Sun Protection for Fruit

A practical manual for preventing sunburn on fruit - 2011

State Government Victoria

Fruit Growers Victoria

Apple & Pear Australia Ltd

DEPARTMENT OF PRIMARY INDUSTRIES | farm services

If you would like to receive this information/publication in an accessible format (such as large print or audio) please call the Customer Service Centre on 136 186, TTY 1800 122 969, or email customer.service@dpi.vic.gov.au.

Published by the Department of Primary Industries
Farm Services Victoria Division, June 2011.

Authorised by the Department of Primary Industries
1 Spring Street, Melbourne 3000.

ISBN: 978-1-74264-749-4 (print)
ISBN: 978-1-74264-750-0 (online)

Disclaimer
The advice provided in this publication is intended as a source of information only. Always read the label before using any of the products mentioned. The State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

For more information about DPI go to www.dpi.vic.gov.au or phone the Customer Service Centre on 136 186.

Sun Protection For Fruit

A practical manual for preventing sunburn on fruit - 2011

Compiled and edited by:
Sam Lolicato, Department of Primary industries, Tatura, Victoria

Reviewers:
Dr Larry Schrader,
Washington State University, Tree Fruit Research and Extension Centre

Dr Bob Evans,
United States Department of Agriculture, Agricultural Research Service

Dr Ian Goodwin,
Department of Primary Industries, Tatura, Victoria

Pam Strange,
Department of Primary Industries, Irymple, Victoria

Graeme Thomson,
Department of Primary Industries, Knoxfield, Victoria

Dr Simon Middleton,
Agri-Science Queensland

Henry Schneider,
Ethnic council c/o - Department of Primary Industries, Tatura, Victoria

Olive Montecillo,
Department of Primary Industries, Echuca, Victoria

Technical Working Group:
Sam Lolicato, Department of Primary Industries, Tatura, Victoria
Dr Ian Goodwin, Department of Primary Industries, Tatura, Victoria
Chris Peters, Fruit Growers Victoria Ltd
Richard Hawkes, Apple & Pear Australia Ltd
Michael Crisera, Fruit Growers Victoria Ltd

State Government Victoria
Fruit Growers Victoria
Apple & Pear Australia Ltd.

Three types of sunburn on apples

Contents

Introduction

Many fruit trees in northern Victoria are growing close to the upper boundary of their ideal environment for temperature and sunlight. For example, apple production in northern Victoria increased significantly in the 1990s after the development of apple varieties with high market acceptance and higher heat tolerance. Even with varieties more tolerant of heat, it is common for the local industry to experience some level of sunburn on fruit, causing lower-value and more variable pack-outs. Plants growing in an environment with ambient temperatures close to the limit of what they can tolerate will be the first to show definite adverse symptoms caused by predicted climate change.

Some modern fruit production techniques can increase the risk of sunburn. The most obvious example is the use of fruit trees with dwarfing rootstocks growing on trellis and using training systems that allows direct sunlight to penetrate throughout the tree's canopy. This can increase fruit yields and improve colour development but can increase the risk of sunburn.

Orchardists estimate fruit production losses due to sunburn in the Goulburn Valley in northern Victoria vary from 6 to 30 per cent, depending on seasons and the type of fruit. Estimates of recent losses in susceptible orchards without sun protection vary from 10 to 40 per cent in Granny Smith apples, 15 to more than 50 per cent in Gala apples, 10 to 25 per cent in Pink Lady apples and 10 to 15 per cent in Williams pears.

Orchardists in northern Victoria have developed many techniques and infrastructure upgrades to reduce economic losses due to sunburn. Some control measures work better than others and the results are often variable. Some of the variable results are due to difficulties in applying suitable orchard management practices and techniques.

The objectives of this manual are to:

1. Outline the causes of sunburn in fruit;
2. Summarise the different techniques and infrastructure upgrades used by orchardists to reduce sunburn in fruit in Victoria, Australia and the world; and
3. Assess advantages and disadvantages of the main sun protection techniques, including estimates of their economic consequences.

The manual relies heavily on information on apples, but where possible information about pears and other fruit is included.

Also, the manual focuses mainly on sunburn in fruit, which is the obvious visible symptom of an excessively warm climate. During the hottest part of the day, when air temperatures rise above 30 to 35°C, fruit tree photosynthesis is likely to slow, causing general heat stress, which will reduce potential fruit yield. This manual will not deal with this in detail, but we can expect that sunburn control options will also have some general yield benefits due to reductions in general heat stress on trees.

Early sunburn on young Sundowner apples (early December 2010)

Sunburn on Sundowner apples (early April 2011)

Sundowner apples 3 days after a 40°C day in December 2010

What causes sunburn of fruit?

The energy of sunlight can cause damage to the sun-exposed surface layers of fruit.

Sunburn is more due to the radiative force of the sun than air temperature.

The maximum temperature of the sun-exposed fruit surface of apples is often 10 to 18°C higher than the maximum shaded air temperature (Schrader et al. 2003a).

The temperature of a fruit's surface in direct sunlight will always be higher than the officially reported air temperature at the same location. The Bureau of Meteorology normally reports temperatures from thermometers positioned inside shaded or 'screened' boxes. Also, unlike leaves, many types of fruit (e.g. apples and pears) have very limited cooling capacity via transpiration from the skin of the fruit.

As a general guide, sunburn of apples can occur when shaded air temperatures are above 30°C and fruit surface temperatures are above 45°C.

Sometimes sunburn will not be obvious until after a period of cool storage. Heat stress on fruit can also increase the incidence of other skin disorders in apples (e.g. Lenticel Marking, Bitterpit, Splitting and Watercore; Schrader et al. 2003b).

Like human skin, apple fruit skin can become acclimatised to sun and heat. In apple skin this natural sun protection is associated with the presence of antioxidants and 'heat shock proteins' (Brown 2009). Fruit that has been exposed to direct sunlight earlier in the season will be more tolerant of direct sunlight and high temperatures later in the season. Apples exposed to ultraviolet radiation and high temperatures will usually reach maximum levels of skin antioxidants and 'heat shock proteins' after about three days.

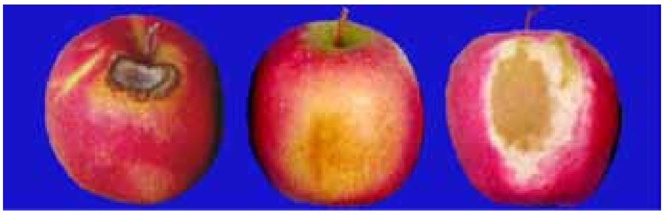
Different types of sunburn have been identified and characterised in apples (Schrader et al. 2003b; Felicetti & Schrader 2008). The appearance and causes of each type are distinctly different.

Types of sunburn on apples

1. Sunburn necrosis

This is caused by heat, when the fruit surface temperature of an apple reaches 52 ± 1°C for 10 minutes. Cells die and later a sunken dark brown or black (necrotic) patch may appear.

Types of apple sunburn (from left to right):
1. Sunburn necrosis 2. Sunburn browning
3. Photo-oxidative sunburn (or bleaching)



(Picture from Larry Schrader)

2. Sunburn browning

This is the most common type of sunburn and results in a yellow, brown or dark tan patch on the sun-exposed side of the apple, usually a few days after the initial damage was done. Cells do not die and damage initially appears superficial, although deeper apple flesh will show more change in cool storage. This damage occurs when the fruit surface temperature reaches a specific point while exposed to direct sunlight. The minimum threshold fruit surface temperature that will cause sunburn browning varies from 46 to 49°C for one hour, depending on different varieties. Sunlight or solar radiation is made up of three main types of radiation. While the infrared and visible components of sunlight are mainly responsible for heating the fruit, relatively small amounts of ultraviolet radiation helps to promote sunburn browning.

3. Photo-oxidative sunburn (or bleaching)

When shaded or partially-shaded apples are moved into strong direct sunlight, they are very prone to sunburn, even when the fruit surface temperature is relatively low (less than 45°C). Often the sun-exposed patch of skin will become white-bleached, indicating that skin cells have died. Usually after a few days the patch will gradually become brown and then black and necrotic. Felicetti and Schrader (2008) showed this type of sunburn is mainly due to direct exposure of fruit to visible radiation and it does not require the other main components of solar radiation, i.e. infrared and ultraviolet. The most likely explanation is that the sudden exposure of the photo-receptors in the skin of non-acclimatised fruit gets "overwhelmed". The excess photochemical energy that cannot be utilized by photosynthesis is diverted to other reactions (e.g. free radicals) that damage the cells through photo-oxidative processes (Felicetti and Schrader 2008).

This type of sunburn can occur when branches suddenly bend under the increasing weight of the developing fruit, or after hand thinning or summer pruning. It can also occur after harvest when fruit bins are left in intense direct sunlight for a relatively short period.

Summary

Fruit surface temperatures that will cause the three types of sunburn:

1. Necrosis – greater than 52 ± 1°C for 10 minutes
2. Browning – 46 to 49°C for one hour
3. Photo-oxidative – less than 45°C

Sunburn damage on Sundowner apples, three days after sudden limb movement.

Photo-oxidative bleaching on a Pink Lady apple 5 days after a front apple was removed for the first colour pick, early May 2011

Even a small amount of yellowing or browning caused by sunlight can limit a fruit grower's markets. For example, hot weather and direct sunlight can cause Granny Smith and other varieties of green skinned apples to become slightly yellow or red. This can lead to very costly downgrading of the fruit when the market is demanding bright green apples. It is not unusual to have 30 per cent of a Granny Smith crop rejected for sun 'yellowing' (van den Ende 2004).

How to assess sunburn risk

Rising fruit surface temperature is the best indicator of sunburn risk, however it is convenient to use current, historical and predicted air temperatures to assess sunburn risk. This information normally comes from the Bureau of Meteorology or automatic weather stations and, as mentioned previously, it is based on shaded temperature. There is a reasonably good correlation between maximum air temperature, maximum fruit surface temperature and sunburn risk. However air temperature alone is not always a good predictor of sunburn risk because fruit surface temperature can be rapidly affected by other weather factors like sunlight intensity or cloud cover, humidity and wind. Sunburn risk is also affected by tree factors, like variety, canopy density and fruit size (Schrader et al, 2003b). Larger fruit are more likely to sunburn than smaller fruit. Position of fruit on the tree also affects sunburn risk. For example, fruit at the outer edge of the canopy and fruit positioned with a westerly aspect will be more prone to sunburn.

Maximum fruit surface temperatures are normally attained between 2pm and 5pm, in the hottest part of summer. Fruit damage usually becomes most apparent after a prolonged hot period. However, photo-oxidative sunburn can occur at any time during the growing season, including periods when the temperatures are mild and fruit is suddenly exposed to direct sunlight.

Summary

Shaded air temperature provides the most convenient indicator of risk:

- Greater than 40°C = High risk of a necrotic patch
- Greater than 35°C = High risk of browning damage
- 30 to 35°C = Damage is variable, depending on wind, sunlight intensity (or cloud cover), humidity and level of fruit acclimatisation to sunlight (Holmes, et al. 2009)

Increased risk:

- Modern intensive orchard production systems on dwarfing rootstocks growing on trellis and, training systems that allow good light-penetration through the orchard canopy
- Fruit positioned with a westerly aspect in direct sunlight
- Sudden movement of fruit from shade to strong, direct sunlight
- Hot, sunny, calm days
- Cool, cloudy weather followed by clear-sky days greater than 30°C
- Plant water stress on hot days (evidence from grower experience)
- Orchards with bare earth between the tree rows, reflecting additional heat into the tree canopy

Reduced risk:

- Overcast sky
- Vigorous trees (with more vegetative growth and more internal shading)
- Smaller fruit
- Light breeze through a well-watered orchard

Risk assessment based on weather records

Figure 1 is based on temperature records collected in shade (i.e. within a standard Bureau of Meteorology screened box) over the last 45 years at Tatura. The lower line shows the average maximum temperatures for each month. Normal summer maximum temperatures are around 30°C. However, the upper line shows the highest temperatures (in the shade) recorded for each month. The highest recorded temperature was 45°C in February 2009.

Table 1 provides a guide to the probabilities of exceeding three temperature thresholds, i.e. greater than or equal to 30, 35 and 40°C, based on historical records. For example, in February there is a 47 per cent probability that a day with shaded air temperatures above or equal to 30°C will occur; 11 per cent for 35°C and; 1 per cent for 40°C. Probabilities for the same threshold values were calculated for the last 10 years of records to test for any possible warming trend. Generally, there appears to be slightly increased frequency of warmer days.

Weather scientists have predicted that average temperatures in the Goulburn Valley will increase by approximately 1°C every 20 years. There is a high level of certainty that this trend is already occurring (Australian Climate Change Science Program: CSIRO and Bureau of Meteorology 2010). The Department of Sustainability and Environment (2008) report predicts the effects of climate change will initially be most obvious in extreme weather events, such as the number of hot days. Their information was used to compile Table 2, which shows the current average number of hot days in a year at Benalla compared with predictions under different climate change scenarios. The predicted trend to at least 2070 is for an increased number of hot days.

Table 1 does not give probabilities for the spring months because, although long term maximum temperature records for Tatura show significant probabilities of exceeding 30°C in October and November, the smaller developing fruit are less at risk of sunburn than later in the season. This is because smaller fruit absorb less heat from sunlight and are less likely to move suddenly into direct sunlight by branch movement.

Risk assessment based on local weather information

Researchers at Washington State University have done considerable research into the factors that cause sunburn in apples. They have developed a computer model, which uses forecasts of the local weather factors causing sunburn, to predict the imminent risk of sunburn. The computer model means local orchardists can receive warnings and apply suitable control measures before any damage occurs. Information on the Sunburn Prediction Calculator is available online from Zhang and Schrader 2010; at http://hort.tfrec.wsu.edu/pages/Sunburn.

Figure 1. Average (mean) maximum temperatures and the highest recorded temperatures for each month at Tatura, based on 45 years of records (from 1965 to Sep 2010).

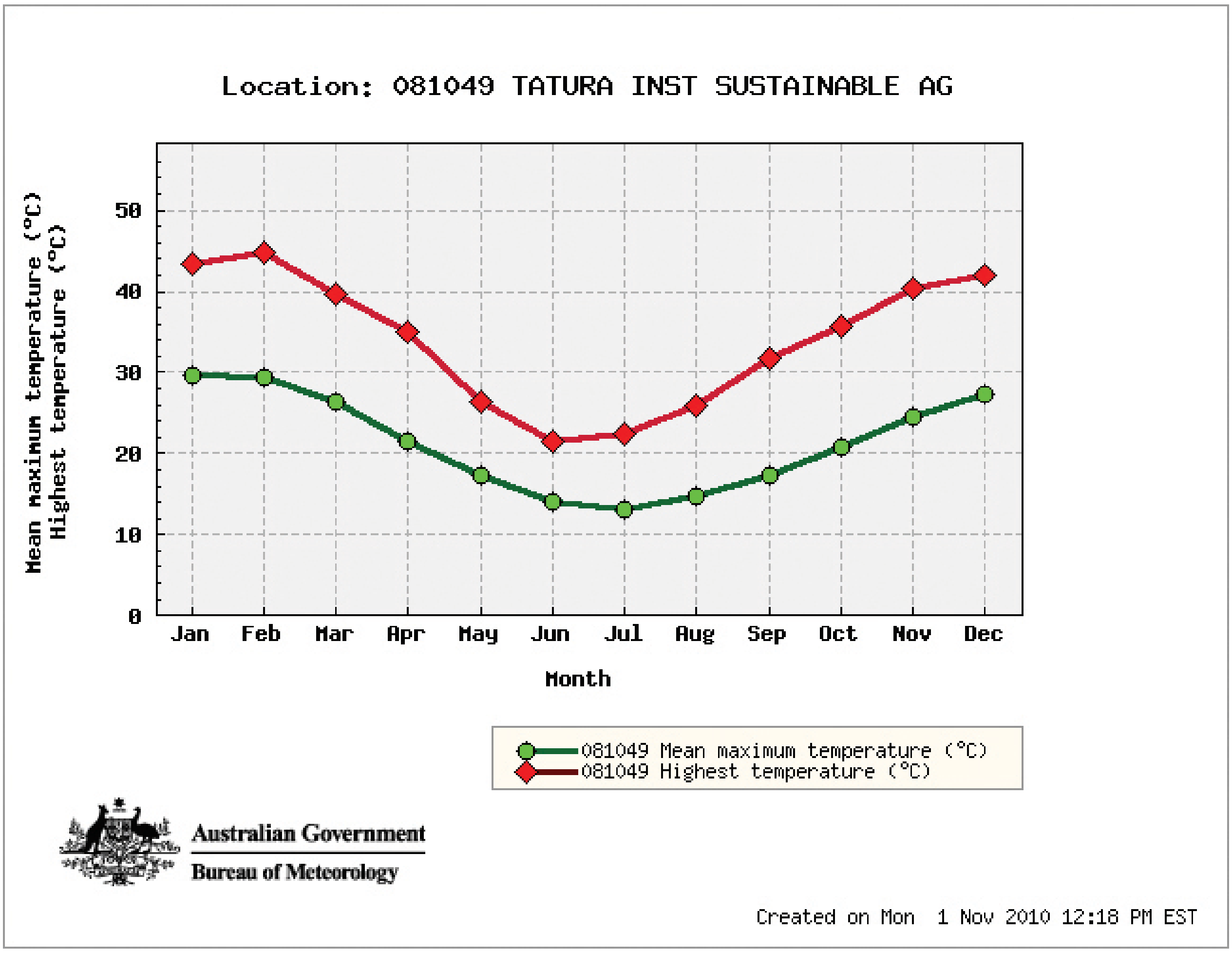


Table 1. Probabilities of exceeding threshold daily maximum temperatures at Tatura, based on long term historical records 1965 to Sep 2010. (Raw data from the Bureau of Meteorology).

Month	December			January			February			March			April		
Threshold Temperatures	≥30°C	≥35°C	≥40°C	≥30°C	≥35°C	≥40°C	≥30°C	≥35°C	≥40°C	≥30°C	≥35°C	≥40°C	≥30°C	≥35°C	≥40°C
Probability % (1965-Sep 2010)	30	7	<1	43	14	2	47	11	1	21	3	0	1	<1	0
Probability % Previous 10 yrs (1999-2009)	32	11	1	50	18	4	45	11	1	25	5	0	3	0	0

Table 2. Average number of hot days per year at Benalla, current compared to two projected climate change scenarios, 2030 with medium greenhouse gas emissions and 2070 with high green house gas emissions. (Department of Sustainability and Environment, 2008)

	Current			2030			2070		
Threshold Temperatures	≥30°C	≥35°C	≥40°C	≥30°C	≥35°C	≥40°C	≥30°C	≥35°C	≥40°C
Number of days	60	14	1	69	19	2	97	37	6
Range of estimates	--	--	--	67-74	18-22	1-2	84-118	28-54	4-12

Sun protection options

Each year fruit grown with modern orchard systems in northern Victoria has some risk of sunburn. Predictions of climate change indicate the risks will only increase over time, making it more important for orchardists to consider sun protection options to reduce the risks if they are to remain profitable.

Orchardists should firstly follow best management practices to minimise sunburn on fruit before considering investment in expensive sunburn protection products and infrastructure such as spray-on sun protection, shade netting or evaporative cooling. Orchardists should identify which fruit blocks are more susceptible to sunburn, what control strategies can be employed in each block and which blocks have the best chance of achieving good returns on the additional investment (Brown 2009). The additional investment options mentioned in this manual would normally involve large expenditure and would normally be economically feasible only if associated with increased and more consistent fruit pack-outs. Shade netting and over-tree sprinkler cooling systems have high set-up costs and should be considered only on the best and most profitable orchard blocks, which are normally well managed and established with high density plantings.

Sun protection options:

1. Best management practices
2. Spray-on products
3. Shade netting
4. Over-tree sprinkler cooling

1. Best Management Practices for sun protection

a. Use fruit varieties that are more tolerant of sunburn

Granny Smith and Royal Gala are considered to be two of the most susceptible of the commonly-used apple varieties in northern Victoria. Other apple varieties that are susceptible to sunburn are Jonagold, Braeburn, Golden Supreme, Ginger Gold and Fuji (Evans 2004). Pink Lady® is more tolerant than Cameo and Honeycrisp (Schrader et al. 2003a).

b. Schedule irrigations to avoid tree water stress

Anecdotal evidence strongly indicates that any water stress during the summer is likely to increase the risk of sunburn. Healthy, fully irrigated trees receive the maximum cooling benefit from transpiration. Irrigation scheduling techniques based on weather forecasts and soil moisture measurements should be used to ensure irrigation is well-matched with the crop's water requirements. Irrigation should be used just before or during heat waves to avoid tree stress and sunburn.

Crop water requirement may increase greatly from one day to the next, especially during heat wave conditions. Even very short-term crop water stress is likely to increase the risk of sunburn. For example, based on long term records, the average water requirement for a typical modern orchard at Shepparton during February is 4.5 mm/day. The average for the heat wave in the first week of February 2009 was 6.3 mm/day. However, towards the end of that heat wave, on 'Black Saturday' there was a further rapid increase when crop water requirement rose to 9.6 mm/day. During this heat wave, if orchard irrigation schedules were based only on long term averages then trees would have suffered significant water stress and probably also more sun damage. Close attention to weather forecasts is highly recommended to anticipate heat waves and to make irrigation scheduling adjustments before trees are stressed and the damage is done.

c. Train fruit trees to develop an appropriate canopy

Apple and pear fruit sunburn is often associated with thin exposed canopies or with the sudden exposure of fruit to sunlight when branches move under the weight of the developing crop. Avoid branch movement by training young trees with less fruit developing at the ends of branches and with scaffold branches that can support the fruit load. You can also help to support the limbs and branches of free-standing trees with bands tied two-thirds of the way up the trees.

An example of appropriate tree training - Granny Smith apples on MM.106 rootstock in high-density plantings. Aim for a short, rigid scaffold structure, with branches in the lower part of the tree, no longer than 1.2 metres that do not bend. In open trees, you should aim to set fruit deeper in the canopy, along the branches and not at the end of the branch (Van den Ende 2004). Often there is a trade-off with conflicting management priorities for light penetration into the tree's canopy. More light penetration should normally increase yield potential and fruit skin colour development, but will also increase the risk of sunburn.

d. Avoid excessive summer pruning and leaf stripping

This is often done to allow light into shaded parts of apple trees to enhance colour development. This should be done carefully to avoid limb movements and sudden exposure of fruit to direct sunlight, especially during hot weather. Recommendations for enhancing colour in apples, while minimising the risk of sunburn are:

- using "red" strains
- delayed summer pruning and leaf-stripping
- delayed use of reflective cloth in the inter-row space
- cool the orchard at sunrise and sunset with evaporative cooling.

e. Protect picked fruit in the bin from direct sunlight

The skins of apples that were in total or partial shade on the tree can burn easily if suddenly exposed to direct sunlight. Even a relatively short period of exposure to intense direct sunlight could cause significant damage. Therefore, recently-harvested fruit in bins must be placed under cover as soon as possible by placing in a shed, under a shady tree or by covering with a light cotton or hessian sheet or 80 per cent shade mesh.

f. Establish suitable cover cropping in the inter-row space

Light coloured bare earth and dead vegetation in the inter-row space is likely to reflect more sunlight into the orchard canopy than green vegetation. In the hottest part of summer this is likely to increase the heat load on fruit and increase the probability of sunburn.

g. Improve air movement through the fruit block

As mentioned previously, the temperature of fruit skin in direct sunlight is higher than the temperature of the surrounding air. Air movement around the fruit helps to remove some of its heat and tends to equalise the temperature of fruit and air.

2. Spray-on sun protection products

What are spray-on sun protection products?

Leaves and fruit of agricultural crops can be sprayed with suspensions of tiny, white mineral particles (clay or calcium carbonate) or with wax emulsions to create a film that provides some protection from the damaging effects of sunlight.

How do they work?

The mineral particles form a white film that blocks and reflects some of the direct sunlight to reduce the fruit's surface temperature and the probability of sunburn. The wax-based product forms a film that absorbs some of the damaging UV radiation and reflects a small amount of the incoming radiation.

These products must be applied several times during the season to maintain a protective cover on the fruit as it increases in size. All spray-on sun protection products must be applied before severe summer heat wave conditions occur and applications must be maintained throughout the hot season to maintain coverage on the expanding fruit. Resellers usually recommend a minimum of three to four applications, separated by seven to 21 days. More frequent applications are likely to provide greater protection.

In the last 10 years, product manufacturing techniques and formulations have improved and more effective spray application techniques have been tried with the use of helicopters and air blast sprayers specially designed to apply products from above the tree canopy.

Types of spray-on sun protection products

a. Clay-based

The type of clay used is white kaolin, which has many industrial uses. The kaolin used in clay-based sun protection products has been refined and modified to produce a wettable powder which can be mixed with water and sprayed onto foliage and fruit to create a white film that will reflect some sunlight. Often the trees will appear 'whitewashed'.

The processed product is much more effective for protecting fruit trees from sunburn than the unprocessed kaolin clay. The technology for these products was originally developed for organic pest control, but subsequent research, mainly in the USA has shown that the amount of clay residue on the fruit is correlated with reductions in fruit surface temperature and, with very frequent and heavy applications, they can reduce fruit surface temperatures by up to 5 to 10ºC (Glenn & Puterka 2005).

Research has shown, although the clay-based coating may reduce photosynthesis at low light intensities, under high light intensities, when there is an over-abundance of light, photosynthesis of the whole tree can be unaffected or even increased due to reduced heat stress and better distribution of light to lower shaded parts of the tree canopy (Glenn 2009).

Results from these products in northern Victoria have been variable, depending on how they have been used (see Case Studies at the end of this manual). They may delay maturity by three to seven days.

Clay-based products can be easily washed-off the tree and must be re-applied after rainfall and over-tree sprinkler irrigation and evaporative cooling.

Some independent scientific reports indicate these products can act like an insect repellent in fruit crops (Glenn & Puterka 2005). They have been used as a general preventative spray to reduce the amount of conventional spraying. It is assumed some insect pests find treated fruit unpleasant or they have greater difficulty finding the host.

Clay-based spray-on sun protection.

Distributors of clay-based products often warn users to be careful to remove visible residues from fruit after harvest; special brushing and pressure washing may be required.

b. Calcium carbonate-based

The main active ingredient is high-grade calcium carbonate or crystalline limestone. These products are marketed as a liquid that is mixed with water and sprayed onto crop foliage and fruit to form a thin crystalline layer that reflects some sunlight. The appearance of the applied film coating is usually lighter than the clay-based coating and distributors claim it is less likely to reduce natural fruit colouring. They are more rainfast than the clay-based products. Distributors of calcium carbonate-based products also warn users to be careful to remove visible residues from fruit after harvest.

There is also a calcium-based fertiliser product which claims good sun protection qualities. It is a high-analysis suspension fertiliser, high in calcium (Ca), zinc (Zn), magnesium (Mg), nitrogen (N) and boron (Bo).

These products have been developed more recently and there is less objective information on their overall performance. Results from these products in northern Victoria have been variable, depending on how they have been used (see Case Studies at the end of this manual).

Calcium carbonate-based spray-on sun protection.

c. Wax-based

The main active component of the wax-based product is carnauba wax, which is produced on the leaves of a tropical palm tree and also used in cosmetics and car wax. Small amounts of reflective compounds based on clay are also added. The wax-based product is a liquid emulsion sprayed onto fruit trees to form a clear film that filters out a significant proportion of the damaging ultraviolet radiation and a small amount of the visible and infrared radiation. It has been shown to significantly reduce sunburn browning of apples (Schrader 2011). It is more effective at preventing sunburn browning than sunburn necrosis. On fruit it appears almost transparent, so that the crop does not appear 'white-washed', allowing easier colour-picking. The product is 'food-grade', so treated fruit does not require special cleaning to remove residues. This product has been commercialised for use on apples, wine grapes and citrus.

As with the clay and calcium carbonate-based products, the wax-based product requires repeated applications throughout the hot season to keep up with fruit expansion. It has some insect repellent qualities and the distributors claim it has no negative effect on beneficial insects and mites.

The applied product is rainfast and can be used in orchards with overhead sprinklers. It is not compatible with other chemicals and a water softener is required when mixing.

Results from this product in northern Victoria have been variable, depending on how it has been used (see Case Studies at the end of this manual).

Fuji apple with three applications of wax-based sun protection. (Picture from Larry Schrader)

Advantages of spray-on sun protection

- Less sunburn allowing better pack-outs of quality fruit.
- Can be applied with existing orchard spraying equipment, although modifications to direct the spray from above the fruit would help.
- The particle film products (clay and calcium carbonate) can be tank mixed with many other common orchard chemicals.
- The particle film products may inhibit or repel some damaging insect pests.
- The particle film products may reduce heat stress.
- The particle film products significantly increase reflected sunlight within the tree canopy, tending to improve the distribution and penetration of sunlight to the "deeper" shaded parts of the tree.

Disadvantages of spray-on sun protection

- The particle film products may inhibit or repel some beneficial insects.
- The particle film products may, in some situations, irritate the skin, eyes and respiratory systems of orchard workers.
- The particle film products may require more effort to remove films from fruit when packing.
- The wax-based product cannot be tank mixed with any other product.

Economics of spray-on sun protection

Table 3 presents a method for comparing scenarios "with" and "without" sun protection. Due to variability in prices and weather and a general lack of locally-derived objective data to directly compare the sun protection options, the numerical figures are a guide only and you should use your own "best estimates" of prices, yields and sunburn damage.

A series of assumptions have been made:

* Figures for costs, returns and application rates are based on 2010 estimates for a modern, high density Gala apple orchard growing on trellis and using best management practices.

* Spray-on sun protection products are equally effective and only price of product and application rates vary.

* Fruit production is 60t/ha, however due to severely sunburned fruit dropped on the ground at harvest, production from the "without" sun protection scenario is 5 percent less, i.e. 57t/ha.

* Apples are sold to a packing shed, with prices set in the orchard at $800/t for apples "with" sun protection and $500/t for apples "without" sun protection.

* The cost of production is the same for 'with' and 'without' sun protection ($6,100/ha) and picking cost is $100/t.

Table 3. Example of a method for comparing the economics of using and not using spray-on sun protection products on Gala apples.

Potential costs			
	Clay-based	Wax-based	Calcium carbonate-based (fert)
Cost of chemicals	$75 per 20 kg bag	$1,250 per 208 L drum	$150 per 20 L drum
Unit cost	$3.75/kg	$6.00/L	$7.50/L
Rate of application		25 L/ha, 5 applications	10L/ha, 5 applications
Initial application	55 kg/ha		
Top-up	25kg/ha, 4 applications		
Total usage	155kg/ha	125L/ha	50L/ha
Sub-total, material cost	**$580/ha**	**$750/ha**	**$375/ha**
Labour			
Mixing and spraying	2hr/ha		
Cost of labour	$100/hr		
Sub-total, labour cost	**$200/ha**		
Total cost	**$780/ha**	**$950/ha**	**$575/ha**

Potential returns				
	With sun protection			Without sun protection
	Clay-based	Wax-based	Calcium carbonate-based (fert)	
Price (per t)	$800	$800	$800	$500
Yield (t/ha)	60	60	60	57
Gross income (per ha)	**$48,000**	**$48,000**	**$48,000**	**$28,500**
Less:				
Production and picking cost	$14,802	$14,802	$14,802	$14,502
Cost of spray-on sun protection	$780	$950	$575	$0
Total variable cost (per ha)	$15,582	$15,752	$15,377	$14,502
Gross margin (per ha)	**$32,418**	**$32,248**	**$32,623**	**$13,998**
Additional value with spray-on sun protection (per ha)	**$18,420**	**$18,250**	**$18,625**	

3. Shade netting

What is shade netting?

Shade netting is made from woven synthetic fibres to provide protection for higher value crops. In recent years, its use in horticulture has increased mainly due to the development of netting materials that are stronger and longer-lasting. Manufacturers claim the new netting materials can last for at least 10 years under natural sunlight.

Netting is used around the world over a variety of crops, ranging from fruit and vegetables to nursery and speciality plants for sun, hail, wind and bird protection. In Australia, netting has been used mainly for bird or hail protection. It is becoming more common to see netting being installed in northern Victoria primarily for sun protection.

Black permanent shade netting with open sides over Granny Smith apples.

How does it work?

Shade netting moderates the adverse effects of climatic extremes, including intense sunlight, wind and hail. As discussed earlier in this manual, sunlight and, to a lesser extent wind have a direct influence on sunburn risk:

a. Sunlight

Direct sunlight is the primary cause of sunburn. Shade netting is usually designed to reduce mid-day sunlight by about 20 per cent. This reduces the heat loading on trees and fruit from visible and infrared radiation and reduces the amount of damaging ultraviolet radiation. Different net designs are available (see below) providing a range of 12 to 25 per cent reduced sunlight.

Often there is no difference between the shaded air temperature inside and outside the netted area, due to the effects of air movement or wind. Sometimes however, on hot, still days it may be possible to measure air temperatures 1°C to 3°C less than outside the netted area.

Research at DPI Tatura, has shown the main sun protection benefits from netting comes from reductions in heat loading on fruit trees due to reduced direct sunlight and not from lower temperatures of the surrounding air.

b. Wind

In some situations wind speeds can be reduced by 50 per cent. This reduction varies depending on the type of netting, whether it is gabled or flat and whether or not side-netting is used as a windbreak or to exclude birds. Anecdotal evidence indicates that wind could either reduce or increase sunburn. There is a complex interaction between fruit surface temperature, tree water status, humidity and wind. For example, wind in a well-watered orchard will reduce temperature of sun exposed fruit, however, if drying winds raise tree water demand above a rate that can be supplied by the roots, then the tree will become stressed and probably also more prone to sunburn.

Different management under shade netting

Shade netting increases the tendency for fruit trees to put on more vegetative growth and, without suitable management, excessive shoot growth could reduce fruit-set and fruit skin colour development. However, with well-managed apple trees grown on dwarf and semi-dwarf rootstocks, excessive vigour should not be a significant problem (Middleton 2010).

It is generally accepted that fruit tree yield is proportional to the amount of sunlight that is distributed and intercepted by leaves throughout the tree canopy. It is likely that shade netting will reduce photosynthesis of fruit trees on overcast days in early spring. However, during most of the growing season and most of the day there is an excess of sunlight for photosynthesis and a 20 per cent reduction of sunlight due to shade netting is unlikely to reduce the yield potential and fruit quality of a well-managed orchard, provided direct sunlight can penetrate evenly throughout the tree's canopy.

Under permanent shade netting, with less wind and sunlight, the orchard floor will stay wetter for longer after rainfall and irrigation. During the growing season the orchard would most likely have a lower irrigation requirement and greater water use efficiency. If irrigation applications are not reduced appropriately, the orchard could become wetter, more humid and more prone to waterlogging.

Less air movement and higher humidity under netting can cause greater pressure from fungal diseases. It is important to regularly monitor the orchard and modify management to allow for these effects.

In apple orchards that require chemical fruit thinning, be warned that in lower light levels under netting the thinning operations tend to be more effective, with more fruitlets dropping (Bound 2010). Growers should modify their crop load management accordingly.

Types of shade netting

There is great variety in the types of netting and in the types and designs of supporting structures. The most basic form of netting is draped directly over the tree canopy or over a simple frame to form a tunnel along each tree row. Normally, draped or tunnel netting is placed over trees or vines for only the period that the fruit is ripening, as a protection against birds. Because these nets are exposed to the weather for only a few weeks of the year, they can be lighter and less expensive, but they involve extra costs in annual spreading, collecting and storage.

It is becoming more common to see netting attached to permanent supporting structures. The structures can be designed to support netting that can be retracted or extended for different periods of the growing season, or they can be designed to support netting that is permanently attached and tensioned to form a complete, immovable cover. Often netting designs will combine protection for sunburn, hail, birds and wind.

Net supporting structures

The most common type of netting structure is designed and built from treated pine poles and tensioned cables. The net covering can be either flat or gabled, depending on the design of each structure. Flat-topped structures are designed to stretch under a build up of hail, while some of the gabled structures are designed to allow hail to open up gaps that will allow a build up of hail to fall through the valley of the gable. The supporting structure should be designed to withstand strong winds with cables attached to solid anchored foundations. Professional advice is available for design and installation of netting (Rigden, 2008). Design and construction of shade netting is a specialised field of work and should usually be done by professional service providers or under their close supervision.

Black retractable shade netting (extended).

Black retractable shade netting (retracted)

Some progressive growers will plan ahead when establishing a new orchard, by installing tree-training trellis posts that can be used as part of the internal net support structure. Later-on they may employ a contractor to install the boundary support structure, bracing stays, internal cables and attach the netting.

Netting design

Shade netting is typically made from high-density polyethylene (HDPE) monofilament strands that are knitted or woven without knots to form a mesh (Rigden, 2008). The mesh can be formed into many varied sizes and shapes. Smaller mesh sizes are usually stronger, heavier, reduce more of the sunlight and are more expensive. Mesh opening sizes may vary from 10 to 37 mm. Some nets have a main mesh opening plus strands of monofilament that stretch across the openings, to form cross-stitches that effectively reduce the size of the openings in the mesh without large increases in weight and cost and without large reductions in sunlight transmission. Nets with four cross-stitches are known as 'quad nets'. The cross-stitches in a shade net will provide greater hail protection and can exclude or deter larger insects like bees and fruit flies.

Bees do not work as well under shade netting. It is advisable to introduce bee hives under the netted orchard during the blossom period and to allow some space between the top of the trees and the netting so that bees can fly freely along the tree rows.

Lengths of net should be woven with selvage so that the edges do not unravel and to provide extra strength for weaving wire along the edge for joining to other lengths of net and to allow easy attachment to supporting cables.

Netting formed by extruding plastic into a grid is cheaper than woven nets, but generally not durable enough to be used in orchards.

Earlier forms of black net lasted longer than white net, but with advances in technology, both black and white nets can be expected to last for about the same period of time. Nets of all colours with the same weave pattern can be expected to intercept similar amounts of sunlight. However, there are differences in the amount of visible (photosynthetically active) radiation that is transmitted to the orchard. Darker colours will absorb more sunlight, while lighter colours will reflect more sunlight. White netting allows more reflected or diffuse visible radiation into the orchard.

White netting is generally preferred for reducing sunburn issues and for assisting with fruit colour development. Different coloured nets can be expected to have slightly different affects on the transmission of sunlight to the orchard. This has an effect on colour development and fruit sugar development.

Permanent shade netting may cause excessive shading in low sunlight intensity periods during spring that could potentially promote excessive shoot length, delay the onset of flowering and reduce fruit set. To avoid these problems,

White permanent shade netting with enclosed sides to exclude birds.

White 'quad' netting

netting can be designed to be pulled back to allow sunlight into the orchard when necessary and to be extended only during the high-sunburn and high-hail risk periods.

Advantages of shade netting

- Less sunburn allowing better pack-outs of quality fruit.

Secondary benefits of shade netting:

- Insurance for hail damage
- Protection from birds and bats (with closed-in sides)
- Less evapotranspiration (with potential water savings)
- Less wind-rub and russet
- Reduced sunlight intensity can make the microclimate more pleasant for orchard workers in hot weather
- Better spraying conditions
- Possibly some frost protection (due to reduced orchard heat radiation at night)
- Possibly increased yields (due to cooler leaves and increased photosynthesis).

Disadvantages of shade netting

- High initial capital cost
- Less sunlight and wind is likely to slow drying of the orchard floor, especially after rainfall in spring and autumn (more disease pressure and tyre ruts)
- More effort is required to 'calm' vigorous orchards
- May reduce colour development in red blushed apple varieties produced on excessively vigorous trees
- May lower fruit-set due to low sunlight in early spring (although this may also be an advantage with trees that normally require fruit thinning)
- More restricted bee activity for pollination.

Economics of shade netting

Potential cost:

The initial capital cost of netting an orchard can range from $17,000 to $72,000 per hectare (Rigden, 2008). The range of available netting types and supporting structures is increasing, however a 'ball-park' figure for permanent shade netting installed in northern Victoria is $40,000 per hectare. This cost can be spread over 10 years for netting and approximately 40 years for well-maintained supporting structures.

On-going operating costs should also be taken into account, including the extra effort in management to maintain crop yields and quality (see Disadvantages above).

Potential economic benefits:

These will depend on the value of the crop under netting and the estimated loss of income without netting. Without netting, in susceptible crops the amount of sun damaged fruit has varied from 5 to 50 per cent. The degree of damage on individual pieces of fruit could vary greatly, with some of the damaged portion of the crop being worthless, while some might be suitable for a downgraded, lower-priced category. An accurate assessment of the potential losses should take into account the proportions of the different damage categories and their respective value in the market. Very slight sunburn might be suitable for immediate sale, but may be unsuitable for long-term cool storage.

Any economic assessment should include an estimate of the value of the secondary benefits of netting (see Advantages above). Potential benefits include the insurance value of netting to protect trees and fruit from weather extremes, including hail and unusual heat waves. This can be treated like a numbers and probability game. A complete economic analysis must estimate both the probability of a damaging incident and the consequences it could have on the value of the harvested crop. For example, consider different scenarios where a damaging hail event occurs once in 10 years, causing 100 per cent, 50 per cent or 25 per cent crop loss. Or consider a heat wave that occurs once in five years that causes 10 per cent sun damage to Granny Smith apples under netting compared to over 40 per cent outside the netting. A method for assessing the break-even value of capital investment in shade netting is presented in Appendix 2.

4. Over-tree sprinkler cooling systems

What are over-tree sprinkler cooling systems?

Over-tree sprinkler cooling systems are designed to reduce sunburn by delivering misted or sprinkled water over the orchard canopy to cool fruit during the hottest part of the day.

The same cooling systems can be used to enhance colour development of 'red' or 'red-blushed' apples close to harvest.

How do they work?

Over-tree sprinkler cooling systems rely on the cooling properties of water to reduce temperature extremes on the fruit's surface. All types of over-tree cooling systems rely to varying degrees on three possible water cooling mechanisms (Evans & Van der Gulik 2011). These are listed below in order of increasing effectiveness, from least to most effective:

a. Aerial evaporative cooling

Orchard air can be cooled by water evaporating from fine droplets as they come from misting sprinklers and travel through the air. On a still day this creates cool air currents that move through the orchard by convection. This process is very inefficient and not effective for reducing fruit surface temperatures and sunburn, especially when there is wind.

b. Hydro-cooling

Water droplets emitted from the over-tree sprinkler system are cooled through evaporation. The cool water runs continuously over the fruit and the rest of the tree, absorbing and carrying away some of the heat. This can be effective, but it tends to use excessive amounts of water and greatly increases the risk of the orchard floor becoming waterlogged.

c. Surface evaporative cooling

Emitters spray droplets over the tree canopy, thoroughly wetting all surfaces to the point of run-off. Fruit is cooled by water continuously evaporating directly from its skin. This is the most efficient way to reduce fruit surface temperatures. The aim with evaporative cooling is to keep the fruit wet during the hottest part of the day and minimise the amount of water running through to the orchard floor.

Using the same amount of water, evaporation can remove 50 times more heat energy than the heat carried away in flowing water.

Please note: Under-tree sprinklers have no significant effect on reducing fruit skin temperatures and sunburn.

Types of over-tree sprinkler cooling systems

Over-tree sprinkler cooling system, with tall risers.

Over-tree sprinkler cooling system, with water delivery pipes attached to tensioned wires.

Design and operation of over-tree sprinkler cooling systems

Every over-tree sprinkler cooling system should be carefully designed to ensure adequate water can be delivered when and where it is required.

Poly delivery pipes for the cooling system are usually run beside the irrigation delivery poly pipes, with tall risers and emitters extending above the canopy. In some situations it may be possible to run poly pipes and emitters above the canopy, attached to wires stretched across tall trellis or net-supporting posts.

Water can be delivered to emitters above the orchard canopy with the existing irrigation system, with two taps in each row to redirect water from the irrigation lines to the over-tree lines. Operating this system requires extra labour which can be avoided by establishing separate valves and sub-mains for the over-tree system. The ideal labour-saving system would have a completely separate control system, with a separate pump, valves, mains and sub-main delivery pipes. Seek professional advice when designing a new cooling system.

Some of the factors to consider when designing a cooling system include:

a. Water delivery rate

Fruit in an orchard will become cooler when the cooling effect of water on fruit is greater than the heating effect of sunlight and warm air. The heat energy coming into an orchard in the middle of a hot summer's day (35°C, clear sky) is approximately 800 Watts per square metre. The amount of water that can be evaporated with that amount of heat energy is estimated to be about 3.1 litres per second per ha. However, heat energy is also carried into the orchard by wind and is estimated to be almost as much as the energy from sunlight, so the flow of water to neutralise the total heat load on the orchard is estimated to be approximately 6.2 litres per second per ha (Evans 2004). This and the following estimated flow rates are a guide only and the optimum flow rates will depend on many local weather and orchard conditions.

Aerial evaporative cooling uses application rates up to 6 litres per second per ha. Very little or no water reaches the ground. With swirling air currents and wind, water droplet and cool air distribution is often not uniform. This process is not very effective at lowering fruit surface temperatures and there is a possibility that damaging concentrations of salt from the evaporating water may accumulate on fruit and leaves (Evans & Van der Gulik 2011).

Hydro-cooling uses application rates that are significantly greater than 6.5 litres per second per ha. The amount of water entering the root zone must be carefully co-ordinated with irrigation to ensure the crop's water needs are met and to prevent waterlogging. Normal irrigation applications should be reduced to take into account the volume of water reaching the orchard floor and entering the root zone. It may be very difficult to prevent waterlogging. The soil surface often becomes saturated, with some runoff (Evans & Van der Gulik 2011).

Surface Evaporative Cooling uses application rates around 6.0 to 6.5 litres per second per ha. This is the most effective way to achieve cooling for sunburn protection while minimising water use. It may be possible to save some water by using sprinklers that direct water to the tree canopy, while avoiding wetting the inter-row space (Evans & Van der Gulik 2011). A small amount of run-off may be necessary to prevent a build-up of salt on fruit and leaves.

b. Cycled water delivery to maximise surface evaporative cooling

It is possible to design water delivery and control systems to cover a bigger area with a similar amount of water by using cycled or pulsed applications. Flow rates should be higher at 9.3 litres to 12.5 litres per second per ha, running for at least 15 to 20 minutes, before shutting-off or diverting the flow to another part of the orchard. Water should be turned on again when free water on the surface of the fruit has evaporated and when fruit temperatures are increasing above a pre-selected value. This might be after 20 to 40 minutes (Evans & Van der Gulik 2011). Larry Schrader, from Washington State recommends 10 minutes ON, 20 minutes OFF, but on extremely hot days this should be 8 minutes ON, 16 minutes OFF. This should keep the fruit skin temperature in the safe zone, below 42°C.

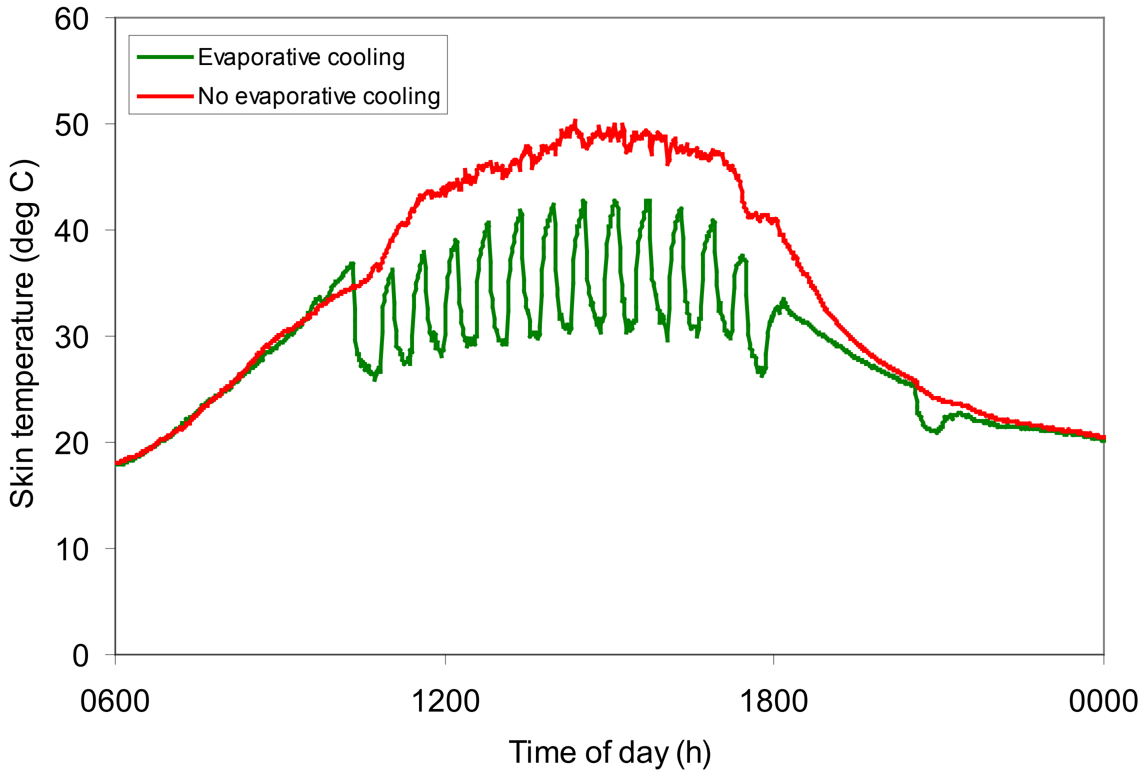
In a local case study in a high-density, central leader Royal Gala apple orchard near Shepparton during January 2011, a flow rate of 6.2 litres per second per ha (2.2 mm/hr) caused significant run-off in the inter-row space. Pulsed water delivery, with 20 minutes ON, 15 minutes OFF, reduced water-use and run-off and maintained fruit surface temperatures below 42°C (Figure 2).

c. When to start the over-tree sprinkler cooling system?

The season, the time of day and ambient air temperatures can be used to estimate when the risk of sunburn is highest and therefore, when to apply cooling. For example, you might choose to start the cooling system about midday to 6.00pm during the summer months when air temperatures reach 35°C. Shaded (or screened) thermometers could be placed in the orchard, or air temperature sensors could be installed in the orchard canopy to give warning of potentially damaging temperatures.

However, as stated previously, fruit surface temperature is the most accurate indicator of sunburn risk. Larry Schrader developed artificial fruit containing surface temperature sensors, which were placed in sunlit positions in the orchard canopy to provide warnings of imminent sunburn (Schrader et al. 2004). He recommended evaporative cooling should go ON when the fruit surface temperature reaches 40°C and it should go OFF when the surface temperature drops to 35°C.

Figure 2. The effect of pulsed surface evaporative cooling on fruit surface temperatures in a Royal Gala apple orchard near Shepparton (watering cycle: 20 minutes ON, 15 minutes OFF).



(Graph from Ian Goodwin, DPI-Tatura)

d. How often are we likely to start the over-tree sprinkler cooling system?

If we were to use long-term records of shaded air temperatures at Benalla to give an indication of the number of hot days in the year (Table 2), sunburn control would be required on:

- 60 days when 30°C is the threshold
- 14 days when 35°C is the threshold
- 1 day when 40°C is the threshold.

e. Water emitters for surface evaporative cooling

Droplets should be large enough to prevent excessive drift and to downwardly penetrate the tree canopy to wet the fruit and leaves at the bottom of the canopy. Typical spacing for risers and emitters is 5 metres, with a 6-metre wide spray pattern.

f. Irrigation scheduling

The amount of water used for over-tree sprinkler cooling should not be considered to be a one-for-one substitution for irrigation. A rough estimate for cycled surface evaporative cooling, based on recommendations from the USA by Evans (2004), is that only 15 to 20 per cent of the water used for cooling could be considered to contribute to the normal irrigation water budget. Total orchard water use, including irrigation and cooling, may increase by 25 to 40 per cent when surface evaporative cooling is introduced (Evans 2004). For example, an orchard that used 6 Mega Litres per hectare per year (ML/ha/yr) for general irrigation could be expected to use at least an extra 1.5 to 2.4 ML/ha/yr when surface evaporative cooling is adopted.

Hydro-cooling will contribute far more water than the orchard requires if the normal irrigation schedule is maintained. Waterlogging will occur if the normal irrigation schedule is not modified.

Aerial evaporative cooling would contribute very little to the normal orchard irrigation water budget.

It is very difficult to schedule irrigations to closely match crop water requirement in orchards that are cooled with over-tree sprinklers. Soil moisture monitoring is essential to confidently avoid waterlogging from over-irrigation and moisture stress from under-irrigation.

g. Other uses

Over-tree sprinkler systems can be used to aid colour development in red-blushed apples. Colouring is directly proportional to the time the fruit is at, or close to 20°C. Four to six weeks prior to harvest the cooling system can be used to rapidly cool the fruit at the end of the day. For example, turn on cooling 30 minutes before sunset, and turn off 20 to 40 minutes after sunset; also possibly turn on for one hour after sunrise. Note that this management may delay the maturity of apples (Evans & Van der Gulik 2011).

Over-tree cooling sprinklers may provide some frost protection in the cooler months. Sprinklers delivering 6.2 litres per second per ha (i.e. 2.2 mm/hr) can raise temperatures by 2 to 3°C on frosty mornings. However over-tree cooling sprinklers are not generally recommended for frost protection because they generally do not deliver enough water for effective control. Even with higher water delivery rates growers should be cautious because there could be severe damage to fruit if the water supply fails and residual water freezes on the blossoms.

Advantages of over-tree sprinkler cooling systems

- Less sunburn allowing better pack-outs of quality fruit
- May be used to enhance colour development in red and red-blushed apples

Disadvantages of over-tree sprinkler cooling systems

- Requires a higher level of management
- Requires extra capital establishment and running costs
- May increase the incidence of foliar diseases, like apple scab
- Will increase the risk of waterlogging (but not with aerial evaporative cooling)

- May increase the risk of salt deposition on fruit and leaves (especially with low quality water and low, misting application rates)
- May interfere with spray programs (washing off sprays and limiting the time when spraying can take place)
- Will normally increase total orchard water use
- If you stop over-tree sprinkler cooling during hot weather (e.g. system failure), apples are more likely to suffer sunburn.

Economics of over-tree sprinkler cooling systems

Cost:

Annual costs will include water, energy for pumping and maintenance costs. The initial capital cost depends on existing infrastructure and your plans for the orchard.

Final cost of the capital investment will depend on how much of the orchard you plan to provide with over-tree sprinkler cooling. A key limiting factor to the extent of the cooling system will be the water delivery rate. Water supply must be able to cope with the usual peak irrigation demand, as well as the extra demands for cooling. A cooling system that can provide protection for the whole orchard during a heat wave will be large and expensive. It will be necessary to do some strategic planning to decide on the area to be protected and the level of investment required.

It may be possible to protect smaller areas of orchard with the existing pump and main-line delivery pipes. Within an orchard block it is advisable to install a new water delivery system for cooling which runs parallel with the irrigation system. The cost of this in a high-density, trellised orchard block is likely to be similar to the cost of establishing a microjet irrigation system (about $2,000 to $3000 per ha). A method for assessing the break-even value of capital investment in over-tree sprinkler cooling is presented in Appendix 2.

Overview

Northern Victoria is one of the most important fruit producing regions in Australia, supplying fresh fruit to a market that usually demands attractive-looking fruit with no visible blemishes. There is usually zero tolerance for visible sunburn.

High summer temperatures, combined with clear-sky days can limit the health, vigour and yield of fruit trees, but the most obvious damage is through sunburn of the fruit.

Sunburn is a significant cost to the industry. Currently orchardists in northern Victoria estimate that 6 to 30 per cent of their produce is damaged by sunburn. Predicted weather trends indicate an increase in the number of hot days, which is likely to increase the level of sun damage and costs to the industry.

Fruit growers have options to cope with increasing hot days. Continued adaptation is essential to maintain orchard profitability.

In summary, there are two main adaptation strategies to cope with increasing temperatures:

1. Modify orchard management
   For example - different tree canopy structures, spray-on sun protection products, better irrigation scheduling, different types of fruit; and

2. Build protective infrastructure
   For example - shade netting and evaporative cooling systems.

There is very little independent published information on the relative effectiveness of the various sunburn protection options in an Australian environment. The spray-on sun protection products are not classed as agricultural chemicals and therefore do not require registration with the Australian Pest and Veterinary Medicines Authority, further restricting the availability of independent information on these products. The industry is already responding with many orchardists investing heavily in sun protection options. Currently, these innovative orchardists can provide the best source of objective information on the relative effectiveness of the various options (see Case Studies in this manual).

References

- Australian Climate Change Science Program: CSIRO and Bureau of Meteorology. Copyright 2007-2010. Climate Change in Australia website. Available: http://www.climatechangeinaustralia.gov.au (Accessed: Nov. 2010).
- Bound, S., 2010. Effective use of thinning tools. Tree Fruit, Magazine. August, pp. 6-9.
- Brown, G., 2009. Minimising sunburn damage of fruit. Australian Fruitgrower (magazine), February, 3(1); 14-18, Apple and Pear Aust. Ltd.
- Evans, R.G., 2004. Energy balance of apples under evaporative cooling. Transactions of the American Society of Engineers. 47(4); 1029-1037.
- Evans, R.G. and van der Gulik, T.W., 2011. Irrigation for Microclimate Control. Chap. 29. L. Stetson, editor. Irrigation. 6th Edition. The Irrigation Association. Falls Church, VA. (In press).
- Felicetti, D.A., Schrader, L.E., 2008. Photooxidative sunburn of apples: Characterization of a third type of apple sunburn. Int. J. Fruit Sci. 8(3), 160-172. DOI: 10.1080/15538360802526472.
- Glenn, D.M. and Puterka, G.J., 2005. Particle Films: A New Technology for Agriculture. In Horticultural Reviews, Volume 31. Edited by Jules Janick. John Wiley & Sons, Inc..
- Glenn, D.M., 2009. Particle film mechanisms of action that reduce the effect of environmental stress in "Empire" apple. J. Amer. Soc. Hort. Sci. 134(3):314-321.
- Holmes, R., Crisera, M., Brown, G., 2009. Harvest and post harvest options for heat affected apples and pears. Australian Fruitgrower (magazine), March, 3(2): 8-10, Apple and Pear Aust. Ltd.
- Middleton, S., 2010. Manage apples under netting. Tree Fruit (magazine). June 8-9.
- Rigden, P., 2008. "To net or not to net". Third edition. State of Queensland, Department of Primary Industries and Fisheries, Brisbane. http://www.dpi.qld.gov.au/16_12622.htm (Accessed: 21 April 2011).
- Schrader, L., 2011. Scientific basis of a unique formulation for reducing sunburn of fruits. HortScience 46:6-11.
- Schrader, L., Zhang, J., Sun, J., 2003a. Environmental stresses that cause sunburn of apple. Acta Hort. 618, 397-405.
- Schrader, L., Sun, J., Felicetti, D., Seo, J., Jedlow, L., Zhang, J., 2003b Stress induced disorders: Effects on apple fruit quality. Washington Tree Fruit Postharvest Conference, 2 – 3 December, Wenatchee, WA; http://postharvest.tfrec.wsu.edu/PC2003A.pdf (Accessed: 21 April 2011).
- Schrader, L., Sun, J., Zhang, J., Tian, J., 2004. Stressed out by sunburn? Here's some relief. A new technology for growers. Proc. Washington State Horticulture Association (100th meeting), pp.98-100.
- Van den Ende, B., 2004. Prevent sunburn of Granny Smith apples, Northern Victorian Fruitgrowers Association Technical Bulletin, June.
- Zhang, J. and Schrader, L., 2010. Interactive Sunburn Model. Washington State University Tree Fruit Research and Extension Center. Available: http://www.hort.tfrec.wsu.edu/pages/Sunburn (Accessed: 2 February 2011).

Appendix 1 – Case Studies

Case study 1

Jason Shields, Plunkett's Orchards, Ardmona
Apples and pears, 22 June 2010

NB: The 'Black Saturday' heat wave was in the 2008-09 season.
All figures are estimates and should be regarded as approximations.

1. What percentage of your total fruit production was damaged by sunburn in the last two seasons (2008-09 & 2009-10)?

2008-09: approx. 30 per cent
2009-10: approx. 20 per cent

2. What was your loss of income due to sunburn damage on your fruit in the last two seasons (2008-09 & 2009-10)?

2008-09: approx. $300,000
2009-10: approx. $200,000

3. Of the fruit blocks and varieties that had sunburn damage in the last two seasons, what was the percentage of damage for each block and variety?

Granny Smith, 2008-09: 35 – 40 per cent; 2009-10: 30 per cent
Pink Lady, 2008-09: 20 to 25 per cent; 2009-10: 10 to 15 per cent
NB: All were treated with spray-on sun protection.
We consider normal sunburn damage for Granny Smiths in the Goulburn Valley to be approx. 60 per cent.

4. Do you think there has been increasing sunburn damage on fruit over the last 10 years?

No, but the market has become more demanding. E.g. The market demands Granny Smiths with uniform dark green colour; no red blush or yellowing.

5. Describe the sunburn protection methods that you have used.

a. Regular use of Spray-on Sun Protection: four different products (clay, calcium and wax based).
b. Shade Netting.

6. What was the cost of the sunburn protection methods that you have used (block by block)?

a. Spray-on: approx. $10/bin or $1000 – $1200/Ha for the season; i.e. 5 – 7 sprays (includes extra time for pre-mixing clay-based products).
b. Netting: approx. $40,000/Ha (net is estimated to last at least 10 years, while the structure could last indefinitely).

7. What was the percentage reduction in sunburn damage due to the sun protection methods used (block by block)? Estimate the increase in income.

* **Spray-on product** observations from a trial done by Plunkett's Orchards in 2009-10 season:
Variety Gala, 3 replicates, 5 applications of product.

Product	Total fruits sampled	Marketable fruit %	Change in marketable fruit %	Change in Major burn %	Change in Minor burn %
Calcium-based (fertiliser)	112	91	+7	-5.6	-1.9
Clay-based	100	85	+1	-5.2	+3.8
Wax-based	104	89	+5	-3.4	-1.5
Control	97	84	0	0	0

Plunkett's conclusion:
For this season only small benefits were observed from using spray-on sun protection products.

* ***Shade netting*** observations from a trial done by Plunkett's Orchards in the 2009-10 season:
Variety Granny Smith from two sites; Undera – Netted; Home – Not netted

Sunburn gradings:
Grade 1 – Very light brown blush; could be marketed as second grade fruit, but will probably go off in storage.
Grade 2 – Visible light brown mark.
Grade 3 – Visible dark brown mark; Grade 4 – Visible dark brown mark, sunken.

Treatment	Good fruit %	Red Blush %	Sunburn Grading			
			1	2	3	4
Net	86	9	1	6	0	0
No net	57	11	15	10	6	0

Netting: Doubled the income from the Granny Smith block; no shade netting 2007-08 income was $150/bin; 2009-10, shade netting, income was $300/bin.

In the year before shade netting was established at Undera, in five-year-old trees:
Good Fruit was 35 per cent, Grade 1 & 2 was 35 per cent and Grade 3 & 4 was 30 per cent.

Under the net at Undera, there was no apparent difference in sunburn damage between the 2008-09 season and the 2009-10 season.

(NB. These results are for a relatively small sample in one season and have not been subjected to statistical analysis. Do not base decisions on these results alone).

8. Describe any additional benefits that you think might have arisen from using the sun protection methods (block by block)? e.g. protection from hail, birds, wind, etc. Estimate the increase in income.

Netting: Protection from hail, wind, birds; Water savings - approx. one third.

**9. Describe any negative effects that you think might have arisen from using the sun protection methods (block by block)? e.g. pollination, waterlogging, disease, etc.
Estimate the loss of income.**

Shade netting:
Bees definitely do not like shade netting; we routinely use bee hives inside the net, but the extra shade may still affect the bees.
Powdery mildew is more of a problem, but it can be controlled with sprays.

Spray-on:
This may increase the pressure of some insect pests (e.g. codling moth), due to the product reducing the coverage and effectiveness of certain insecticides (especially the newer insecticides).

10. Describe any plans that you might have to expand the use of sun protection in your orchard/s.

All new orchard developments will use longer posts for the trellis posts to allow easier installation of netting, i.e. Combine trellis posts with the netting structural frame. Also, while the irrigation system is being installed, all new orchard developments will probably include extra sub-mains for evaporative cooling within the orchard canopy.

Other Comments:
It is important to maintain good, healthy trees to maintain their resistance to sunburn.

Case study 2

Maurice Silverstein, Silver Orchards, Orrvale
Apples and pears, 2 September 2010

NB: The 'Black Saturday' heat wave was in the 2008-09 season.
All figures are estimates and should be regarded as approximations.

1. What percentage of your total fruit production was damaged by sunburn in the last two seasons (2008-09 & 2009-10)?

2008-09: approx. 10 – 20 per cent
2009-10: approx. 10 per cent
Mostly due to lower grade Granny Smith and Gala apples

2. What was your loss of income due to sunburn damage on your fruit in the last two seasons (2008-09 & 2009-10)?

2008-09: approx. $50,000 - $100,000
2009-10: approx. $50,000
(Based on an average price of $250/bin for 4,000 bins; losses per bin varied from $10 to $50).

3. Of the fruit blocks and varieties that had sunburn damage in the last two seasons, what was the percentage of damage for each block and variety?

2008 - 09:
Granny Smith, under net approx. 2 per cent; out-of-net approx. 10 per cent
Gala, 30 – 75 per cent
Pears, 5 – 10 per cent

2009 – 10:
Granny Smith, about the same as last season
Gala, with over-tree sprinklers at the hottest times approx. 1 – 2 per cent; without over-tree sprinklers approx. 5 per cent

4. Do you think there has been increasing sunburn damage on fruit over the last 10 years?

Yes. Because of hotter, drier weather, drought, water shortages. It has been necessary to modify farm practices to prevent an increase in sunburn damage.

5. Describe the sunburn protection methods that you have used.

a. Spray-on sun protection on apples, including clay and wax based products.
b. Fold-back, black shade netting over Granny Smith apples; net is folded back to avoid potential problems with reduced bee activity, excessive tree vigour, increased fungal disease, increased woolly aphid infestation.
c. Over-tree sprinklers on Gala apples; used only in the hottest weather; we used the normal irrigation system to deliver water, with each row having paired taps to divert water between the irrigation emitter poly line and the over-head cooling poly line.

6. What was the cost of the sunburn protection methods that you have used (block by block)?

a. Spray-on: Used less than recommended number of applications; was not impressed with the result. We heard of a local reseller using a specialised sprayer that could deliver spray-on products from above the tree canopy.
b. Netting: approx. $30,000/Ha, but we installed the system ourselves.
Net is estimated to last at least 10 years, while the structure could last indefinitely.
Labour to spread or retract the netting is approximately two workers with cherry pickers for one day per hectare..
c. Over-tree sprinklers: This is an improvised system using poly pipe from an old orchard and new 'Snap Jet' sprinklers delivering 25 – 35 Litres/hr, one emitter per tree at a spacing of 2 – 2.5 metres. The poly pipe is attached to the top of apple trees which are trained as central leaders; Labour for installation was approximately two workers with cherry pickers for three days per hectare.

7. What was the percentage reduction in sunburn damage due to the sun protection methods used (block by block)? Estimate the increase in income.

It is difficult to estimate because a lot of the sun damaged fruit is dropped on the ground at picking time. A rough estimate for Granny Smith apples is that the use of netting doubled the income from the fruit which was packed and sold. In the packing shed, sun protection (i.e. netting with Granny Smith apples and overhead cooling with Gala apples) allowed 10 to 12 per cent more fruit to be packed.

8. Describe any additional benefits that you think might have arisen from using the sun protection methods (block by block)? e.g. protection from hail, birds, wind, etc. Estimate the increase in income.

Netting: Protection from hail, less wind-rub damage and there would be some water savings.
Overhead cooling: Perhaps increased colour in Gala apples; the trees and the inter-row looks greener and fresher.

9. Describe any negative effects that you think might have arisen from using the sun protection methods (block by block)? e.g. pollination, waterlogging, disease, etc. Estimate the loss of income.

Over-tree sprinklers: We use more water, but only during the hottest days; there have been no obvious problems; it is possible that the last spray will be washed off resulting in more storage rots.
There were no obvious problems with using netting and spray-on sun protection.
NB. With fold-back netting you may have periods when there is no protection from hail.

10. Describe any plans that you might have to expand the use of sun protection in your orchard/s.

All new apple blocks have been designed with netting support structures which will allow net to be installed more easily at a later date for hail and sunburn protection. Also, new apple blocks will be installed with additional sub-main water delivery pipes for possible future installation of over-head sprinklers for cooling and frost control.

Case study 3

Chris Turnbull, Turnbull Brothers Orchards, Ardmona
Apple and pears, 2 September 2010

1. What percentage of your total fruit production was damaged by sunburn in the last two seasons (2008-09 & 2009-10)?

2008-09: approx. 6 per cent
2009-10: approx. 8% per cent
Mostly due to lower grade Granny Smith apples

2. What was your loss of income due to sunburn damage on your fruit in the last two seasons (2008-09 & 2009-10)?

2008-09: approx. $140,000
2009-10: approx. $220,000
(Estimated loss $60/bin)

3. Of the fruit blocks and varieties that had sunburn damage in the last two seasons, what was the percentage of damage for each block and variety?

In both seasons:
Granny Smith, 20 to 25 per cent
Gala, 15 to 20 per cent
Williams pears, 10 – 15%

NB:
2008 – 09: Only about 12 per cent of all the harvested apple bins had been treated with clay-based spray-on sun protection.
2009 – 10: Only about 26 per cent of all the harvested apple bins had been treated with clay-based spray-on sun protection.

4. Do you think there has been increasing sunburn damage on fruit over the last 10 years?

No

5. Describe the sunburn protection methods that you have used.

a. Regular use of spray-on sun protection on apples: Clay-based products. We will consider using spray-on sun protection in pears.
b. Shade Netting: only 1 Hectare of black netting over Granny Smith apples, so far.

6. What was the cost of the sunburn protection methods that you have used (block by block)?

a. Spray-on: approx. $400/Ha for the season; i.e. 3 – 4 applications, including extra time for pre-mixing and operating the machinery (approx. $100/application).

b. Netting: approx. $50,000/Ha
Professional installation; approx. 20 per cent sunlight reduction.
(net is estimated to last at least 10 years, while the structure could last indefinitely).

7. What was the percentage reduction in sunburn damage due to the sun protection methods used (block by block)? Estimate the increase in income.

* Spray-on product resulted in 5 to 10 per cent improvement in the quality of apples (estimate).
* Shade netting was installed only 12 months ago and the fruit are not packed yet, but we estimate there is a 60 per cent improvement in Granny Smith apple fruit quality.

8. Describe any additional benefits that you think might have arisen from using the sun protection methods (block by block)? e.g. protection from hail, birds, wind, etc. Estimate the increase in income.

Shade netting: Protection from hail, less wind-rub damage and there would be some water savings.

9. Describe any negative effects that you think might have arisen from using the sun protection methods (block by block)? e.g. pollination, waterlogging, disease, etc. Estimate the loss of income.

Shade netting:
- Bees are less active under shade netting; less seed development in the fruit reducing potential fruit size.

- Bud and flower development is weaker, with smaller buds and some possible yield reductions.

- Trees tend to be more vigorous, with approximately doubling of the water shoot lengths.

Spray-on:
Our packer said they had some trouble removing clay from harvested fruit using plain water.

10. Describe any plans that you might have to expand the use of sun protection in your orchard/s.

We will continue to use some spray-on sun protection and we intend to try it on pears.
We are working on improving our management of trees under netting and intend to increase our use of netting for sun protection on established apple trees and maybe also on pears.

In new plantings of apples we will consider orchard over-tree sprinkler systems for frost control, colour development in red apples and orchard cooling to reduce sun damage.

Case study 4

Luciano Corallo, Strawberry Springs, Milgrove
Strawberries, 21 December 2010

All figures are estimates and should be regarded as approximations.

1. What are your main farming enterprises?

Since 1995 growing, packing and marketing strawberries.
We have been at Strawberry Springs since 2000.
Previous experience in retail marketing of fruit and vegetables.

2. What area do you normally crop with strawberries?

12 Ha (30 acres).
Half a million plants per year.

3. What is your normal strawberry production?

- Production: Average yield is 1kg per plant of marketable fruit. The plants have the capacity to yield 1.5 to 2kg per plant. It is normal to lose 30 to 50 per cent of the fruit to adverse weather.
- Types of damage: wind, wetness, heat, humidity.

4. What area is normally protected by shade netting?

30 per cent of the farm is covered by shade netting.

5. Describe the shade netting that you use

Pearl coloured, quad netting providing 10 to 15 per cent shade, flat and gabled.
We tried gabled netting first, but now we use flat netting because it allows wider spans between the posts and more space to work machinery. Gables provide more wind protection, but there is more wear-and-tear. Post heights above the ground are 4.5 to 3.5 metres with the gabled design and 4.7 metres with the flat design. The gabled design allows hail to fall through the bottom of the 'valley', while flat netting is designed to stretch. Cables that hold the flat netting are more likely to require re-tensioning after a hail event. Netting is generally not used on the sides of the covered area. Although side netting is very good for reducing wind damage, we often require wind to dry the paddock quickly to reduce disease. This applies especially in autumn when plants are bigger and denser. We need to find the right balance.

6. Describe the benefits of having shade netting over strawberries. (Estimate percentage losses with and without netting).

Better and more uniform plant establishment resulting in stronger plants with 15 to 20 per cent better yields and 50 per cent less low-value, small fruit (20 per cent reduction in size is enough to downgrade strawberries).
Sunlight affects ripening of strawberries and research from Israel has shown that pearl coloured netting is the best to achieve uniform ripening.

More uniform size and ripening has secondary economic benefits, i.e. picking rate increased by 20 per cent and packing rate increased by 30 per cent (greater worker efficiency). Also at least 20 per cent greater water use efficiency, due to less sunlight and wind.

7. What is the cost of establishing shade netting over strawberries and how long will it last?

About $50,000 per ha (supplied and assembled by Netpro). The netting should last for 10 to 15 years.

8. Describe the disadvantages of having shade netting over strawberries. (apart from the cost).

- They have a significant impact on the appearance of the local landscape that some people find unattractive.
- Additional wetness and humidity in autumn due to less air movement and sunlight while the plants are large and dense can make it more difficult to control fruit rot and other diseases. This is usually not a serious problem in a normal year.

9. Have you used other techniques to protect strawberries from weather? (Please describe costs and benefits).

The use of irrigation to cool the plants on extremely hot days. This has been effective in preventing heat damage.

10. Describe any plans that you might have to expand the use of weather protection on your farm.

We are trying Haygrove Tunnels for the first time. They are being installed now. They are 7.5 metres high and cover five rows. Humidity and heat may be a problem but we can open the sides to increase air movement. They cost about $60,000 per hectare plus $10,000 to $20,000 for assembly.

Appendix 2 – Estimating the pay-back period for shade netting and over-tree sprinkler cooling

This section presents a simple method that growers can use to estimate the ***minimum annual losses*** from full sun exposure that would justify an investment in sun protection infrastructure over three specific pay-back periods. You must estimate the cost of establishing the sun protection infrastructure and then the annualised cost of the investment must be less than your expected annual losses from full sun exposure to make the investment worthwhile. This method can be applied to netting and over-head sprinkler cooling systems. The method assumes the annualised cost of the new infrastructure is the same throughout the specified period, i.e. there is no inflation and therefore interest rates and the level of financial risk stay the same. The specified pay-back periods are two, five or ten years. It is assumed the salvage value of the capital investment will be zero at the end of the specified time period.

Steps to follow to apply the method are:

1. Estimate the capital cost of the investment (e.g. $/ha)
2. Estimate the annual maintenance and operating costs (e.g. $/ha/year)
3. Choose the number of years you would like your investment to break even (2, 5 or 10 years).
4. Choose the rate of return you would like to receive from the investment (6, 7, 8 or 9 percent). Alternatively consider the rate of return you could get from investing the money elsewhere; such as in a term deposit.
5. The maintenance and operating costs over the life of the investment need to be converted into today's dollars. This is to account for the fact that if you invest a dollar today at 6 percent, at the end of the year the dollar will now be worth one dollar and six cents. Step 5 accounts for this change in value of money spent over the life of the investment.

   Multiply the annual maintenance cost (in **Step 2**) by the number from the appropriate cell (below) corresponding to the chosen number of years to break-even and the chosen rate of return (**Steps 3 and 4**); this is Factor 1.

   Factor 1 values (Present value of an annuity)

Interest rate	Number of years to break-even		
	2 years	5 years	10 years
6%	1.8334	4.2124	7.3601
7%	1.808	4.1002	7.0236
8%	1.7833	3.9927	6.7101
9%	1.7591	3.8897	6.4177

6. Add the estimated capital cost of the investment (in **Step 1**) to the answer in **Step 5**. This will give the present value of the total cost for the life of the investment.
7. Multiply the answer in **Step 6** by Factor 2 from the cell with the corresponding number of years and rate of return. This will be the minimum loss every year from full sun exposure that would need to occur for the investment to break-even given your chosen number of years and rate of return. Compare this with your own estimate of expected losses without sun protection (you might want to include estimates of secondary risks, like hail damage).

   Factor 2 values (Annuity whose present value is one)

Interest rate	Number of years to break-even		
	2 years	5 years	10 years
6%	0.5454	0.2374	0.1359
7%	0.5531	0.2439	0.1424
8%	0.5608	0.2505	0.1490
9%	0.5685	0.2571	0.1558

8. You can convert the answer in Step 7 to number of tonnes of lost fruit by dividing it by your price per tonne.

Worked examples estimating the annual loss that would make investment in sun protection infrastructure worthwhile over specific periods (2, 5 and 10 years)

Steps	Example 1: Shade netting	Example 2: Over-tree sprinkler cooling
1. Cost of the investment	$40,000/ha This is the total cost of netting and structure.	$3,500/ha This is total cost of emitters, poly pipe, sub-mains and valves added onto an existing system.
2. Maintenance and operating costs	$400/ha/year	$498/ha This is made up of: - Total pumping costs: $25/ha/year. - The system operates for 10 days and operates 6 hrs/day (60 hrs/ha). - Water use is 6 L/sec/ha or 1.296 ML/hr/ha. Pumping cost is $19/ML. - Total water cost: $73/ha/year. Cost of high reliability water is $57/ML - Annual maintenance cost: $100/ha. - Total labour cost: $300/ha/year. Labour requirement is 1 hr/ha/day at $30/hr for 10 days/ha/year
3. Target year to break-even	10 years (effective life of netting)	2 years
4. Required rate of return	7 %	7 %
5. Total maintenance and operating costs over the life of the project in today's dollars	$400 x 7.0236 (Factor 1) = $2,809/ha	$498 x 1.808 (Factor 1) = $900/ha
6.Total cost of investment in to-day's dollars	$40,000/ ha + $2,809 / ha = $42,809/ha	$3,500 + $900 =$4,400/ha
7. Cost each year to pay-back the investment or the minimum loss from fruit sunburn that would enable the investment to break-even	$42,809 x 0.1424 (Factor 2) =$6,096/ha	$4,400 x 0.5531 =$2,434/ha
8. Minimum yield loss from sunburn at $800/t that would be required for investment to break-even	$6,096 ÷ $800/t = 7.6t/ha/year The minimum yield loss would be higher if the price is lower. For example if the price is $600/t, the minimum yield loss 10.2t/ha/year.	$2,434 ÷ $800/t =3t/ha/year The minimum yield loss would be higher if the price is lower. For example if the price is $600/t, the minimum yield loss 4.1t/ha/year.
Conclusion	Investment in shade netting would be worthwhile if your expected annual loss due to fruit sunburn was $6,096/ha/year or more for 10 years.	Investment in over-tree sprinkler cooling would be worthwhile if your expected annual loss due to fruit sunburn was $2,434/ha/year or more for two years

www.dpi.vic.gov.au

ADP-0098