maximum and minimum temperatures during the trial period for each of the sites, as recorded by the local Bureau of Meteorology weather station

During the trial period a number of frosts were experienced at the Camden site and two light frosts at Werribee. As expected, daily maximum temperatures were higher in Camden than in Werribee, even though night time minimums were lower.

Crop temperatures

All of the fleeces increased temperature and humidity compared to the uncovered control plots. This increase was 2-3°C overall. However, the amount that the fleece materials raised the temperature was not equal across the temperature range, being greatest at low temperatures and once ambient temperature increased to 20°C or more (Figure 47).

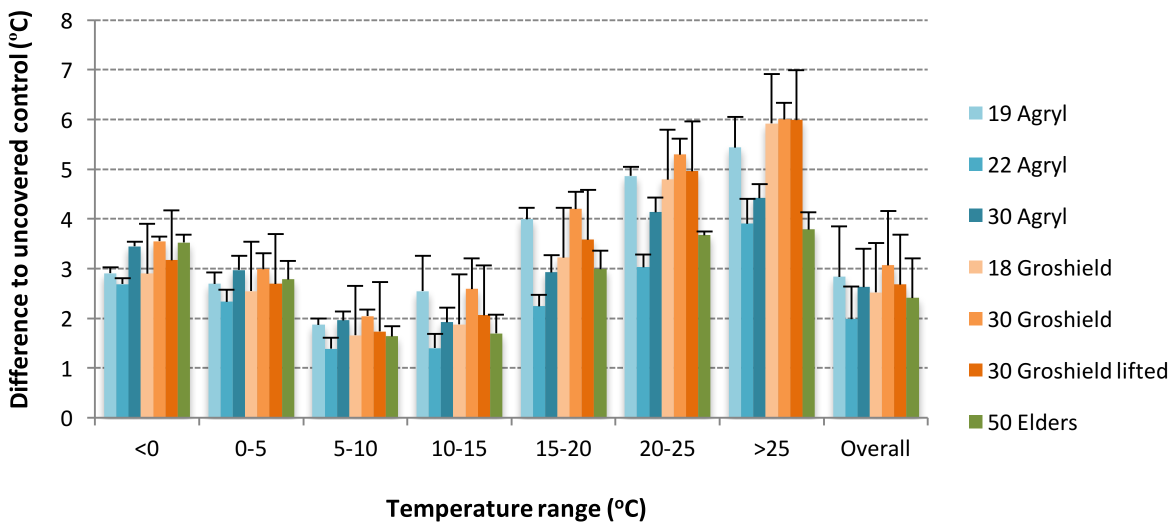

Figure 47. Difference in air temperature between the uncovered control and different types of fleeces, for temperatures recorded in 5°C bands. Bars indicate the standard deviation of each mean value.

Perhaps surprisingly, the weight of material made little difference to the resulting increase in temperature.

As with temperature, all of the fleece materials tested increased RH around the plants. This increase was greatest (although highly variable) when ambient RH was low (<70%). Overall, all of the fleece materials increased RH by around 5-15%.

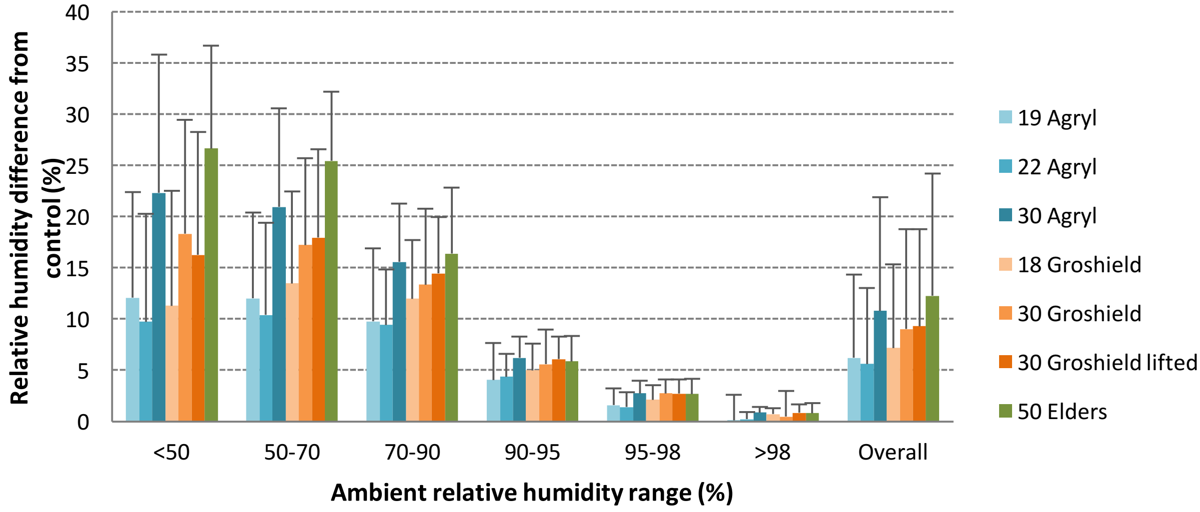

Figure 48. Difference in relative humidity (RH) between the uncovered control and different types of fleeces, for RH values recorded in different bands. Bars indicate the standard deviation of each mean value.

Soil temperatures were also elevated by all of the fleece covers. Soil temperatures generally increased by 2°C on average, regardless of fleece type or weight. The greatest increases occurred when soils were cold, being below 8°C. The exception occurred once ambient soil temperatures increased to 20°C or more. Under these conditions, the soil remained slightly cooler under the fleece, although this difference is unlikely to be statistically significant.

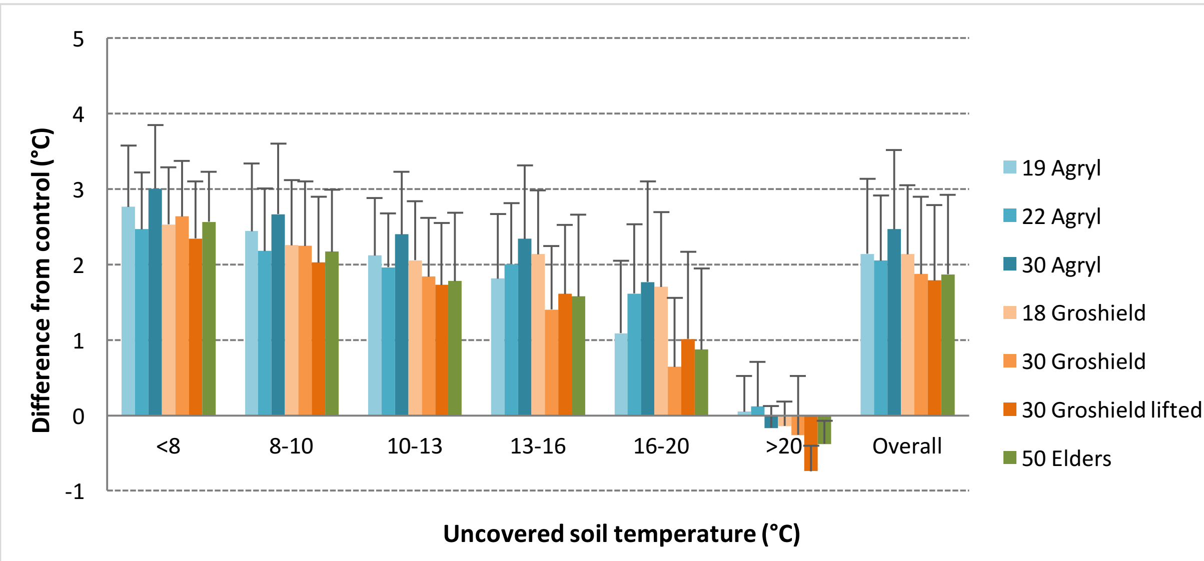

Figure 49. Difference in soil temperature between the uncovered control and different types of fleeces, for temperatures recorded in 2-4°C bands. Bars indicate the standard deviation of each mean value.

4.3.2. Yield

Werribee, Victoria

Well before harvest, there were clear differences between the lettuce grown under the fleece and those left unprotected. Yield of lettuce was significantly increased for the lettuces protected by either 18g/m^2 or 30g/m^2 Groshield compared to those left unprotected (Figure 51, Table 8). The lettuces grown under the 50g/m^2 material were intermediate. It was noted that some of the lettuces grown under this material appeared to have been damaged by the material. Some of the 50g/m^2 material came loose during the trial, due to being fractionally too narrow for the beds. This fleece had to be removed two weeks prior to harvest, as it could no longer be secured without crushing the lettuces underneath.

Figure 50. Size differences in cos lettuce grown without (left) and with (right) fleece protection materials in Werribee during winter months.

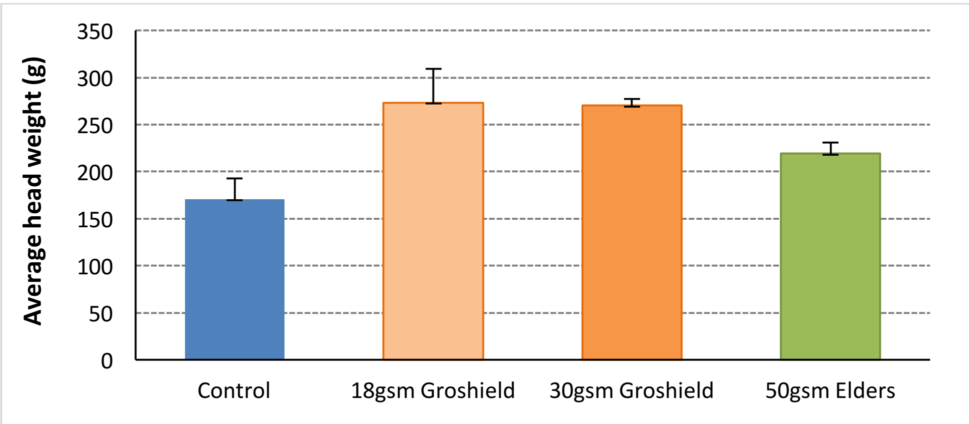

Figure 51. Average weight of lettuces grown in Werribee during winter 2015 and left uncovered, covered with 18 or 30g/m^2 Groshield or covered with 50g/m^2 frost protection material. Bars indicate the standard deviation of each mean value (n=3).

Table 8. Average weights of lettuces grown in Werribee under different frost protection materials. Letters indicate means that are statistically different (p<0.01)

Treatment	Weight (g)	
Control	171.6	c
18g/m^2 Groshield	273.3	a
30g/m^2 Groshield	270.7	a
50g/m^2 Elders	215.4	b

One issue experienced during the trial was loss of lettuces due to 'bottom rot' (*Rhizoctonia solani*). This appeared to increase under the 50g/m^2 covers; one of the three replicate plots was not assessed due to extensive collapse of the lettuces underneath. Incidence was similar in the uncovered controls and the plots with Groshield.

The lettuces appeared paler under the fleece materials, particularly the 50g/m^2 material. There was also some damage noted under all of the fleece materials where the covers had restricted crop growth. Loosening the covers more than once during crop growth may have avoided this damage, although over-loosening may also increase wind rub from flapping material.

Camden, NSW

Even a week after seeding, differences started to appear between the covered and uncovered plots. Germination was increased, with seedlings under the fleece materials developing rapidly compared to those left uncovered.

Figure 52. Growth of lettuces in the open compared to under fleece, one week after seeding (left) and at initial harvest (right). Poor germination and stunted growth can be seen in the lettuces left uncovered at the front of the picture, compared to the lush growth of those under the fleece (right)

The uncovered lettuce were still extremely small at harvest 1. Germination in these plots was uneven, and the lettuces themselves appeared stunted. After a further two weeks (harvest 2), they were approximately the same size as the lettuces in treated plots at harvest 1, indicating that the fleece treatments brought harvest forward by approximately 2 weeks (Figure 53).

Figure 53. Second harvest of babyleaf lettuce from the Camden site

However, during this two week period, lettuces in the plots covered with fleece approximately tripled in size. Sunny conditions, regularly reaching 20°C during the day, undoubtedly assisted this rapid growth.

The fleece treatments were all approximately similar, with the exception of the 50g/m^2 material. As noted in Werribee, this material had some negative impacts on growth, likely due to being too heavy for the plants underneath. Even after the material was removed, these plants failed to fully recover and catch up with those protected using lighter materials.

Lifting the fleece off the plants appeared to have some benefits, although these plots were very patchy according to the high and low points of the material. Results from the Agryl and Groshield were statistically similar, although a trend to increased growth under the Agryl may be observed. There appeared to be no benefits in using heavier weight materials: the lightest (and cheapest) of the materials tested gave the best results overall (Figure 54).

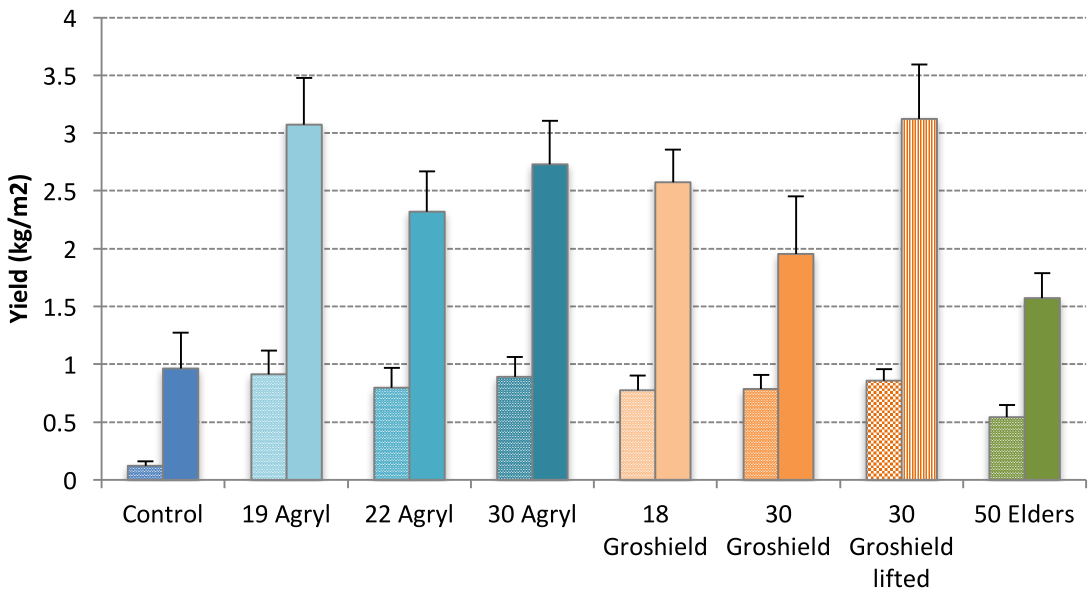

Figure 54. Yields from an initial and second harvest at Camden, harvests conducted two weeks apart using different sections of the bed. Bars indicate the standard error of each mean value (n=8)

Yield from the control plots was significantly lower than that from all the other treatments at harvest 1, and significantly lower than all except the 50g/m^2 treatment at harvest 2 ($p<0.01$) (Table 9). Stored samples were assessed subjectively after 1 and 2 weeks at 5°C. After one weeks storage the control was graded as significantly lower quality than the other samples ($p=0.01$), however after 2 weeks all samples were considered unacceptable.

Table 9. Yields from an initial (harvest 1) and second (harvest 2) harvest at Camden, harvests conducted two weeks apart. Letters indicate means that are statistically different (p<0.01)

Treatment	Yield (g/quadrant)	
	Harvest 1	Harvest 2
Control	11.1 b	87.0 c
19gsm Agryl	82.4 a	277.0 a
22gsm Agryl	72.0 a	209.1 bc
30gsm Agryl	80.3 a	246.0 ab
18gsm Groshield	64.6 a	232.0 ab
30gsm Groshield	70.9 a	230.8 ab
30gsm Groshield lifted	77.2 a	281.3 a
50gsm Elders	49.1 a	141.6 ab

Insects

Insects were generally low at both the Werribee and Camden sites, as would be expected during winter months.

Significant vegetable weevil larvae damage was noted in two of the plots in Werribee (30g/m^2 and 50g/m^2 fleece), although no actual larvae were found. It is possible that reduced penetration of insecticides and/or warmer conditions under the fleece might favour insects emerging from soil underneath the covers.

In total, 41 pest insects were recovered from the control plots, compared to 3, 16 and 0 insects from the 18g/m^2, 30g/m^2 and 50g/m^2 treatments respectively. Most of these were aphids, as well as small numbers of Rutherglen bug and leafhoppers.

In Camden, less than 6 insects/plot were found for all of the lettuces covered by fleece materials. Higher numbers were found in the control, which averaged 25 insects/plot. Green leaf hoppers were the dominant pest, particularly in the controls. Brown sowthistle aphids and thrips were found in all treatments, although in lower numbers under the frost protection materials.

4.4. Conclusions

All of the fleece materials tested increased yield of lettuces grown over winter. The fleeces significantly increased both air temperature and soil temperature, and slightly raised humidity around the crop.

The fleece materials also reduced the number of insects within the crop, which could affect both crop damage and contamination of packed product. It appears that the best strategy may be to use these materials over winter until air temperatures increase to a regular daytime maximum of approximately 20°C. After this time they may be removed to allow the crop to 'harden up' and possibly develop a richer colour.

There were few differences noted between the materials, with the exception of the $50g/m^2$ fleece, which gave less positive results. It is notable that the lightest materials – which are also the cheapest – gave just as good a result (if not better) as heavier fabrics.

5. Netting for capsicum production

5.1. Introduction

Capsicums are a warm weather crop. They are often planted in spring and summer, with harvest extending into winter, although production can continue virtually year round in the Bundaberg region. While high temperatures increase growth, they can also result in increased blossom end rot and sunburn, both of which cause significant losses. High temperatures can also cause flowers to abort and fruit to drop[22].

Floating covers and netting have been widely reported to increase growth and yield of capsicums grown in hot climates[23]. Shading with row covers can increase marketable fruit by preventing sunburn and reducing blossom end rot[24]. They can also reduce water use[25] and even help prevent infection with certain diseases[26].

A series of trials were conducted examining the use of various floating row covers with capsicums grown in Silverdale, NSW and Bundaberg, Qld.

5.2. Method

5.2.1. Silverdale, NSW

Capsicum seedlings were planted at a commercial vegetable farm in Silverdale, Western Sydney, NSW in November 2014. Three large sections of VegeNet were applied soon after initial fruit-set. Each piece covered four rows, with two pieces 20m long, and the third piece 10m long (Figure 55). Hobo UX100 external temperature and RH data loggers were placed under the netting and in the uncovered control and recorded temperature and relative humidity for a period of the trial.

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[22] Deli J, Tiessen H. 1969. Interaction of temperature and light intensity on flowering of *Capsicum frutescens* var. *grossum* California Wonder. J. Am. Soc. Hort. Sci. 40:493-497.
[23] Rylski I, Spigelman M. 1986. Effect of shading on plant development, yield and fruit quality of sweet pepper grown under conditions of high temperature and radiation. Sci. Hort. 29:31-35.
[24] Alexander SE, Clough GH. 1998. Spunbonded rowcover and calcium fertilization improve quality and yield in bell pepper. HortSci. 33:1150-1152.
[25] Moller M, Assouline S. 2007. Effects of a shading screen on microclimate and crop water requirements. Irrig. Sci. 25:171-181.
[26] Brown JE et al. 1989. Black plastic mulch and spunbonded polyester row covers as method of southern blight control in bell pepper. Plant Dis. 73:931-932.

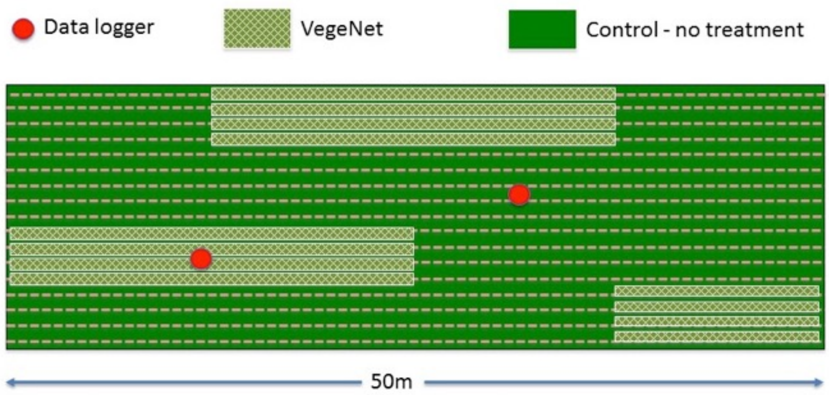


Figure 55. Trial plan of VegeNet application on capsicums grown in Silverdale, NSW.

Figure 56. VegeNet on capsicum plants grown in Silverdale, NSW. Weeds became a problem (right) soon after the trial commenced.

At harvest maturity (12 March 2015), total yield and fruit marketability was estimated using 6 plants per plot. All fruit were stripped from each plant, weighed and graded according to colour and marketability.

5.2.2. Bundaberg, Queensland

Trial 1, Autumn 2015

The trial was set up using a commercial capsicum crop. Seedlings were planted at the beginning of February 2015. The nets were installed four weeks later, which allowed time for the plants to establish. At this stage plants were approximately 40cm high and starting to flower.

Two 30m long sections each of VegeNet and Insect Net were used in the trial. As the Insect Net was relatively heavy for a floating cover, it was suspended over the plants using cloche hoops. These are used for low tunnels, particularly for cut flower production. The hoops can be unclipped on one side to allow access to the crop. The cloche hoops were placed at 2m intervals, and clamped the net quite tightly.

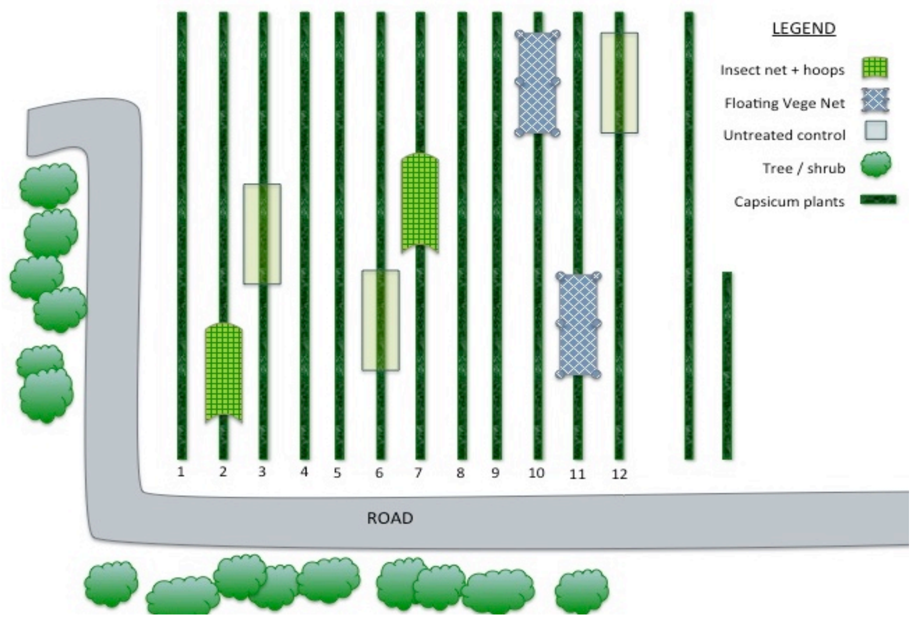


Figure 57. Trial plan for capsicums in Bundaberg

Yellow sticky traps were placed inside and outside each netting type to monitor insects. Temperature and humidity data loggers were installed within the uncovered crop and under each netting type.

Figure 58. VegeNet (left) was draped directly on capsicum plants while the Insect Net (right) was secured using low cloche hoops

Five days before the first commercial harvest the netting was removed and 2 x 5m long sections in the centre of each unit were vacuumed using an electric blower-vac. Insects were collected and kept for counting and identification (Figure 59).

Figure 59. Temperature logger installed within the crop and collecting insects using an electric blower-vac

Yield and quality was assessed using eight randomly selected plants from each treatment block (including the untreated controls). These plants were strip-picked of all fruit, including those below marketable size (n=16 / treatment). The harvested fruit were individually weighed and assessed in terms of insect damage, colour and quality. Total yield, total potential yield and marketable yield were calculated for each treatment.

Trial 2, Winter to Spring 2015

In Bundaberg, harvesting of the autumn capsicum crop usually finishes by mid-July. While the spring crop is planted at about this time, there is a break in production between August and November. While capsicum production in Bowen covers much of this period, there is a period of several weeks when supply is short in the market. Increasing the temperature around capsicum plants could bring harvest forward. Earlier maturation, particularly if it increased the number of red fruit, could be a major benefit of using frost protection materials.

Another potential benefit is the protection afforded by frost protection materials to wind. Bundaberg is prone to strong winds and storms. Previous trials with insect netting demonstrated that protecting the plants from wind resulted in healthier looking plants with improved fruit quality.

This trial therefore tested the application of different weights of fleece for advancing the maturity of winter grown capsicum in Bundaberg. Fleece material was applied in 20m sections to 1 week-old capsicum seedlings on a commercial vegetable farm in Bundaberg. Four separate rows of capsicum were used, with uncovered buffer rows in-between those used for the trial (Figure 60). As this was a winter crop, capsicums were planted in a single row, rather than a double row as is usual during warmer months. The edges of the fleece were secured with soil (Figure 61).

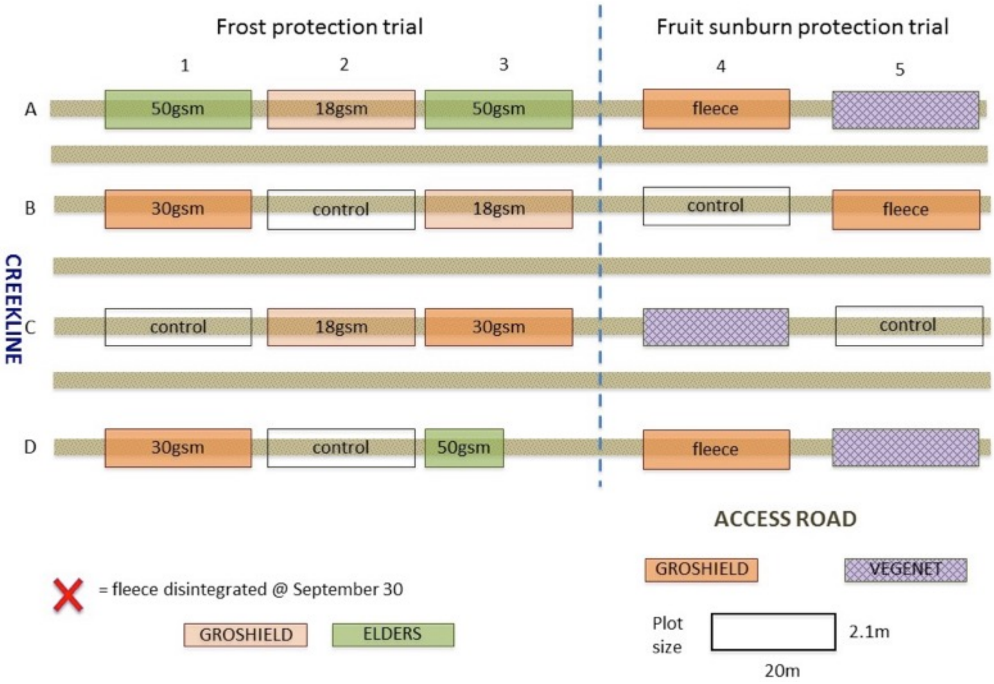


Figure 60. Winter - spring trial plan in Bundaberg

Figure 61. Initial trial setup in Bundaberg

From spring to autumn, sunburn can reduce the marketability of capsicum fruit. Therefore additional netting and fleece material was installed on adjacent areas of the same crop three weeks before harvest to test effectiveness for sunburn prevention.

Air temperature and RH was monitored using Hobo UX100 outdoor loggers. These were fixed to short posts placed in the centres of each treatment area. Soil temperature was also monitored, using i-buttons inserted into tubes backfilled with perlite. The tubes were buried in the ground to a depth of approximately 6cm, this being the main zone of root development.

A number of crop assessments were conducted in Bundaberg. This was partly due to storm and wind damage, which destroyed some of the fleece materials being tested. Assessments were:

1. 3/9/15 – Six plants per treatment unit cut off at the base. Fruit counted and weighed. Plant leaves and stems weighed.
2. 22/10/15 – Early harvest of mature green fruit. Six plants per treatment unit of remaining treatment blocks strip picked. Fruit were counted, weighed and quality graded.
3. 10/11/15– Commercial harvest of mature green and red fruit. Six plants per treatment unit of remaining treatment blocks strip picked. Fruit were counted, weighed, quality graded and colour recorded.

Trial 3 - Summer 2015

Previous trials found benefits from floating row covers including increased yield and quality of fruit, and a reduction in insect pests. However floating row covers can disrupt farm practices such as spraying. Ideally, they should be placed on the crop as late as possible, but early enough to still allow for the benefits that the row covers provide. This trial tested the application of VegeNet at three crop stages;

1. Start of flowering — 11th November 2015
2. After fruit set — 9th December 2015
3. Three weeks before harvest — 18th December 2015

Sections of single rows 10m long were covered using VegeNet at the appropriate times. Fruit fly traps (Biotrap®) were placed in one plot per treatment and were checked fortnightly for fruit flies. Air temperature and humidity were recorded as previously.

All fruit from six plants per plot were harvested on 13 January 2016. Fruit were weighed and assessed for colour (red, red-green, neutral, green-red or green), quality grade (perfect, good, ok, and non-saleable), and defects such as rots.

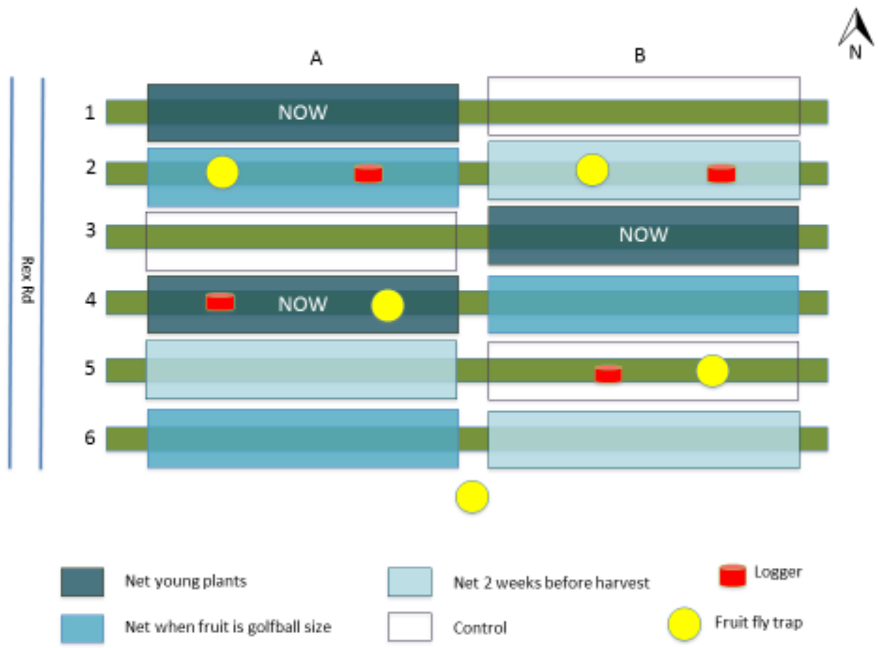


Figure 62. Trial plan for testing the optimum time for application of VegeNet to a capsicum crop in Bundaberg

Figure 63. Size of plants when nets were first installed (left, top), second installation (right, top) and fruit three weeks prior to harvest when final installation was completed (below)

5.3. Results

5.3.1. Silverdale, NSW

Maximum temperatures were slightly raised under VegeNet, which was likely due to reduced air movement around these plants. Minimum temperatures were similar between netted and uncovered plots. Minimum relative humidity tended to be higher under the VegeNet between irrigation events, as the uncovered plots began to dry out.

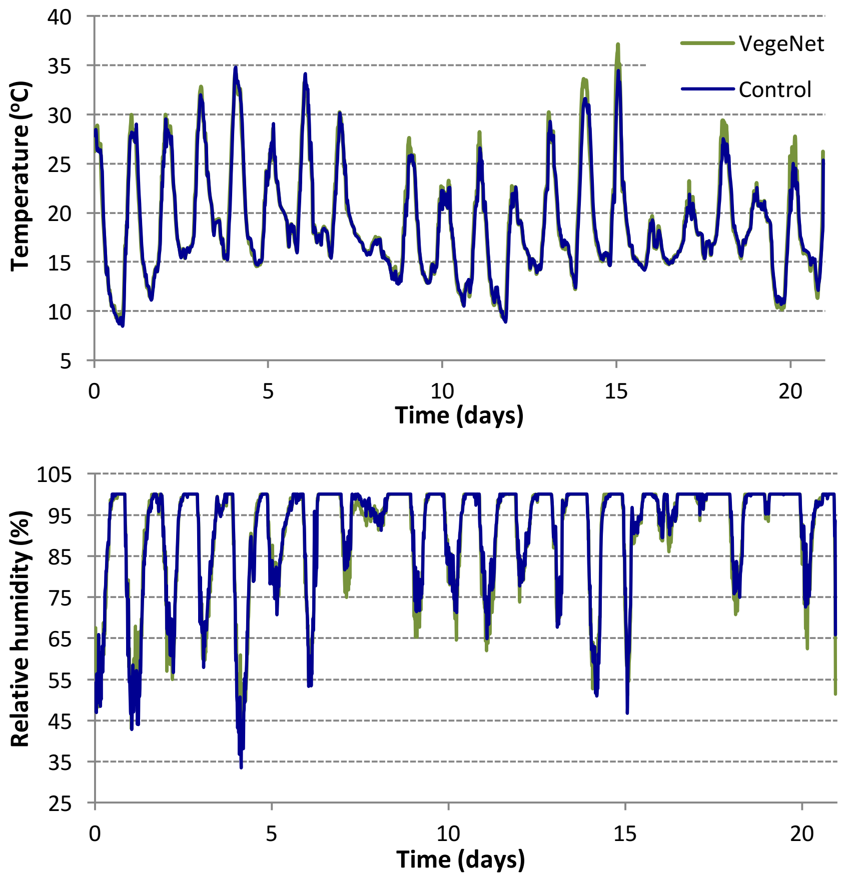


Figure 64. Temperature (top) and relative humidity (below) of capsicums grown under VegeNet or left uncovered (control)

Capsicums grown under VegeNet had a similar total yield to that of the uncovered controls. However marketable yield was 37% higher in plants grown under VegeNet (Figure 65). Common defects that deemed fruit unmarketable included sunburn, deformed fruit, and thrips damage.

VegeNet reduces fruit sunburn by diffusing strong sunlight. The plants were also protected from strong wind under the VegeNet, potentially resulting in less deformed fruit. The netting also helped to protect the plants from insects, both as a physical and as a visual barrier. This may have reduced damage by heliothis and other larger pests, and possibly even smaller insects such as thrips through acting as a visual barrier.

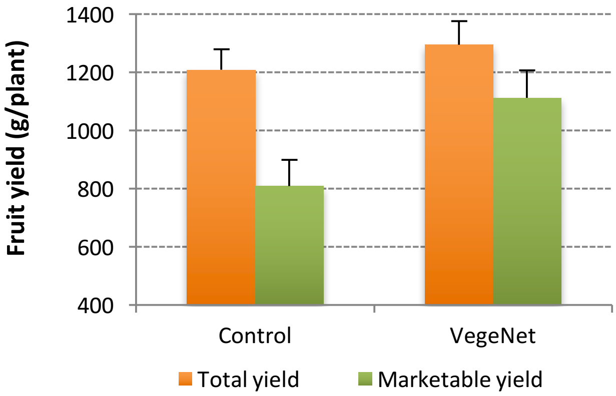


Figure 65. Total and marketable yield of capsicums grown under VegeNet and an uncovered control

5.3.2. Bundaberg, Queensland

Trial 1, Autumn 2015

Temperatures under the VegeNet were generally similar to those in the open field. In some cases night temperature was slightly (~1°C) higher under the net, but this was not always the case. Temperatures under the hoops with Insect Net were also similar to the untreated control at night. However, in this case the netting reduced daytime maximums by up to 5°C. This was particularly apparent during hotter weather (>30°C) and where there was a large swing between day and night extremes.

Perhaps surprisingly, relative humidity (RH) was slightly lower under the VegeNet than in the open field, at least during evening periods. Under the VegeNet it rarely exceeded 95%, whereas in the field, RH approached 100%. While this is a small difference, this could result in a difference in leaf wetness. It seems possible that the netting reduces overnight settling of dew on the crop, which could provide some benefits in terms of disease control.

Results from the sticky traps suggested that there was an increase in the number of thrips under the Insect Net. An average of 52 thrips/trap were recovered from under the hoops compared to 15 thrips/trap from the open field. However, aphids and jassids were found on the sticky traps in the open field whereas none were found on those under the insect net.

Similar results were found in the samples removed by vacuuming. As shown in Table 10 there was a greater diversity of insects in the open field, whereas the Insect Net with hoops system appeared to favour thrips. This may be because of reduced penetration of insecticides, or because the protected environment inside the hoops was more suitable for these pests.

Table 10. Average numbers and types of insects recovered by vacuuming a 5m section of capsicum plants

	Thrips	Whitefly	Aphid	Jassid	Click beetle	Heliothis
Open field	2	7	2	1		
Hoops	5	3				4
VegeNet	3	3			1	

While no measurements were taken to establish plant health, capsicum plants grown under either type of netting appeared to be healthier and stronger than those grown in the open field (Figure 66). The leaves were dark and undamaged, whereas those in the open tended to have curled edges and showed signs of wind / abrasion damage. It was also noticeable that although there were significant numbers of sunburned fruit in the open, none were observed under the netted areas. There were also more signs of healed insect damage in the open field (Figure 67). These benefits may be due to reduction of wind damage (the site was quite exposed and near the coast) as well as filtering of direct sunlight.

Figure 66. Plants grown under netting (left) appeared healthier and more robust than those grown in an open field (right)

Figure 67. Damage observed on plants grown in the open field; sunburned fruit, healed insect damage (weevil) and leaves with dry, curled edges

While total yield was not affected by the netting, there was a significant increase in marketable yield from plants under the VegeNet compared to those from the open field. This was partly due to a reduction in sunburn and other types of damage. Thrips damage was also greatest in the untreated control fruit, while the number of fruit with rots was increased under the InsectNet. Total potential yield was also greatest under the VegeNet, with the total number of fruit increasing from 8.5 to 9.3 per plant.

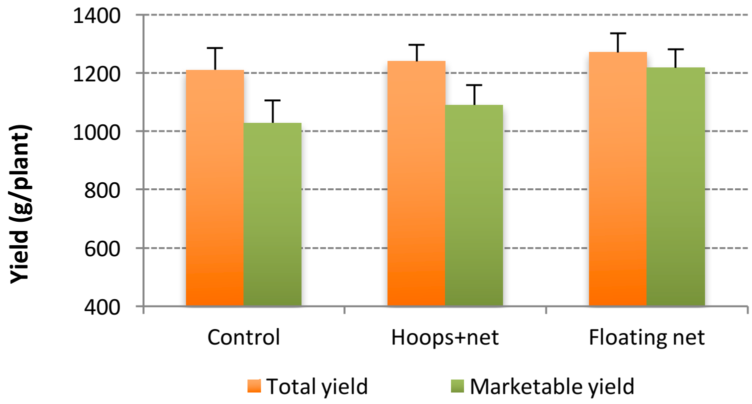


Figure 68. Total yield and marketable yield from capsicum plants grown in the open, under hoops covered with InsectNet and under a floating cover of VegeNet

While this study was limited by reliance on a single harvest (whereas commercially there may be 2 – 4), it appeared that fruit grown under VegeNet matured faster than those from other treatments, with an approximate doubling in the number of red fruit.

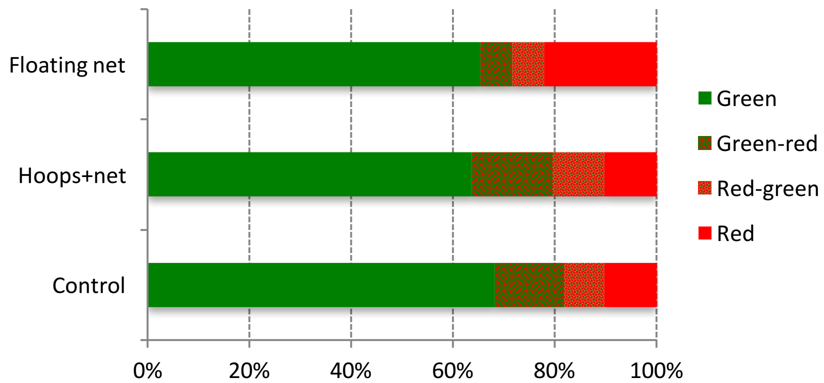


Figure 69. Proportion of harvested capsicums which were green, mostly green, mostly red or red

These results suggest that a floating row cover can improve quality and yield of capsicums. It also seems likely that insecticide and water use could be reduced under this system.

Trial 2, Winter to Spring 2015

Strong winds damaged fleece material, with some pieces completely disintegrating and others with large holes. The material that was least able to withstand the conditions was the 50g/m^2 fleece, which was completely shredded by wind and rain. Perhaps surprisingly, it was the lightest, 18g/m^2 fleece, which remained the most intact at the end of the trial.

Although all of the fleece materials significantly increased plant size (Table 11) only the 18g/m^2 fleece increased the number and total weight of fruit on each plant. It should be noted that at the time of this assessment all 50g/m^2 fleece and one 30g/m^2 fleece had been destroyed by a severe weather event, assessment was conducted approximately two weeks later.

Table 11. Mid season assessment of plants with immature fruit. Letters indicate means which are significantly different ($p<0.05$, n=18)

	Shoot weight (g)		No. of fruit / plant	
Control	295.7	a	6.7	a
50gsm fleece	419.2	b	7.8	a
30gsm fleece	406.2	b	7.6	a
18gsm fleece	419.2	b	10.8	b

Figure 70. The plants covered by the fleece were noticeably taller than those left uncovered

No further assessments were conducted of the 50g/m^2 treatments as the covers were destroyed. One of the 18g/m^2 and half of a 30g/m^2 treatment were also damaged so as to be partly or fully ineffective.

At the early harvest of green fruit significant differences in fruit yield and quality were again found for the plants protected with 18g/m^2 fleece compared to the uncovered controls. Plants protected with 30g/m^2 fleece were intermediate. The total number of fruit per plant did not vary significantly among the treatments, demonstrating that yield differences were due to larger fruit size on the protected plants.

This difference carried through to commercial maturity. The plants covered with the 18g/m^2 fleece had both significantly more marketable size fruit (>120g) and more high quality fruit than any of the other treatments ($p<0.05$). The number of fruit graded as 3 or less was halved in the 18g/m^2 fleece.

Applying fleece or netting 3 weeks prior to harvest did not improve any of the yield or quality attributes assessed in this trial ($p>0.05$). The number of sunburned or damaged fruit was extremely low regardless of treatment. It appears possible that floating covers applied shortly before harvest could provide greater benefits during the peak of summer, when sunburn is more of an issue for capsicum producers.

Table 12. Early and commercial harvest of capsicum plants with protective covers applied to young plants (cool weather protection) or mature plants (sunburn protection). Letters indicate means which are significantly different ($p<0.05$, n=12 or 18).

	Total yield of fruit (kg)				No. of fruit ≥120g/plant				No. of grade 1 or 2 fruit/plant			
	Early		Mature		Early		Mature		Early		Mature	
Control	1.28	a	1.65	a	5.2	a	7.3	a	2.7	a	4.4	a
18g/m^2 fleece	1.83	b	2.35	b	8.3	b	10.2	b	6.1	b	8.1	b
30g/m^2 fleece	1.54	ab	1.66	a	6.4	ab	6.4	a	4.4	b	4.7	a
Sunburn - control			1.88	ab			7.5	a			4.6	a
Sunburn fleece			1.89	ab			7.7	a			4.5	a
Sunburn - VegeNet			1.95	ab			7.3	a			4.6	a

The number of red or turning fruit was slightly increased under the 18g/m^2 and 30g/m^2 fleece materials (Figure 71). However, results were highly variable between individual plants, so differences were not statistically significant ($p<0.05$). It is likely that maturity was not advanced under the fleece materials due to the higher yield of fruit on these plants.

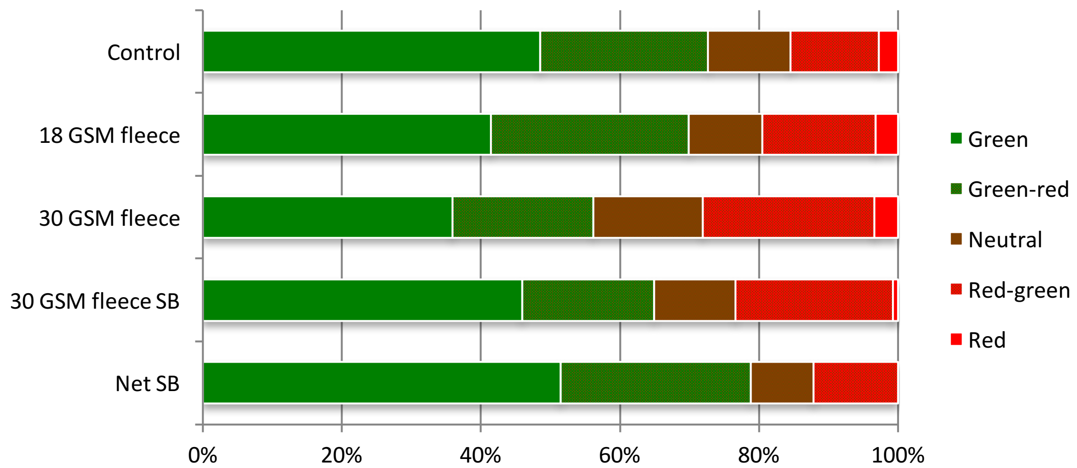


Figure 71. Percentage of the crop classified as green, mostly green, 50/50, mostly red or red from plants protected with fleece or netting early or late (SB) in crop development.

The fleece materials did not advance crop maturity as much as had been hoped. However, there were clear benefits in terms of quality and yield from placing the fleece over the crop. It is interesting to note that the lightest material also provided the best result in terms of yield, although the heavier fleece did increase the number of red fruit.

Trial 3 - Summer 2015

Plants were looking large and healthy until a severe amount of rain and wind hit the site in early January. Unfortunately this resulted in a large amount of fruit falling off the plants, as well as rotting fruit on the plants. However this did provide an opportunity to assess the performance of VegeNet under these conditions.

Temperature and humidity was altered under the netting. When air temperatures were below 35°C, temperatures under the netting were slightly higher than the control, while at temperatures above 35°C the shading effect of the netting kept temperatures lower. Humidity was higher under the netting at low humidity levels, but lower under the netting when humidity was above 75% (Figure 72).

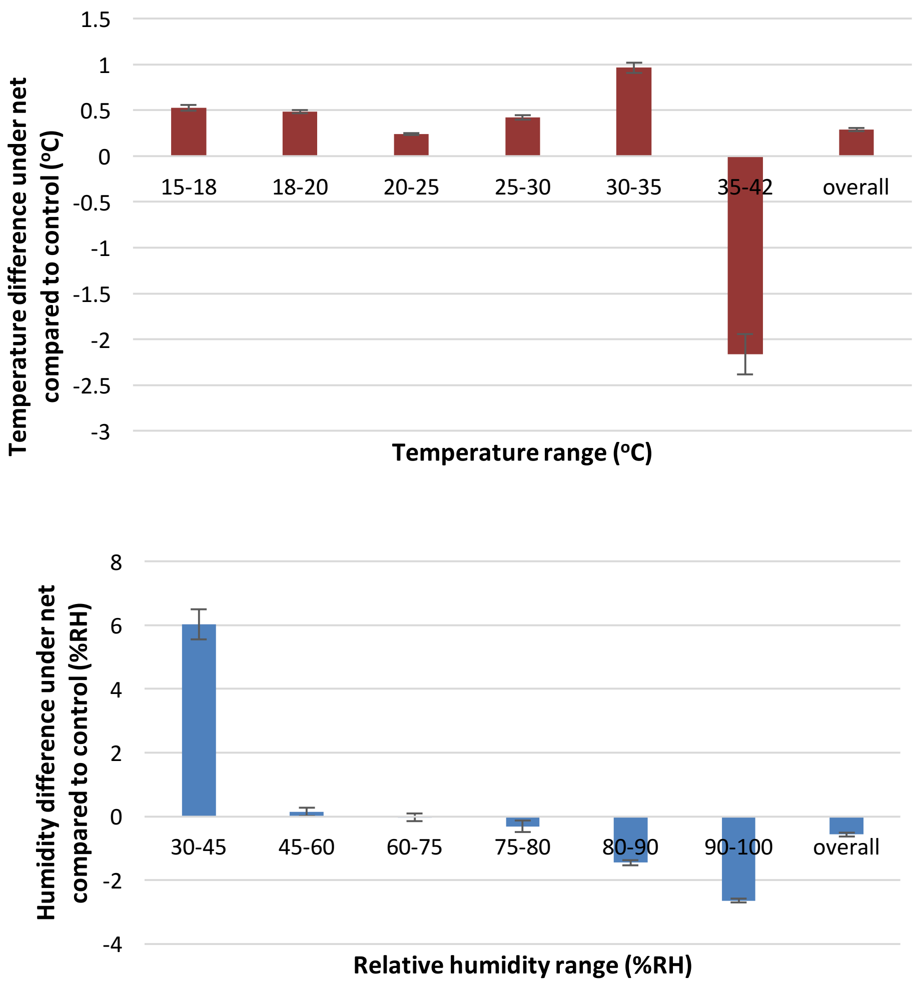


Figure 72. Effect of a floating row cover of VegeNet on temperature and humidity inside a capsicum crop

Fruit maturity was most advanced in plants that were netted the earliest, with 51% of fruit categorised as red, compared to only 34% in the uncovered control. Plants that were netted when older had slightly more red fruit than the control, while netting plants three weeks before harvest did not advance maturity (Figure 73).

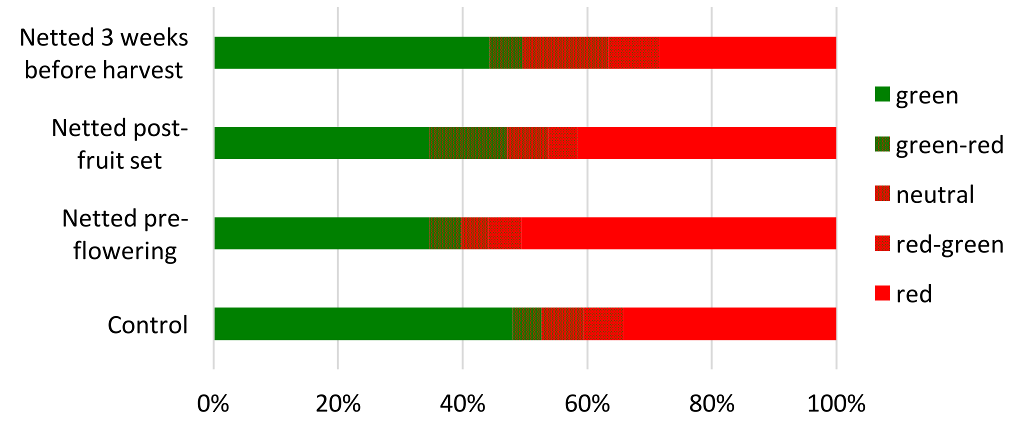


Figure 73. Colour stages of capsicum fruit covered with VegeNet at three different growth stages as compared to an uncovered control.

Total yield was higher in all netted treatments, although this was not statistically significant. Marketable yield was also higher under all VegeNet treatments, however only significantly higher (by 52%) under plants netted post-fruit set (Figure 74).

Individual marketable fruit weight was 17% higher in plants that were netted pre-flowering. There were less rotten fruit on netted plants, and plants that were netted pre-flowering had half the number of rotten fruit compared to the control. Netted plants tended to have more grade 1 fruit, although this was not statistically significant (Table 13).

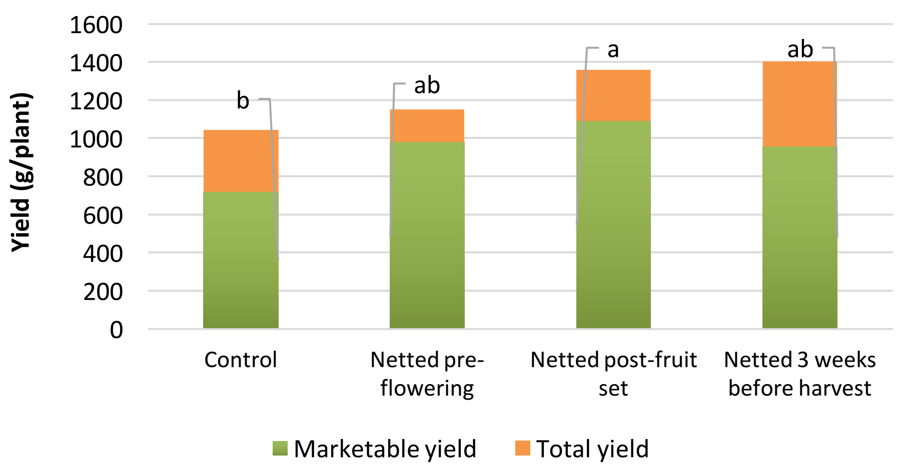


Figure 74. Marketable and total yield of capsicums covered with VegeNet at three different growth stages as compared to an uncovered control. Letters indicate marketable yields that are significantly different (p <0.05). Total yields were not significantly different.

Table 13. Quality parameters of capsicums when covered with VegeNet at three different growth stages as compared to an uncovered control. Means in columns with different letters are significantly different (p < 0.05).

	Average marketable fruit weight (g)	Rotten fruit (%)	Grade 1 fruit (%)
Control	177 b	38.1 a	8.5
Netted at flowering	207 a	18.6 b	17.5
Netted after fruit set	187 ab	28.6 ab	17.2
Netted 3 weeks before harvest	179 b	27.1 ab	10.8
			ns

Fruit fly populations in the uncovered control and nearby tree were relatively low in the earlier stages of the trial, but had a major increase towards the end following a wet period. Even under these significant fruit fly populations, plants netted before flowering or at the green fruit stage (young and old plants) were well protected from fruit fly. No fruit fly were trapped under the plants that were netted after fruit set although some were trapped under nets that were put on young plants, possibly as a result of the net becoming unsealed (Figure 75).

When plants were netted only 3 weeks before harvest fruit fly trap numbers remained reasonably constant well after netting application; fruit flies may already have been present in the crop.

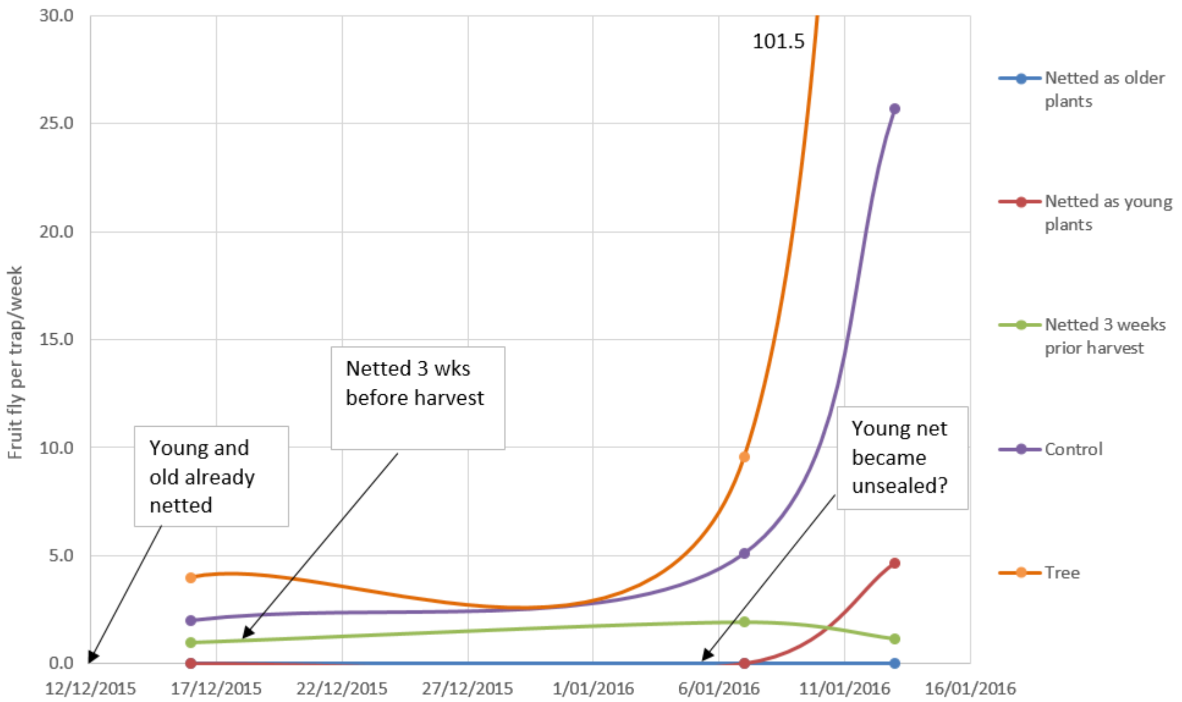


Figure 75. Number of trapped fruit flies in capsicums netted before flowering (young), at the green fruit stage (old) or 3 weeks before harvest compared to an un-netted control and nearby tree.

Application of VegeNet either when plants were just starting to flower or soon after fruit-set advanced fruit maturity and tended to increase average fruit weight and marketability of capsicums grown over the summer. Furthermore, netting applied at or before fruit-set helped to reduce the probability of infestation by fruit fly. Yield, quality and reduced fruit fly pressure benefits were maximised when netting was applied earlier, while little benefit was apparent when VegeNet was applied 3 weeks before harvest.

Fewer rotten fruit were found on plants netted earliest, although it is difficult to attribute this directly to the VegeNet. As these fruit were more mature, any rotten fruit may have detached from the plants before assessment.

5.4. Conclusions

Capsicum plants grown under a floating row cover of VegeNet had improved yield and better fruit quality. Floating row covers reduced the incidence of sunburn and could lower temperatures around the plants during hot weather by providing some shading. The results were best when the row covers were installed when plants were still young, with less significant gains when the covers were installed late in development.

Plant growth was also enhanced under fleece type materials. Although plant maturity was not brought forward by as much as had been hoped, fruit maturity was somewhat advanced under these materials. Durability was an issue, especially under the windy conditions common in Bundaberg.

Although difficult to measure, perhaps one of the most striking effects of both the fleece and the VegeNet was improved plant growth. Plants that were protected from strong light and wind had larger leaves and appeared generally larger and healthier, without the curled leaf edges and sprawling habit of plants that were grown in the open. While this did not always directly result in improved yields, it seems likely that healthy plants will be less susceptible to disease and more resistant to pest attack. By reducing losses of moisture from the soil, plants protected using floating covers are likely to need less irrigation, while all of the covers tested proved effective at deterring one of the most significant pests of capsicums, Queensland fruit fly.

6. Netting for chilli production

6.1. Introduction

Chillies are extremely susceptible to infestation by fruit flies, such as Qfly. The loss of pre- and postharvest chemical controls has left growers with few options for control of this pest. Moreover, growers using integrated pest management (IPM) techniques to control other pests are reluctant to spray insecticides which will disrupt an otherwise well functioning IPM program.

Floating row covers had proven effective at excluding Qfly from capsicums. Moreover, the increases in yield and quality helped justify the cost and labour involved. If similar results can be shown for chillies, which are a relatively high value (although labour intensive) crop, then floating covers may provide a cost effective solution to the Qfly issue. They could also help exclude other pests of chillies, including virus vectors such as aphids.

Trials were therefore conducted in Silverdale, NSW and Bundaberg, Qld, examining the use of floating covers for chilli production.

6.2. Method

6.2.1. Silverdale, NSW

A combination of Cayenne and Birdseye chilli seedlings were planted on 16 November 2015 at a commercial vegetable farm in Silverdale, south-west Sydney. Following the issues with weeds the previous season, the seedlings were planted in single rows through black plastic mulch. Ideally plastic mulch would be combined with drip irrigation. However, as this system was not available plants were irrigated with overhead sprinklers. This proved effective as the soil on site has a high content of clay and organic matter, so excellent water holding capacity.

Establishment was initially slow due to high temperatures stressing the young seedlings. The netting materials were therefore not installed over the crop until 19 January 2016. At this stage plants were flowering, but had not yet set fruit. Three x 20m long sections of VegeNet, Insect Net and Vent Net were draped over the plants in a randomised design (Figure 76) and the edges secured with shovels of soil (Figure 77). A Biotrap fruit fly trap with Cuelure wafer was installed under each section of netting as well as in the control blocks. A temperature and RH datalogger (Hobo, UX100) was placed under one of each of the four treatments, and set to record values every 15 minutes.

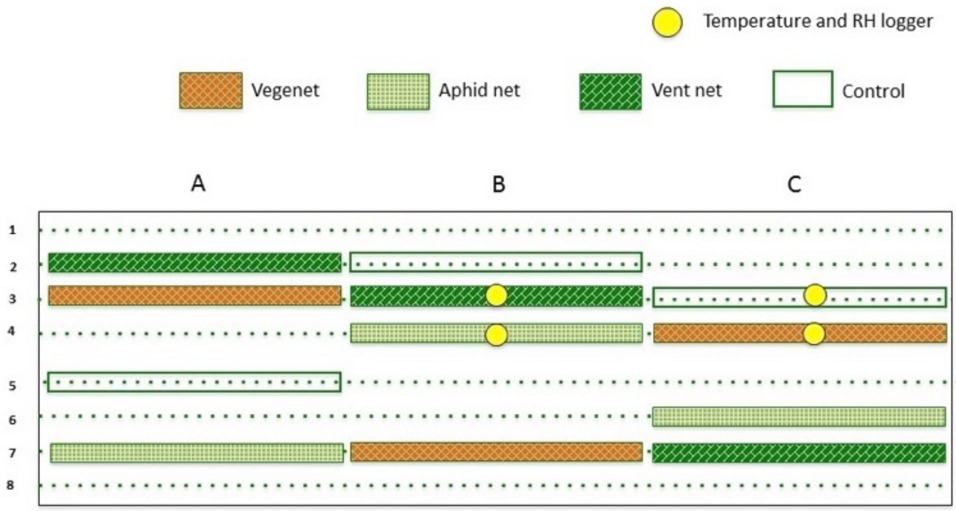


Figure 76. Chilli trial plan in Sydney. Total block length approximately 60m, outer rows used as buffers only.

Figure 77. Aphid net (L, top), VegeNet (R, top), Vent Net (L, below) and a Biotrap located in the crop.

Although Queensland fruit flies (Qfly) are endemic in the area where the trial was conducted, the lack of suitable natural hosts means that populations generally remain low. We therefore conducted a number of inundative releases of Qfly to test whether the netting materials were effective at excluding this pest. The flies were obtained from the Macquarie University Department of Biological Sciences, reared from pupae supplied by the NSW DPI fruit fly colony at Camden. Approximately 2,000 fertile adult (minimum 10 days from pupal emergence) male and female flies were released on four occasions between February and April, 2016.

Catches in the traps were recorded weekly. While each release resulted in a spike in trap catches, by the end of the trial there appeared to be a resident population of flies present in the crop.

Yield and quality of Birdseye and Cayenne chillies were assessed on 18 March and 31 March respectively. Three plants per treatment unit were cut off at ground level and all the fruit stripped from the plant. The fruit were then weighed, sorted by colour and scored for marketability.

6.2.2. Bundaberg, Queensland

Two or three-week old Cayenne chilli plants in a commercial planting in Bundaberg were covered with 10m lengths of either VegeNet or 18g/m^2 fleece on 10 December 2015. In each of the two and three week-old plants there were two replications of each treatment. Temperature and RH were monitored as previously.

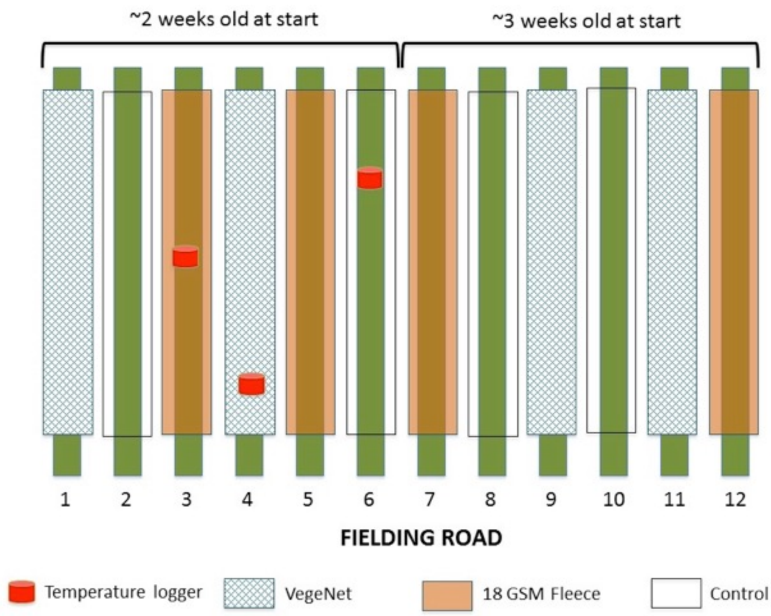


Figure 78. Trial setup for Cayenne chilli plants in Bundaberg

Yield and quality were assessed on 10 February 2016. Six plants from each treatment plot were cut at soil level, with whole shoot weight, fruit weight, fruit colour and other quality attributes recorded.

Figure 79. Trial setup on unsprayed Cayenne chillies in Bundaberg, QLD.

6.3. Results

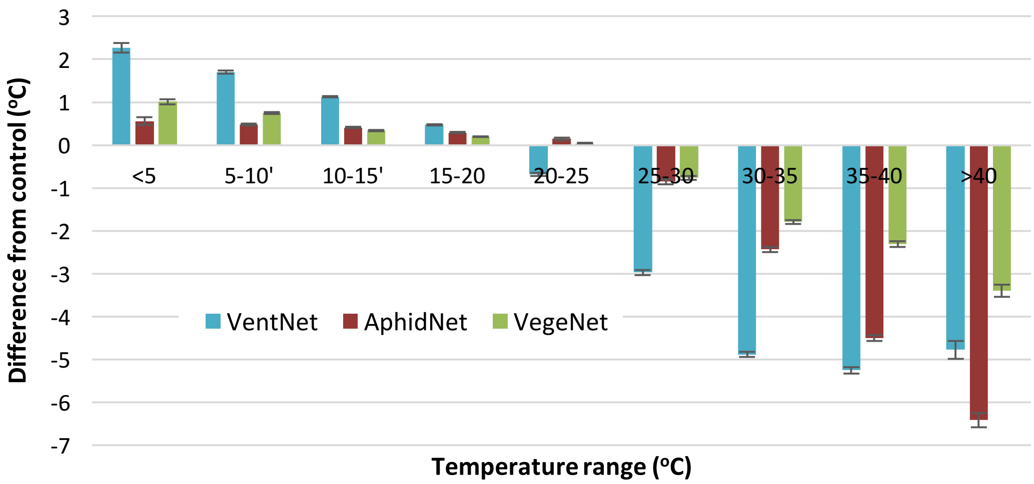
6.3.1. Silverdale, NSW

Temperatures were increased slightly under netting when ambient conditions were 20°C or less. Perhaps surprisingly, this effect was most noticeable under the Vent Net, even though this might be expected to have a higher rate of air movement than the other materials tested. Above 25ºC, temperatures were markedly lower under netting, with Vent Net and Aphid Net reducing temperatures by up to 6ºC. Relative humidity was increased under netting, most notably below 70% RH (Figure 80).

Yield varied considerably between plants. As a result, differences between the netting types were not significant (Figure 81). Differences in fruit maturity were also relatively small, and not significant, although there was a slight trend to increased numbers of red Cayenne chillies in the uncovered controls and Vent Net treatments.

Between 4 February and 27 April a total of 2,963 flies were captured by the three traps located in the uncovered control areas. This compares to 839 flies under the Vent Net, 26 flies under the VegeNet and 7 flies under the Aphid Net. However, 22 of the flies captured by traps under the VegeNet were in a single trap in the last three weeks of the trial. At this time inter-row weeding had damaged the net, and some gaps had been opened up. Over the majority of the fruit production period, only four flies were caught inside the VegeNet material.

Also in the last few weeks of the trial, large aphid populations were found underneath the Aphid Net. This is consistent with previous research, which has indicated that populations of aphids can increase rapidly under permanent nets because the net acts as a physical and visual barrier against predators and parasitoids[16]. These increases were not observed in the larger mesh size materials or in the controls, indicating that natural biological control agents were able to keep the aphids under control under these materials.



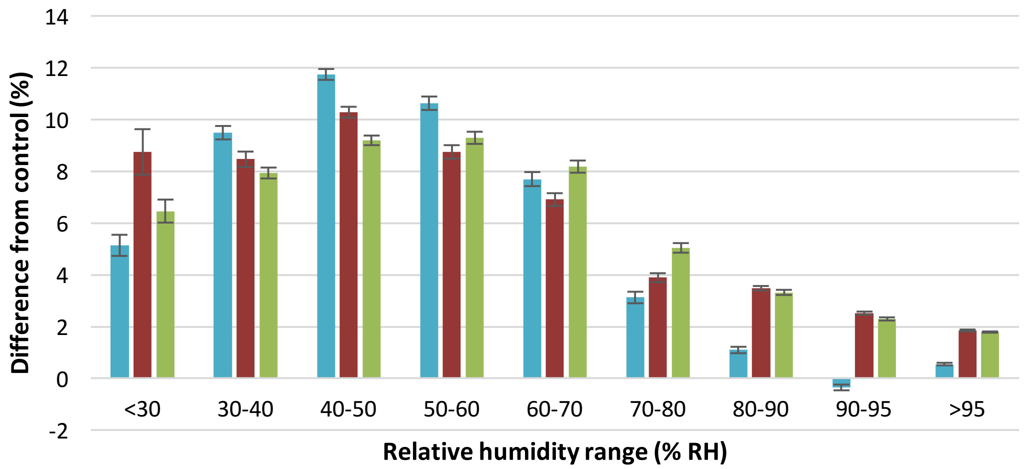


Figure 80. Temperature (top) and RH under different types of netting compared to the uncovered control plots. At temperatures above 25°C the netting cooled the chilli plants, whereas at temperatures below 20°C they provided some slight warming. Relative humidity was higher under the nets than in the ambient environment, especially between 30-70%RH.

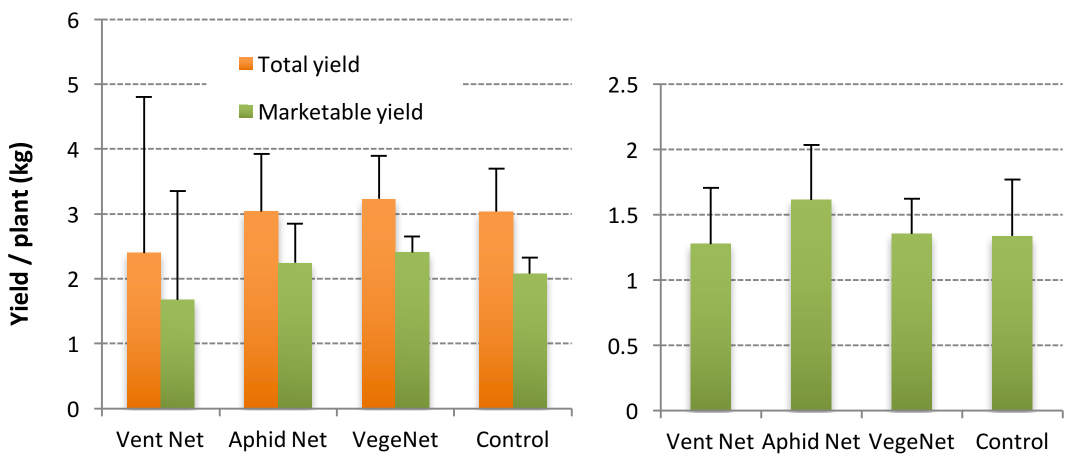


Figure 81. Total and marketable yield per plant of Cayenne chillies (left) and Birdseye chillies (right). Bars indicate the standard deviation of each mean value (n=9)

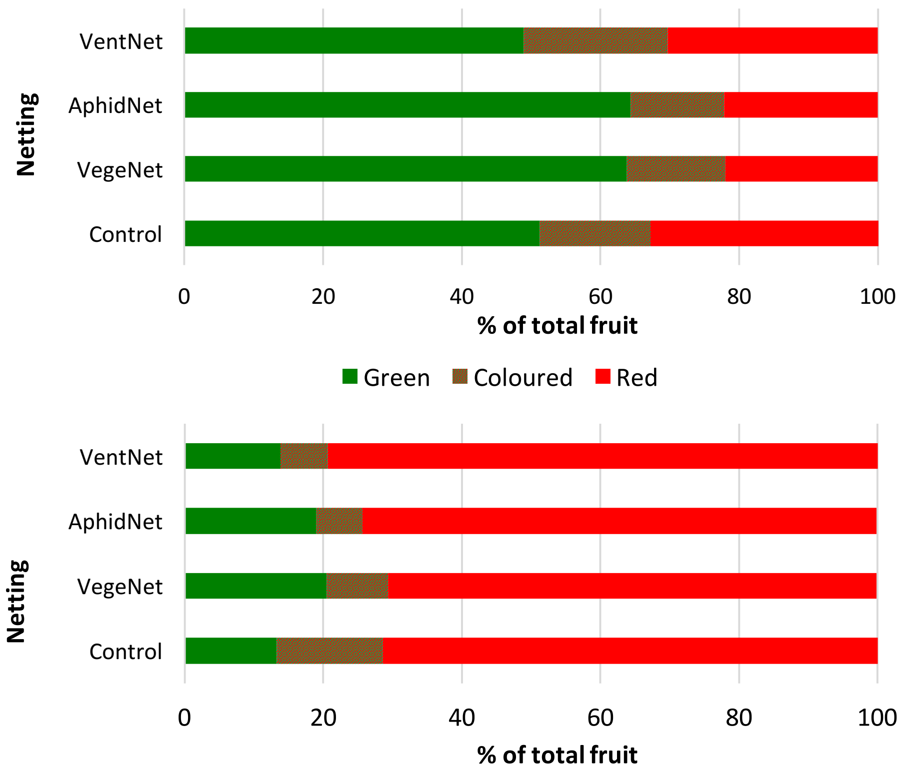


Figure 82. Percentage of Cayenne (top) and Birdseye (below) chillies that were green, red, or partially coloured at yield assessment

Figure 83. Aphids infested the chilli plants that were under the Aphid Net by the end of the trial

6.3.2. Bundaberg, Queensland

The chilli plants grew larger than the capsicum plants that had previously been studied. As a result the fleece material proved too narrow, and could not be effectively secured to the ground. The VegeNet remained on the crop, although it became very tight near the end of the trial. The VegeNet reduced both temperature and RH compared to the uncovered control, particularly when the air was relatively dry or temperatures exceeded 26°C.

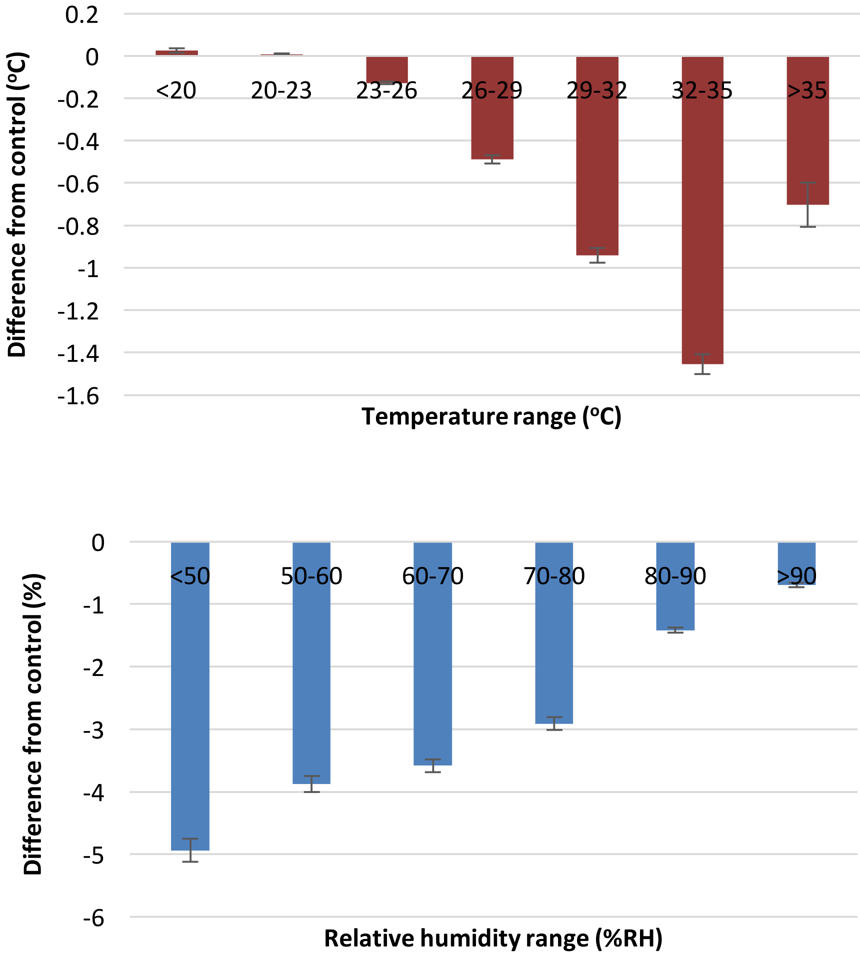


Figure 84. Temperature (top) and RH (below) under VegeNet compared to the uncovered control. At temperatures above 26°C the netting provided shading, while RH was reduced by the netting, especially when humidity generally was low.

Bundaberg was affected by heavy rain during January. More than 300mm of rain fell over only a few weeks, resulting in severe waterlogging of the crop. Large amounts of fruit rotted and fell from the plants. Although yield results suggested that there were more rotten fruit under the VegeNet, and that yield was reduced, the amount of rotten fruit means that this result cannot be reported with confidence. There was also little effect on fruit maturity, with similar percentages of red fruit found in the control and the netted plants.

The chilli plants covered with VegeNet did not perform as well as the uncovered plants. This is different to the results with capsicums, where yield and quality was improved and maturity advanced.

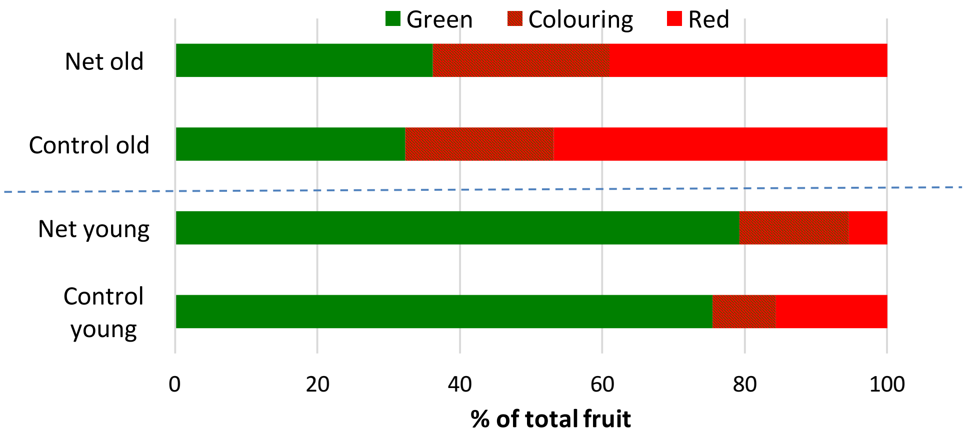


Figure 85. Maturity of chillies at assessment when VegeNet was placed over seedlings planted 2 (young) or 3 (old) weeks prior, compared to uncovered plants (controls)

6.4. Conclusions

Capsicums responded well to floating row covers. Increases in yield and quality were found, as well as reductions in pests and protection from sunburn.

The same effects, however, were not observed for chilli plants protected by fleece or netting. No increases in either yield or quality were observed for Cayenne or Birdseye chillies grown with floating covers. The large size of the plants and more frequent harvests also made use of floating covers more problematic for chili production. The major benefit of using floating covers for chilli plants was protection from fruit fly. This is not insignificant, as control of fruit fly is particularly problematic on chillies, which are an excellent host.

Although the same species as capsicum, there are clear differences in the response to floating covers by these two crops.