Assessing the impacts of environmental covers on apple production input costs and benefits

2016

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Executive Summary

Producing the best quality fruit now and in the future in the face of a changing climate will require adaptation using alternative practices to mitigate stresses imposed on horticultural crops. The main factors affecting production of apples in the Riverland growing region is excessive heat and high solar radiation. Environmental netting is one option available to apple growers to manipulate the growing environment and better manage trees in challenging environments.

This report presents the first season of measurements taken as part of a three-year investigation of the effects of netting in an apple orchard in the hot Riverland climate. Results to date indicate that environmental netting has little effect on ambient air temperature and “feels like” or apparent temperature. Netting comes in a range of colours, but for a high light environment such as the Riverland a darker colour such as grey or black are advised by netting suppliers to have the greatest effect and for this study grey netting is being assessed. Light reduction/shading through the environmental netting is up to 25%, depending on the colour of netting used. This reduction in light can be significant over the whole growing season and also for a single high light day. Lower amounts of direct sunlight reduces heating of exposed surfaces such as leaves and fruit, preventing overheating and consequently reducing sunburn incidence. In the first season fruit damage from sunburn and wind under netting was greatly reduced under netting while yield was significantly greater.

Effects of the environmental netting on water use efficiency (WUE) are difficult to assess after only one season of observation. In this particular study there is a need for separation of irrigation between the netted and control blocks in order to quantify if there are any WUE improvements under netting.

The time the trees have spent under the cover, only 6 months from the start of the observation, is not long enough to argue there has been time to acclimatise to the new and changed environment. Further improvement of tree performance under the netting can be expected with time. The trees will adjust to the changed light environment and grow accordingly to maximize light interception. Also adjusting the management of trees to account for differences in growth outside and inside the netting will further increase differences in performance over time.

Overall netting seems to improve apple tree performance and enhance yield compared to the un-netted control. The time needed for cost recovery for the approximately AU$36,000 per hectare for the netting material and installation, and the potential water savings over time, need to be monitored for several years in order to analyse the financial efficacy of the netting.

1. Introduction

Horticultural industries are facing less and less favourable conditions for production. Not only are they competing with urbanization for land, but also increasingly inconsistent weather and changes in the overall climate (Shahak, 2012). There is also increasing pressure from the market for improved quality and reduced chemical use, as well as food safety and sustainability of production (Shahak, 2012). To satisfy demands and challenges new ways of production must be investigated and if shown to be effective adopted. An example of this is the use of environmental netting as a management option for apple production. Environmental netting for apple production has been proven to be effective in protecting fruit from damage through climatic factors such as hail (Amarante et al., 2011; Bogo et al., 2012; Jakopic et al., 2007; Middleton, 2004; Middleton and McWaters, 2004) and vertebrate/invertebrate pests mostly birds (Bomford and Sinclair, 2002; Dawson and Bull, 1970; Slack and Reilly, 1994; Tracey et al., 2007).

In South Australia (SA), the food, wine and fibre sectors generated approximately $18.8 billion in annual revenue and accounted for 44% ($4.8 billion) of SA's total merchandise exports in 2012-13. The Riverland and Murrayland regions currently represent about 14% (~$2.1 billion) of SA's annual food production (~$15 billion). More than half of the fruit produced in SA (58%) comes from these two regions. The Riverland contributes approximately 15% of the states apple production with the South Australian apple industry as a whole producing approximately 20,000 tons per year; therefore a major contributor to the state's economy (APAL, 2016).

In many production areas, there is increasing pressure to produce more sustainably, with fewer inputs particularly water and chemicals. A potentially more sustainable management option for producers is the use of environmental netting. Even though it is costly (approximately AU$36,000/ha) environmental netting is used in the Adelaide Hills, another major apple production region in SA. Nevertheless, some benefits have been reported in other growing regions in Australia and internationally. The main reasons for its use have been to reduce bird damage (Bomford and Sinclair, 2002), hail (Middleton, 2004; Middleton and McWaters, 2004; Middleton and McWaters, 1997), and sunburn (Agriculture.Victoria, 2011; Amarante et al., 2011; Darbyshire et al., 2015; Schrader et al., 2001). This report outlines preliminary investigations into the use of environmental netting in apple production in the Riverland region.

2. Methodology

2.1 Site description

To assess the influence of netting on apple production in the Riverland a trial was established in an apple orchard in Loxton, South Australia on mature 'Crisp Pink' trees (fruit sold as Pink Lady ™) planted in 2009 on M26 rootstock. The trees are generally in good health and have had very little problems with biennial bearing. The planting density within the row is 1 m and 4.5 m between rows – creating a planting density of 556 trees/ha. The posts supporting the netting are 6 m in height and therefore allow the canopy enough space to grow with sufficient airflow between the netting and the top of the canopy, which is at a height of 2 m.

Heat damage to the fruit from sunburn is reduced in the apple orchard (both netted and un-netted areas) through the application of sunscreens generally, potassium silicate at a cost of between $6-8 per application. These sunscreens are applied regularly and effectively in order to prevent fruit damage from sunburn.

The current irrigation system does not allow for separate and specific watering according to differences in water use under the netting and outside. The trees under the environmental cover and outside are therefore uniformly watered. Irrigation is run as three 1-hour cycles per day during the summer with an average application of 3.8 mL/ha.

After harvest, the application of irrigation is ceased or greatly reduced to induce leaf senescence and dormancy. Apple trees, even though they are deciduous, are not sensitive to day length, but rather to cooler temperatures that induce dormancy (del Real-Laborde et al., 1989; Heide and Prestrud, 2005). The weather conditions during autumn in the Riverland, as can be seen in 3.3.2, are nowhere near the temperatures needed to induce dormancy in apple trees, which should be closer to 5 to 15°C on average (Heide and Prestrud, 2005). Forcing the trees to shed their leaves though stresses such as drought will help induce dormancy (Bederski, 1987; Samish, 1954). In addition to drought stress, trees are sprayed with a combination of copper, zinc and urea to burn off the leaves (Bederski, 1987). Important is to get the mixture to a strength that allows for a relatively slow drop and does not cause sudden shedding of all leaves.

Dormancy overall is poorly understood but it is known and widely accepted knowledge that the tree will have to experience a sufficient amount of chilling units to release dormancy and have even bud break. Not fulfilling the chilling requirement sufficiently will lead to uneven bud break, prolonged flowering time, and other unwanted side effects of uneven development of the trees (Naor et al., 2003). To ensure a sufficient amount of chilling is accumulated in the Riverland climate a copper, zinc and sulphur mix are applied to the leaves earlier in the autumn to stimulate the trees to enter into dormancy.

2.2 Environmental netting

In March 2015 0.88 ha of apple trees were netted with a grey cloth 'Raschel Warped Knitted' with 20 mm^2 holes and a weight of 67 ± 5 g/m^2. The shading is about 20%, therefore, about 80% of sunlight is transmitted though the cloth (http://www.commercialnetmakers.com.au/pdf/20mmcross.pdf). The installation and netting cost are approximately AU$36,000 per ha. 0.56 ha of apple trees remain un-netted and are treated as the control trees in this investigation.

2.3 Data collection and measured parameters

2.3.1 Soil moisture

Soil moisture measurements in the Orchard (both inside and outside the netting) are performed with a Sentek EnviroSCAN Probe (Fig. 1 A and B) which records between 10 minutes and hourly data depending on the setup. Each tube can be equipped with a varying number of sensors. Around each sensor a high frequency electrical field is created that extends through the access tube into the soil. This is used to measure electrical capacitance and soil water content (Alva and Fares, 1998; Bell et al., 1987; Fares and Alva, 1998). Data interpretation is based on a calibration for Murray soils and can be adjusted over time depending on the data output. Using historic data as calibration can be very useful to capture minute differences in soil profile and response of each orchard to irrigation and rain events.

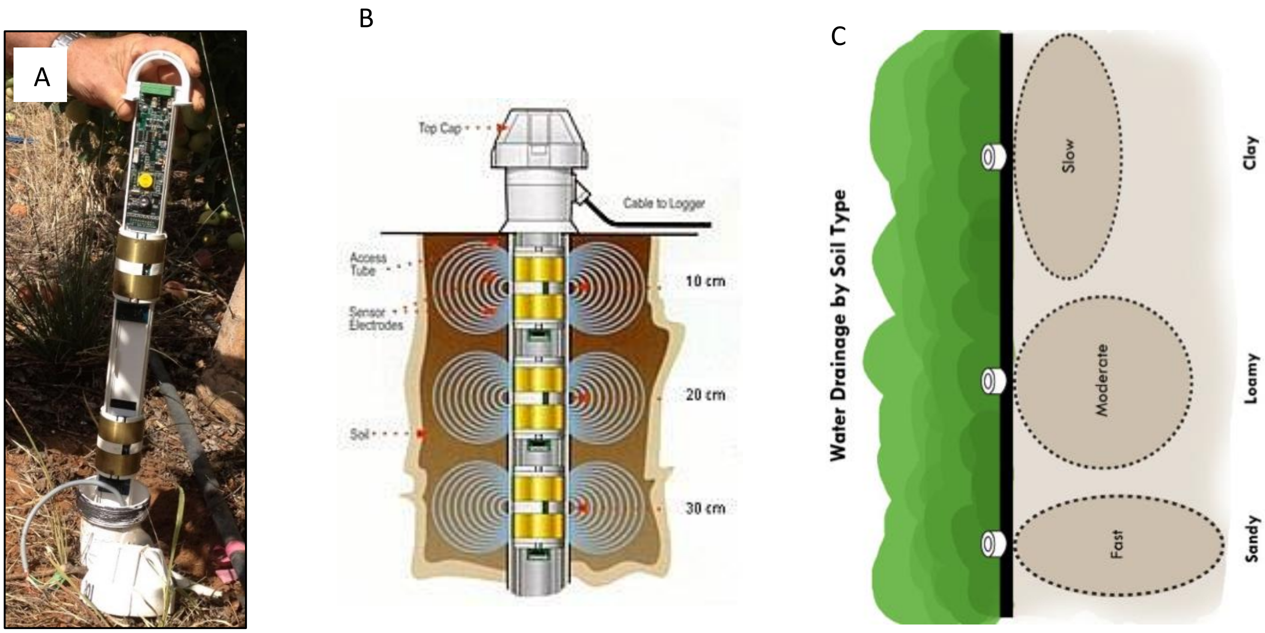

Fig. 1 *Soil moisture sensor EnviroSCAN by Sentek installed the apple orchard (A) – the measurements are done between 5 and 15 cm, 25 and 25 cm and so forth, the 10 cm span measures the conductivity of the soil in that region (how it is installed: http://www.sentek.com.au/products/enviro-scan-probe.asp#enviroscan) – B) Schematic of how the sensor measures the soil moisture (http://www.agralis.fr/index_fr.php?cat=produits&page=enviroscan); C) Soil wetting profile depending on soil type and dripper output speed (https://www.dripdepot.com/article/know-your-soil-type)*

The probe is installed approximately 10 cm from the dripper line to ensure the correct measurement of the soil moisture (Trevor Sluggett – personal communication). Wetting ability and the form of wetting profile changes with soil type and length of irrigations cycles (Fig. 1 C). Longer cycles of irrigation irrespective of the soil type will lead to a deeper and wider wetting of the soil, were as shorter pulses of irrigation will lead to more surface wetting (Raats, 1973; Smith, 1983). The soil moisture probe reaching down 110 cm into the sub-soil allows for monitoring of water runoff and over watering as well as profiling whether longer irrigation cycles can reach the lower profiles of the soil. Occasional irrigation down into the subsoil layers can have beneficial effects on the wetting profile and allow root growth into lower sections; depending on soil structure and profile, this can be desirable.

2.3.2 Weather data

The measurement of environmental data such as air and soil temperature are important to determine the effectiveness of the environmental netting in altering the growing conditions. For apple production in the Riverland most restricting is the heat. Excessive heat and radiation cause the fruit surface area to heat up to temperatures, which are detrimental to plant growth and fruit quality, causing sunburn on fruit and wood. Data from weather stations under the net and outside of the netting is presented to understand what factors are influenced by the application of netting.

The weather station outside the netting is a MEA (Measurement Engineering Australia) premium stations (MEA 103) (http://mea.com.au/soil-plants-climate/weather/weather-stations) equipped with wind speed and direction sensors, a sensor for solar radiation, temperature and humidity, a leaf wetness sensor, as well as soil moisture, soil temperature and rainfall meter. The station (MEA 104 – junior station) under the netting is equipped with the same wind meter and radiation sensor as the premium version. Only temperature and relative humidity are measured with slightly different sensors. Specifications for each of the stations can be found in the list below.

- **MEA103** (premium weather station) aluminium tripod frame and ProMAX data logger interface: WMS301 Wind speed/wind direction (WS/WD) sensor, HMP155 ambient temperature/relative humidity (AT/RH) sensor, LP02 GSR sensor, RIMCO8020 rain gauge
- **MEA104** (junior weather station) post mounted with MAX data logger interface in weather proof enclosure: WMS301 WS/WD sensor, HMP155 AT/RH sensor, LP02 GSR sensor, TB6 rain gauge

According to MEA the output of the two rain gauge types should be very comparable and the usually different sensors for wind (speed and direction) were upgraded in the junior stations to be the same models as used outside. Therefore the main differences remaining is the mounting on different post types and the data logger used to record the data.

2.3.3 Tree and fruit assessments pre-harvest

On 17th of March 2016 20 trees from outside and under the netting were photographed and evaluated for fruit damage. Images were taken to estimate leaf area index or ground area covered by each tree and canopy porosity to see whether there is a difference in light interception inside and outside the netting using an image analysis App called VitiCanopy (De Bei et al., 2016). Visual tree evaluations were made on the average amount of fruit per tree, comparative vigour, development of fruit colour, wind and sun damage (sunburn) on fruit and/or wood were made and are reported in the results section.

2.3.4 Fruit quality at harvest and post storage (Yield)

At harvest, fruit quality assessments include evaluation of fruit firmness (kg) on two sides of the fruit at the equatorial measured with a fruit penetrometer equipped with a 11 mm tip and fruit sweetness as total soluble solids concentration (SSC – Brix) was measured with a refractometer. A visual assessment of sun damage on 100 fruit (%) was performed on randomly selected fruit. Fruit maturity was assessed using the starch pattern index (SPI). This index is supplied through AgroFresh and is based on a 1 to 6 scale with 1 = full starch (all blue-black) to 6 = free of starch (no stain) (Fig. 29 – subliminal martial).

3. Results

3.1 Soil moisture

Soil moisture measures are used to extrapolate plant water use and water use efficiency. The only drawback is that the soil moisture sensor data only reflects the soil moisture and not plant transpiration, evapotranspiration off the soil surface and other environmental factors effecting water uptake and water use of the plant. Therefore, the data presented should be interpreted with this in mind. The graphs contain only the water content calculated within the soil based on a generic soil type and assuming the soil is relatively similar between the spots where the probes have been placed (Jabro et al., 2005). Variations in soil type and soil composition will change the water holding capacity of the soil. For analysis, it will be assumed that the soil inside the netted area and outside the net are very similar and that the soil is representative of the Murray River Area.

According to the soil moisture data logger (Fig. 2), outside the netting received slightly less water over the course of the season from 1st October 2015 to 1st April 2016 with approximately 3690 hectolitres (hL) vs. 4673 hL in the netted block plot; a difference of close to 1000 hL. The difference in total amount irrigated can be explained in a number of ways. Firstly, dripper distribution can be uneven and therefore the amount deposited at a certain position to that of the sensor for example, can differ. Therefore, it might seem that less water was applied, but it may be the way the dripper or the sensor were positioned relative to each other. Another explanation may be that the amount of water deposited by the dripper which was closest to the sensor outside the netting deposited less water over the season due to slightly lower pressure in that particular line. Other explanations could be a blockage in the dripper due to dirt.

Commercial production of apples is based on cloned material, generally scions grafted onto dwarfing rootstocks. The Loxton site has ‘Crisp Pink’ scions grafted onto M26 rootstocks. M26 is a dwarfing rootstock, which creates trees of approximately 3 m height at full growth (10 years after planting). The dwarfing rootstock has a relatively shallow rooting pattern, and deep subsoil irrigation might not be very beneficial for Riverland conditions. On the other hand if irrigation water is high in salts, shorter periods of watering with less water can cause salt crusting around the wetting zone which can lead to other problems such as poor water availability for the tree (Bravdo and Proebsting, 1993; Fereres et al., 2003; Levin et al., 1980; Pasternak, 1987; Sokalska et al., 2009).

Water is available differently to the plant depending on the depth of the soil. Irrigation applied in any manner will reach the top soil layers and only after the first soil profile has been filled to capacity will water though gravity and capillary traction be transported further down into the soil (Doran and Parkin, 1994). This happens for drip irrigation in a relative small soil area (Fig. 2). Never the less as shown in Fig. 3 the soil over the measured area (EnviroSCAN by Sentek 10 -110 cm soil depth) shows differentiation in how much water was received at different distances in the soil profile. The total measured amount of water in the soil (Fig. 3) is similar for both the netted and un-netted areas while the soil moisture profile at different soil depth is very different (Fig. 2).

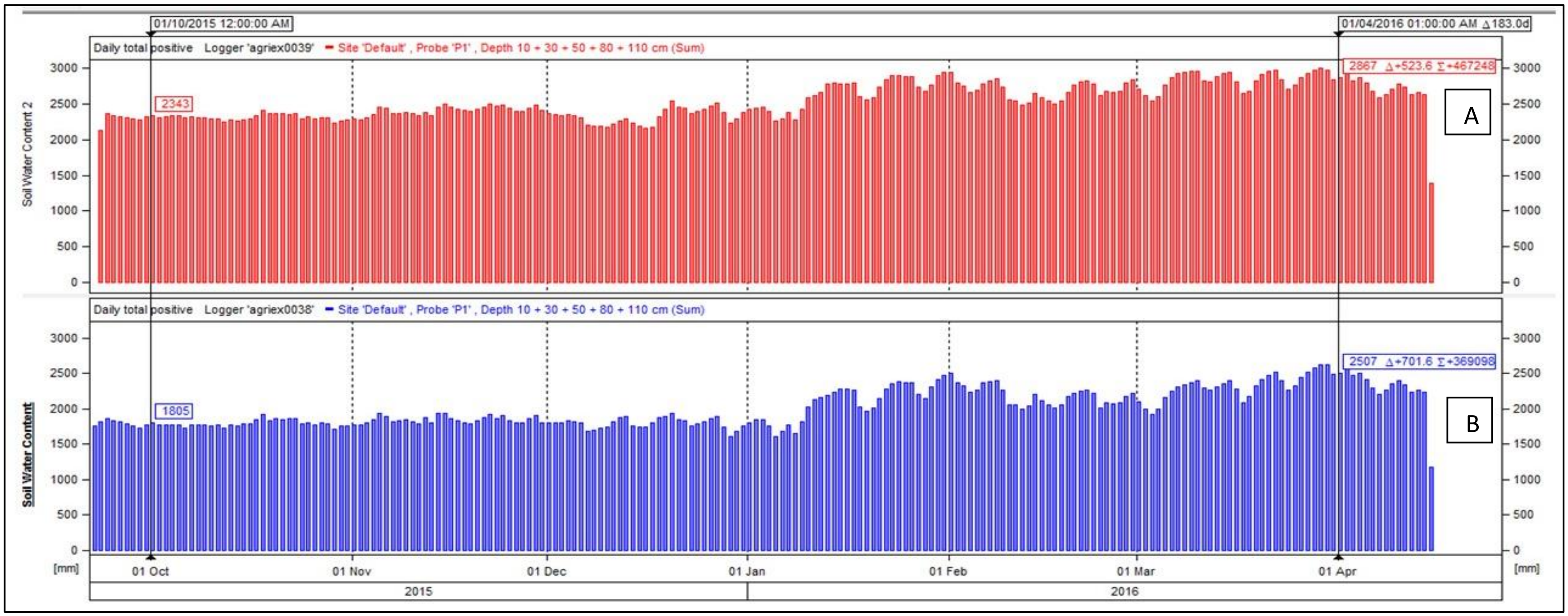

Fig. 2 *Total positive change in soil moisture content at the Loxton side – Top panel (A – Logger 39) is under the netting and (B – Logger 38) is outside the netting – Sum of total water content in the soil profile from 10 to 110 cm between 1. October 2015 and 1. April 2016 for A (netted): 467248 mm and B (un-netted): 369098 mm.*

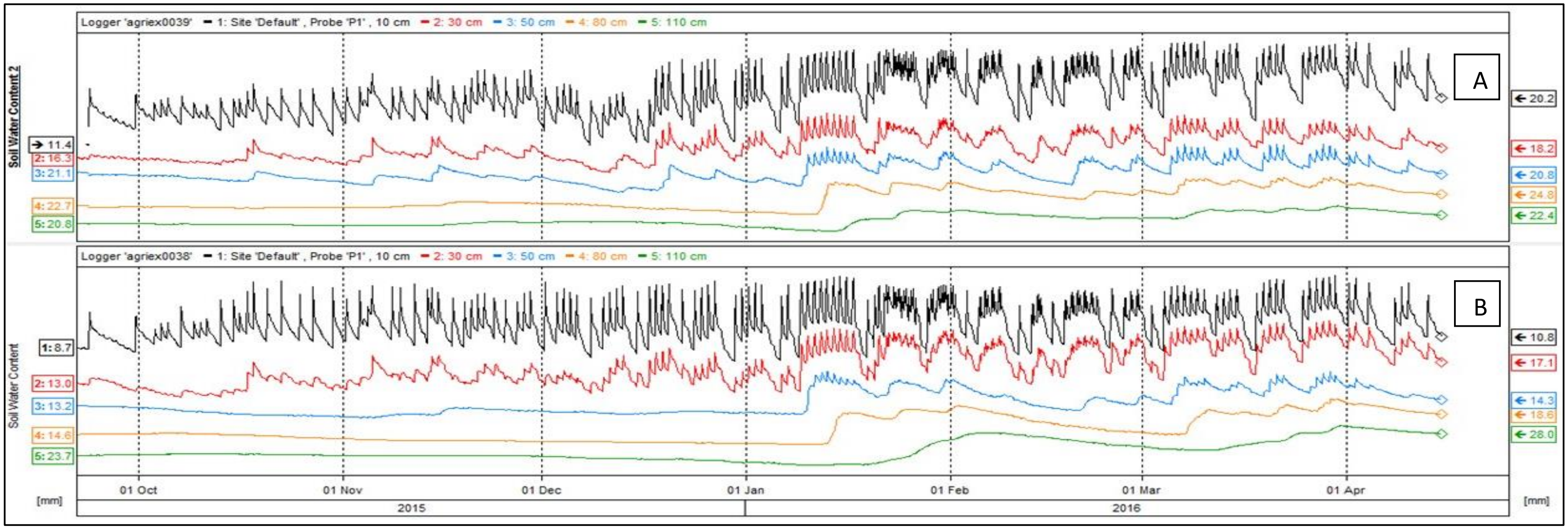

Figure 3 Soil moisture sensor readings in mm at 10 cm (black), 30 cm (red), 50 cm (blue), 80 cm (yellow) and 110 m (green) for under the environmental netting (A) and un-netted block (B).

The soil in both blocks is not evenly wet throughout the profile (Fig. 3 and Table 1). As can be seen irrigation is applied evenly to the top surface (Fig. 3 black line (10 cm soil depth)), but not all irrigation reaches the deeper layers of the soil profile (Table 1). Soil moisture at time intervals of approximately one month are presented in Table 3 with clear differences in soil moisture content at the same soil depth under the netting and in the un-netted control area. Generally higher soil moisture (mm of water) was observed in the netted area compared with the control especially at a depth of 50 to 80 cm at which the netted area maintains on average 10 mm more water. Apple trees can easily root to a depth of 50 to 80 cm and draw water in those areas (Atkinson, 1974; Green and Clothier, 1999; Green et al., 2003). If those areas are not wetted sufficiently root growth and therefore water, nutrient uptake capacity will stop, and the root zone will be restricted to the higher soil profiles, which also tend to heat up more.

Table 1 *Soil moisture content (mm) at different soil depth and on different dates (25. Feb – before irrigation (1 AM) and after irrigation (1 PM)) measured outside the netting (control) and under the environmental coverage (netted).*

Soil profile	Soil moisture at 10 cm (mm)		Soil moisture at 30 cm (mm)		Soil moisture at 50 cm (mm)		Soil moisture at 80 cm (mm)		Soil moisture at 110 cm (mm)	
Date	**Control**	**Netted**	**Control**	**Netted**	**Control**	**Netted**	**Control**	**Netted**	**Control**	**Netted**
01/10/15	12.5	18.6	12.3	16.2	12.8	20.6	14.8	22.5	23.9	20.7
01/12/15	9.0	15.7	13.6	17.3	12.2	20.3	13.3	23.2	23.6	21.0
01/01/16	11.5	19.3	13.7	18.1	11.9	19.5	12.9	21.6	22.3	20.1
25/02/16 (1 AM)	8.9	18.2	15.1	18.3	14.2	21.9	15.3	25.3	25.8	21.8
25/02/16 (1 PM)	18.6	27.8	20.9	21.8	14.0	21.9	15.3	25.2	25.7	21.8

As shown in Table 1 the amount of moisture measured at 80 cm is significant for the assessment of plant water availability and sufficiency of irrigation. If irrigation reaches this layer of soil the top soil is sufficiently irrigated for the plants to be able to take up water. If the water does not reach the lower soil profiles, then the irrigation is shallow and water will only be available in the top soil. This can be beneficial for low rooting crops and field crops but for apples the recommendation is to irrigate down to at least 60 to 80 cm in the soil profile to guarantee good root development and a secure water source and sufficient uptake of nutrients (Bar-Yosef et al., 1988). At the Loxton site outside the netting (Fig. 3 panel B) very little water reached the lower soil profile areas with only 17.8 mm soil moisture at 80 cm on the 1st of October 2015. Compared to 22.5 mm at the same soil depth on that date under the netting. In addition, under the netting clear uptake of water by the roots is shown in Fig. 4 between 1st December 2015 and the first deep irrigation on 13th of January 2016 – this root water uptake is indicated through the staircase line pattern. If enlarged this can be tracked back to day and night water uptake patterns (Fig. 5).

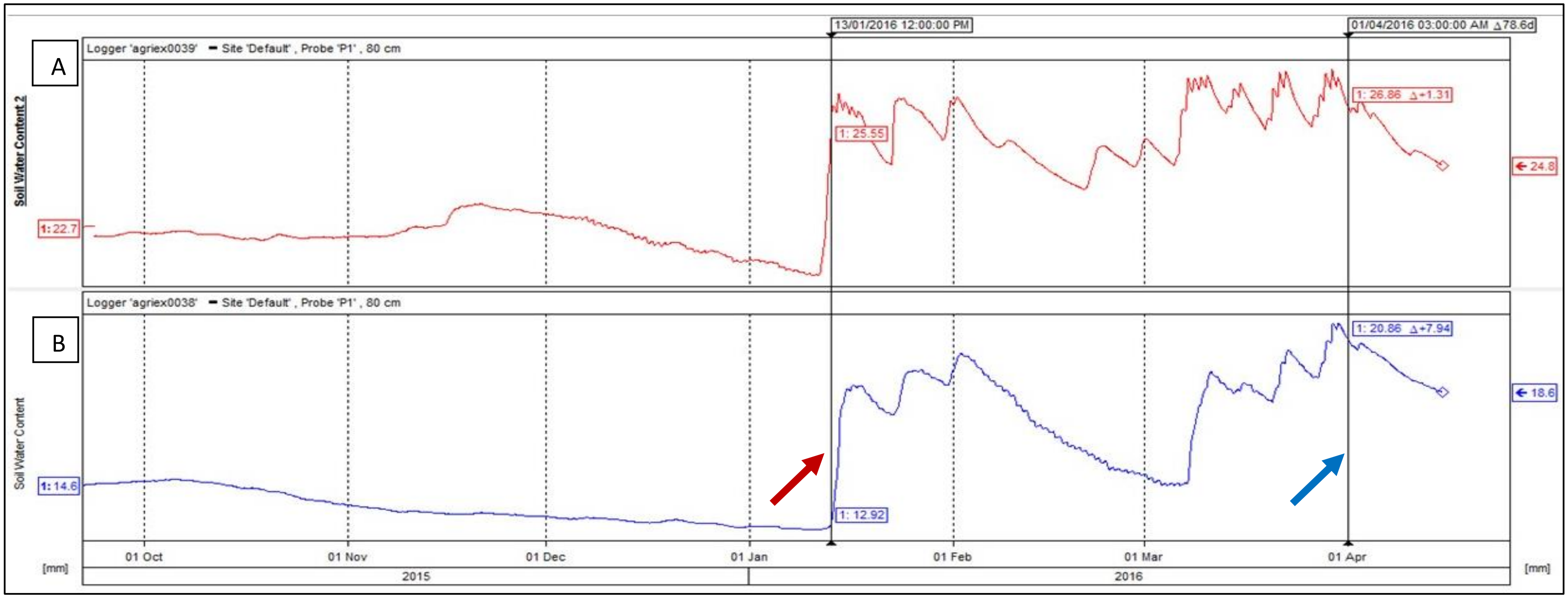

Fig. 4 *Soil moisture content (mm) at 80 cm soil depth at the Loxton site – Top panel (A – Logger 39) is under the netting and the lower panel (B – Logger 38) is outside the netting (control) – the first dividing line marks the date of 13th January 2016 (red arrow) and the blue arrow marks 1st April 2016 – soil moisture (mm) on 13.01.16 at A (netted): 25.55 and B (control): 12.92 on 01.04.16 for A: 26.83 and B: 20.86.*

The observed increase in soil water content during the night at certain time points can be explained by drainage of water from the higher soil profile areas into this lower profile after irrigation. Generally, the soil moisture declines during the day and stays relatively stable during the night (Fig. 5). In the control area (un-netted) little movement of soil water can be detected at 80 cm depth before the 13th of January 2016 when enough water is applied that drainage into the lower soil profile is possible. No diurnal patterns of water uptake at 80 cm soil depth can be seen before this, indicating that very little viable root mass remains in the lower soil profile without netting. Only after sufficient water has been applied does the 'staircase' pattern occur again (after 14.01.16) even in the control block. Whereas the irrigation, as can be seen by the regularly occurring spikes, almost always reach this level of soil under the netting (Fig. 3 A).

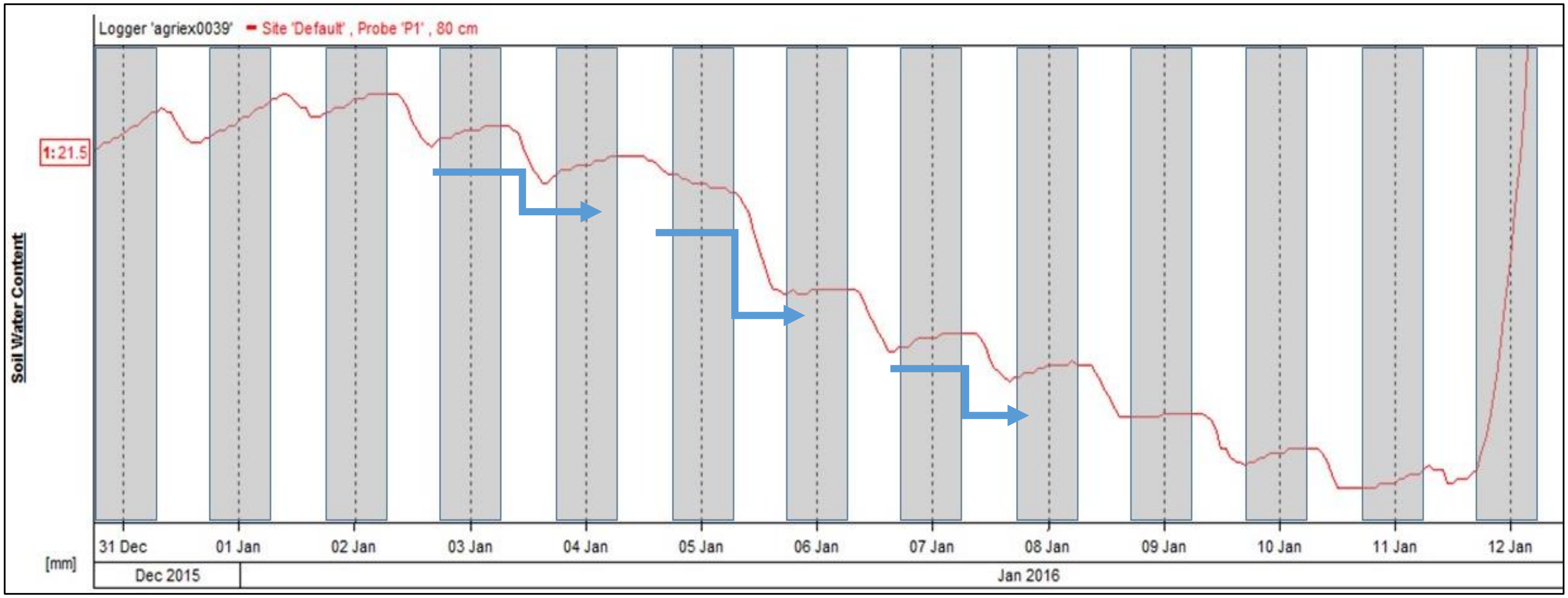

Fig. 5 *Soil moisture content (mm) at 80 cm soil depth at the Loxton site under netting with the dark areas indicating night-time and the light areas day light.*

These findings suggest that netting indeed has an effect on irrigation efficiency. With similar amounts of water apple roots in the lower soil profiles (80 cm) will be better irrigated under the netting compared with the control block. Being able to reach the lower soil profiles without having to apply significantly more water, means the efficiency of irrigation is enhanced thought the netting.

3.2 Weather data

Seasonal variation in temperature and climate are important for fruit quality and tree health. At the Loxton site temperatures are higher in the summer and spring months (October to February) than in the autumn (March and April) (Figs. 6 and 7).

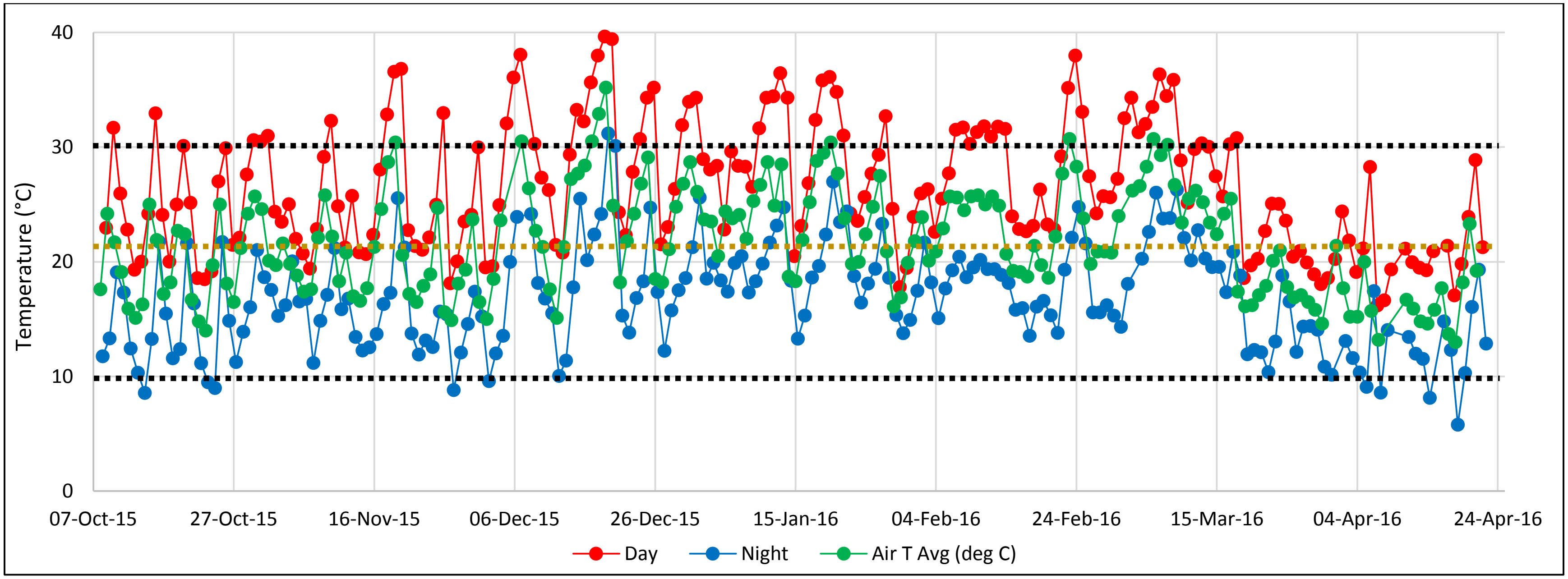

Fig. 6 *Day and night average temperature (Day = 9am to 8pm, Night = 9pm to 8am) as well as average 24-hour temperature for Loxton weather station (control) from* 8th *October 2015 to 22nd April 2016, the black lines indicating 30 and 10°C – data from NRM Board (2016).*

The effects of the netting on daily maximum and average temperature is small (Fig. 7). On some days the temperature is even higher under the netting compared to the area outside of the netting. The black lines in Figs. 6 and 7 indicate critical temperatures. If the temperature reaches over 30°C the likelihood of the surface of a fruit reaching critical temperatures which can cause heat/sun damage are likely to occur. The lower critical value of 10°C is important in the autumn and winter for the accumulation of chilling hours to break dormancy in the winter and to induce dormancy in the autumn, to end the growing season. As can be seen (Figs. 6 and 7) neither in the netted nor in the control block did the night temperatures drop below 10°C very often. Only from the 20th March 2016 did the average day temperature not rise above 30 °C. Such warm temperatures late in the season can cause problems with coloration of the fruit, especially with higher temperatures during the night, which can cause bleaching.

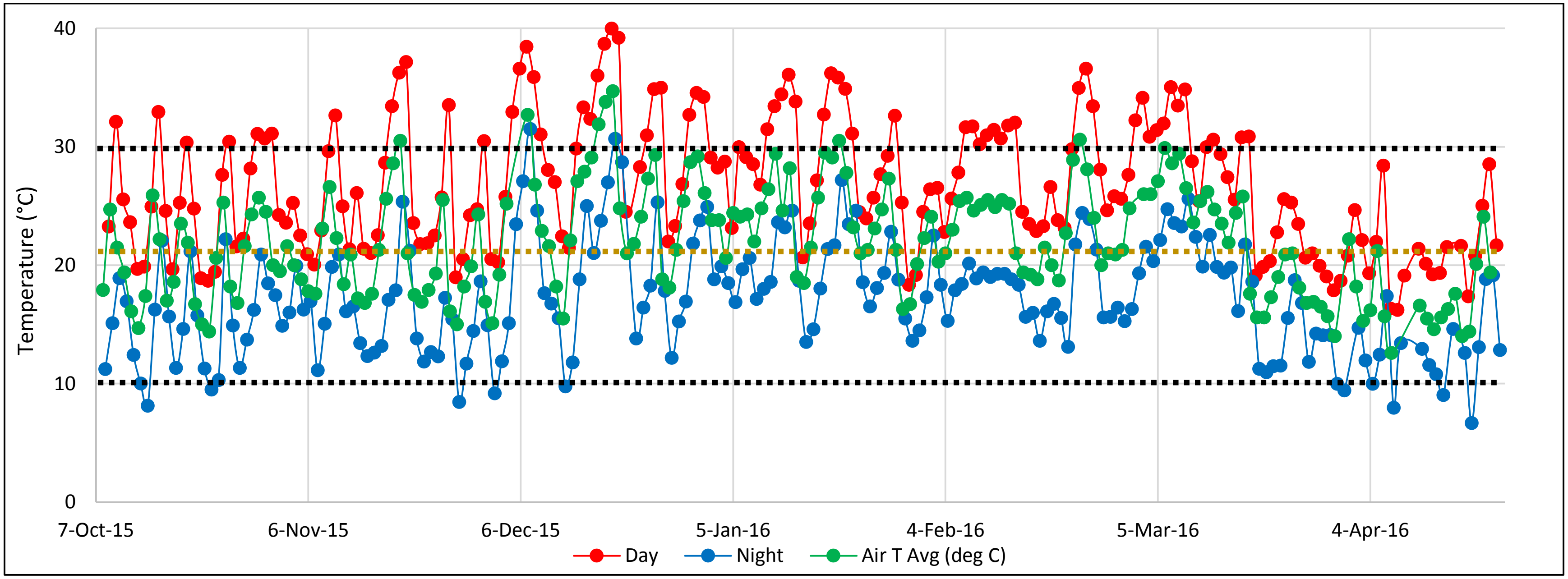

Fig. 7 *Day and night average temperature (Day = 9am to 8pm, Night = 9pm to 8am) as well as average 24-hour temperature for the Loxton weather station under the netting **(netted)** from 8th October 2015 to 22nd April 2016, the black lines indicating 30 and 10°C – data from NRM Board (2016).*

Night temperatures of around 11°C have been found to be good for colour development, whereas higher temperatures (about 22°C) are found to have negative effects on red colour development (Blankenship, 1987). For both, control and netted area, the night temperatures during fruit ripening (Mid-January to Mid-March 2016) are above 10°C but are often below 20°C which allows for good colour development. Unfortunately, there are periods of very warm night temperatures which can have a negative effect on the colour development through "bleaching".

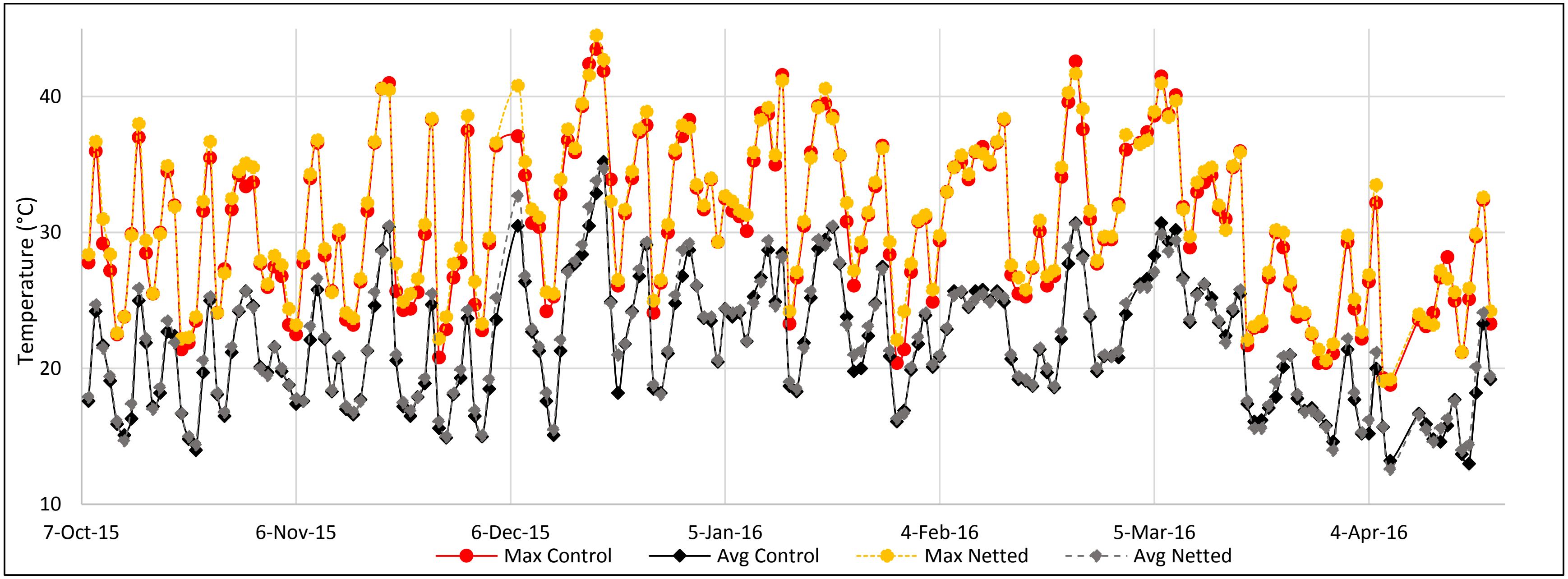

*Figure 8 Daily average and maximum temperature over 24-hours for uncovered (**control**) and **netted** area at the Loxton apple orchard, 8th October 2015 to 22nd April 2016 – data from NRM Board (2016)*

The difference in daily maximum and minimum temperatures are as small as for the day and night temperatures (Fig. 8). Therefore, ambient temperature does not appear to be significantly difference between netted and un-netted areas.

One of the factors that influence fruit development and has a great impact on fruit damage due to heat/sun damage is solar radiation (radiation) (Fig. 9). Netting has a much more pronounced effect with an average reduction of about 25% compared to the un-netted control. The specifications of the netting by the company say that the light is reduced to about 80% and on average this reduction is about 75% of the ambient light). There is a much higher daily accumulation of solar radiation in the control block compared with the netted area – in total from October 2015 to April 2016 it is a difference of almost 1.3 mW/m^2 (1.3 million W/m^2). The effect of less direct sun interception can in turn lead to less sunburn under the netting even though the air temperature is not reduced compared with the control. Sunburn is directly caused by heating of the fruit or wood surface, therefore heat causes the actual damage, but the intercepted radiation is what causes the increase in surface temperature above a critical level.

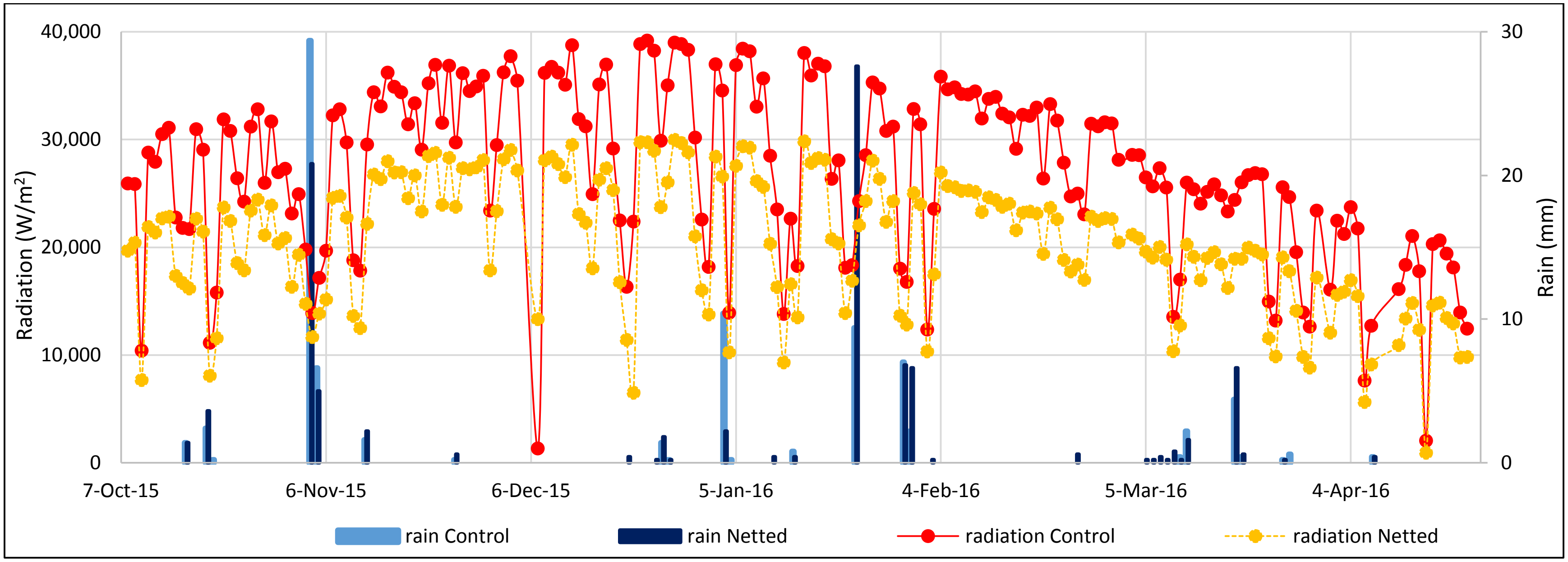

Fig. 9 *Daily sum of solar radiation (W/m^2) and rainfall (mm) for the apple orchard weather station un-netted (**control**) and the station under the nett (**netted**), 8th October 2015 to 22nd April 2016 – data from NRM Board (2016).*

The amount of rain in the control area and the netted is very similar (Fig. 9) – with a total of 82 mm and 92 mm over the time-period for the control area and the netted block respectively. Slight differences in the amounts measured can be due to drift and localized rain patterns. Never the less this indicates that the netting has little effect on rain penetration and distribution.

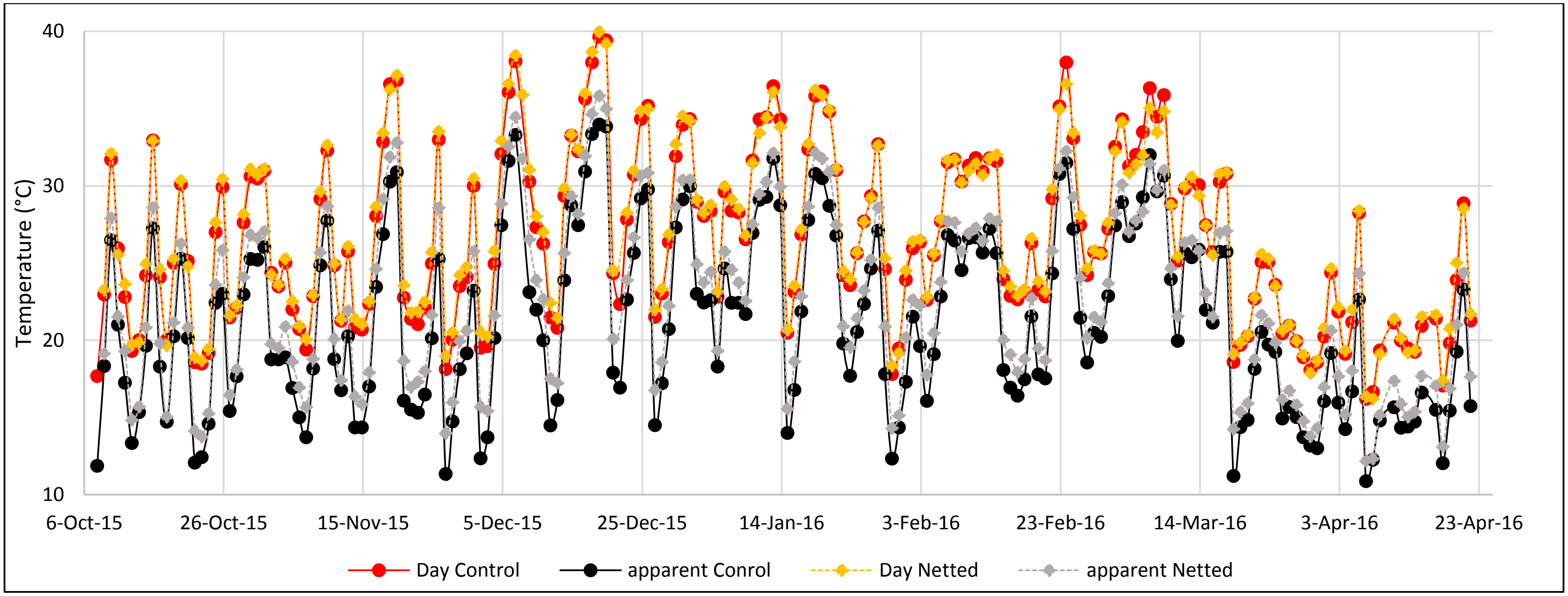

Fig. 10 *Day time and day time apparent temperature for the un-netted weather station (**control**) and the station under the nett (**netted**), 8th October 2015 to 22nd April 2016 – data from NRM Board (2016)*

Temperature effects can be measured as ambient (Day Control and Day Netted) as well as apparent (Fig. 10). Apparent temperature can be above or below the ambient air temperature depending on the weather conditions. The Bureau of Meteorology (BOM) calculates the apparent temperature and defines it as an adjustment of the ambient temperature based on the current humidity and wind speed (http://www.bom.gov.au/info/wwords/). Direct sunlight interception which heats up surrounding surfaces can further contribute to the apparent temperature but is not considered in the BOM measurements. As can be seen in Fig. 10 the temperature ambient or apparent are not different for the un-netted control and the netted apple orchard area.

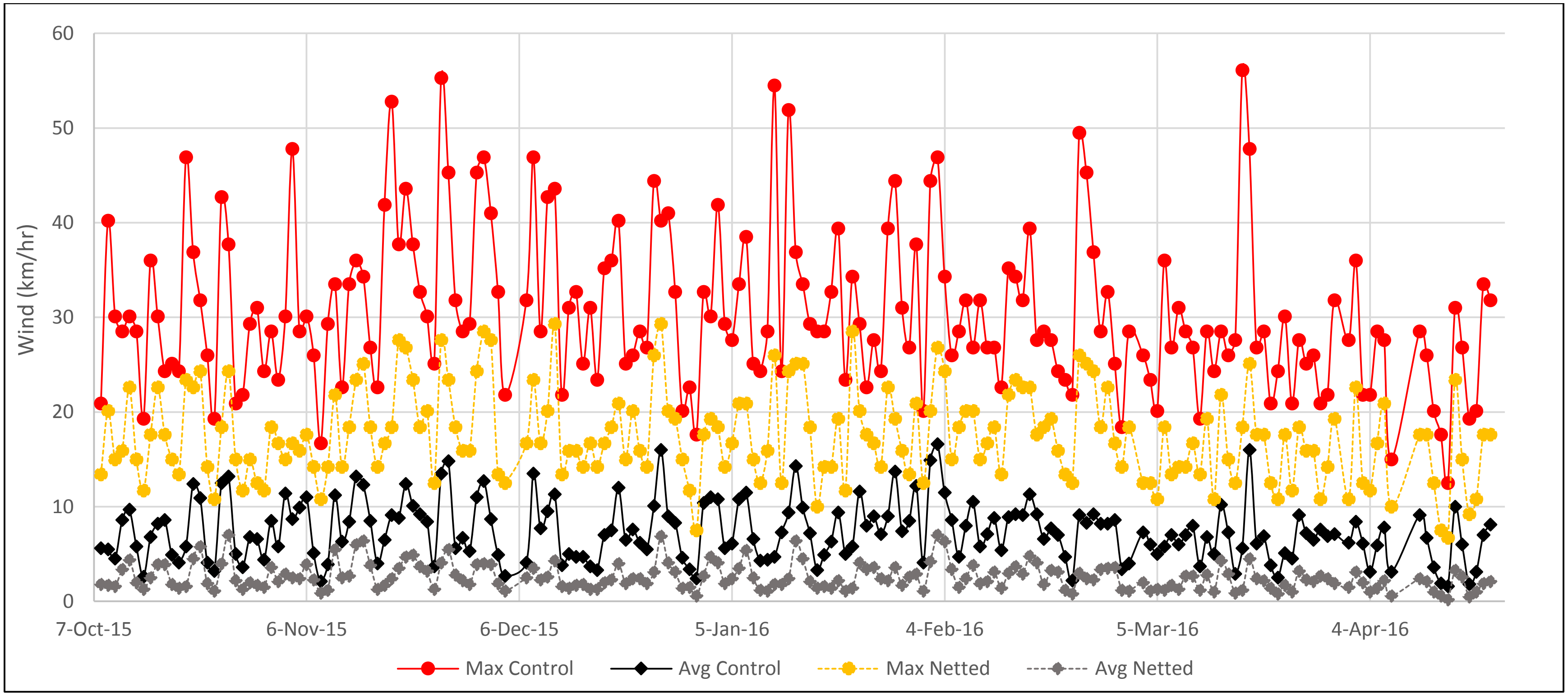

***Fig. 11** The wind speed (km/hr) measured as daily maximum and average under **netting** and the uncovered **control**, 8th October 2015 to 22nd April 2016 – data from NRM Board (2016).*

Wind is another factor that can have a great effect on fruit quality especially if strong winds damage the fruitlets and young leaves early in the season. Wind damage on the fruit and the wood caused by other tree parts such as small branches and leaves constantly brushing against each other or another fruit can cause damage to the bark or skin. Strong wind can also cause fruit drop or bruising on the fruit and collision with another fruit hanging in close proximity or by other tree parts can affect fruit quality. The environmental netting as shown in Fig. 11 reduces total wind speed. Most damage done to apples is through breaking of branches and tipping over of whole trees and branches due to the low vigour of rootstocks and shallow rooting patterns (such as for M9) (Figs. 22 to 25).

Not only the air temperature (ambient temperature) but also the temperature of the soil can influence the development of the trees and fruit. Higher amounts of direct sunlight intercepted by the soil will increase the temperature similar to that of fruit surface. The temperature of the soil changes depending on the depth of measurement and therefore has different effects on different parts of the root system depending on rooting depth and pattern. Often if water is applied with a drip irrigation system the main root system is concentrated around the area that gets wetted though the irrigation and therefore can be comparatively shallow and concentrated in a small soil area (Thorburn et al., 2003). This can have other negative effects besides the effects of heating of the soil. At the Loxton site the differences between the soil temperature under the netting and without are very minimal for the average soil temperature (Fig. 12) with sometimes higher values under the netting especially earlier in the experiment. However as shown in Fig. 12 the maximum daily soil temperature is on average 5.6°C higher in the control compared to under the environmental cover (netted); indicating an advantage of reduced radiation on the soil.

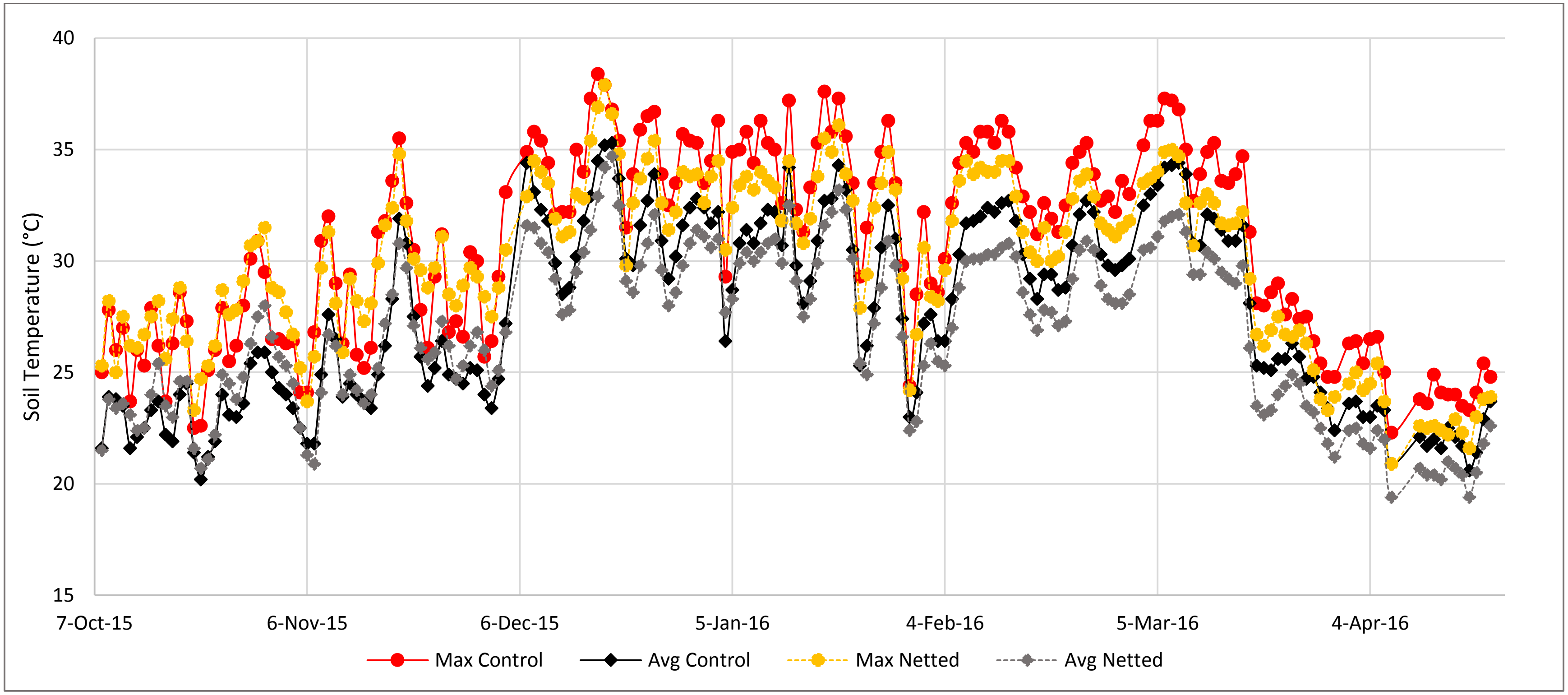

***Fig. 12** Daily maximum and average soil temperature (°C) for the uncovered **control** plot and the **netted** part of the apple orchard in Loxton, 8th October 2015 to 22nd April 2016 – data from NRM Board (2016)*

This also positively influences the relative humidity (RH) and therefore VPD (vaper pressure deficit) under the netting. Less evaporation of the water from the soil through decreased maximum heating of the orchard floor increases retention of moisture in the soil, which in turn increases transpiration. Unfortunately, the effect of netting on retaining RH (%) at a higher level is minimal or not demonstrated on most days for the average daily RH (Fig. 13). The maximum RH at times is higher under the netting but does not retain much throughout the day.

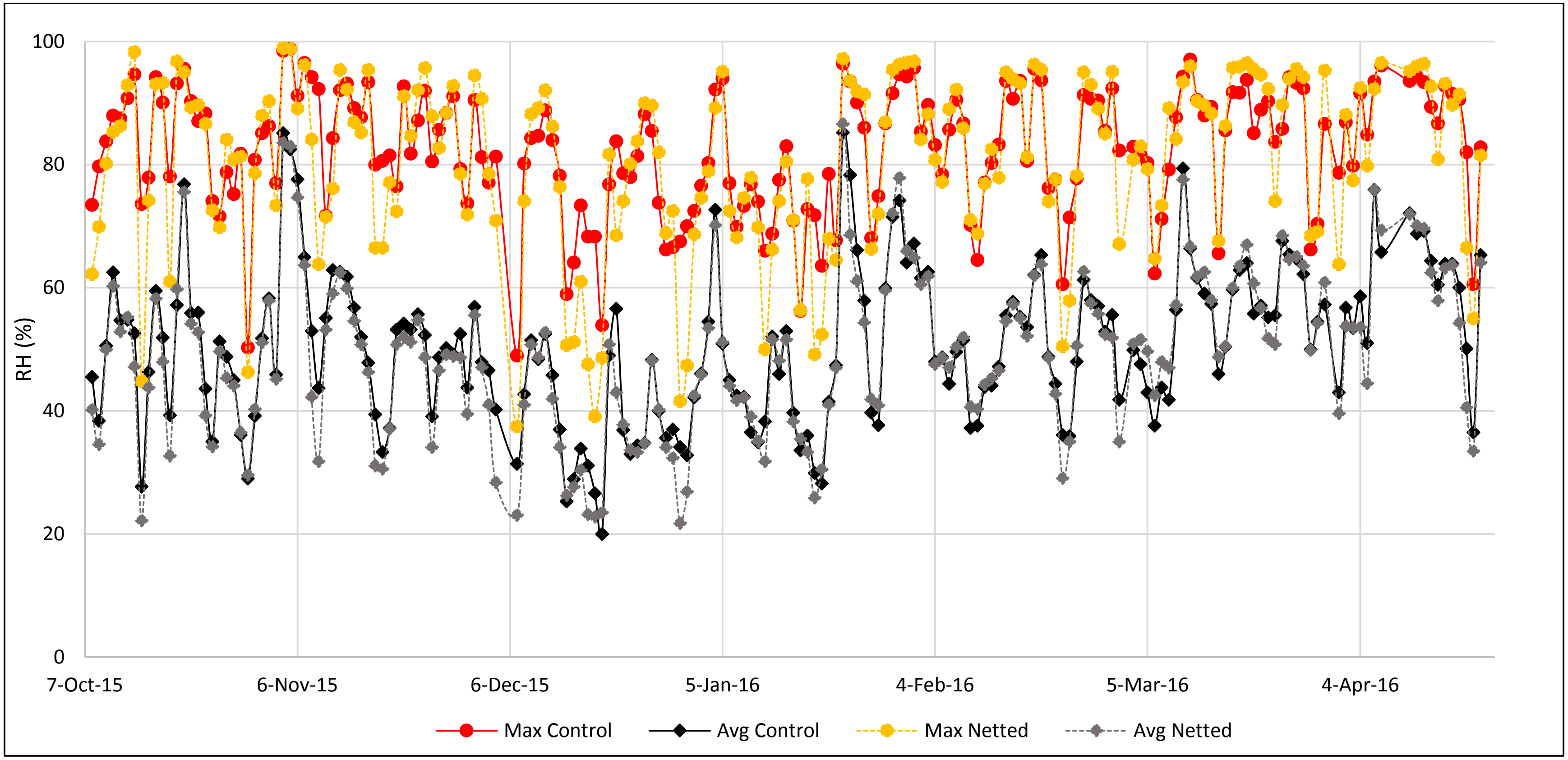

Fig. 13 *Relative humidity (RH, %) under the environmental* ***netting*** *and in the uncovered* ***control*** *orchard, 8th October 2015 to 22nd April 2016 – data from NRM Board (2016)*

Overall the netting does effect some of the climactic parameters measured such as solar radiation, soil temperature, and wind speed. Effects on temperature are minimal due to the netting. Further observations of the effects of netting on vegetation and climatic factors are needed in order to quantify the observed effects.

Netting has many beneficial functions besides shading the trees in the summer and therefore preventing the surface of leaves, fruit and wood from heating up beyond a temperature that causes damage (Shahak, 2012; Shahak et al., 2008a). The netting can also help with frost protection (Gordon, 2013). The microclimate within the structure and the more protected environment can (anecdotally, Gordon (2013)) raise the temperature on cold days by up to 2°C which in a frost night – just below freezing, can make all the difference to whether frost damage will manifest or not. Preventing frost events without having to use frost irrigation not only saves water but also prevents the soil from getting soaked (filled above field capacity). Apple trees do not care for wet, meaning an anaerobic/anoxic soil environment in conducive to root damage and can cause other problems.

3.3 Tree and fruit assessments pre-harvest

Pre-harvest tree and fruit assessments were conducted on 17th of March 2016. Twenty trees from each block, under the netting (netted) and outside (control) were assessed within two rows in the central area of the block.

Table 2 *Scoring of fruit (sunburn and wind damage) and tree damage (wind damage) as well as tree performance (vigour and fruit colour) for the control and the netted orchard block section.*

Treatment	Sunburn	Wind damage	Fruit colour	Vigour	Canopy porosity	LAI
Control	40%	20%	30%	Low	0.141	3.53
Netted	10%	5%	40%	Moderate	0.116	3.89

Canopy porosity and LAI measures suggest that the netted trees have a greater leaf coverage of the ground area and less light getting through the canopy. This suggests that netted trees have a greater leaf area (leave area index) LAI of 3.89 compared to the control trees with LAI 3.53. The canopy appears to be more open 0.141 compared to the netted trees with a porosity of 0.116. The reduction in leaf area and canopy cover may leave fruit more exposed to sunlight and higher temperatures and be part of the reason fruit outside the netting has greater damage due to sunburn.

Trees outside the netting (control) appeared to be less healthy than the netted trees with more signs of stress (sunburn and wind damage on fruit and wood) and poorer growth (less vigour – low). The fruit outside (control) were more exposed due to lower vigour, lower leaf coverage and greater canopy porosity leading to more sunburn (approximately 40%) and some wind damage (around 20%). As some fruit did show signs of both sun and wind damage these calculations have been kept separate and should not be combined as 60% damage overall.

Some control trees (not included into this evaluation) dropped all of their fruit indicating a high level of plant stress (Fig. 14) which was not observed in trees under the netting.

Fig. 14 *Tree outside the netted area with total fruit loss.*

3.4 Fruit quality at harvest and post storage (Yield)

Fruit were picked on two harvest dates, 11th April and 22nd April 2016 both from the control block (0.56 ha) and under the netting (0.88 ha). The two parts of the apple block are not equal in area, therefore in Table 3 both the actual number of bins harvested from each block are shown and how that compares to how much would be harvested on a per hectare basis. Despite the differences in the area planted the increase of yield under the netting was significant compared to the control which had very little fruit

Table 3 *Quantity (bins) harvested for the control and the netted Loxton Apple orchard block on the two harvest dates 11th April and 22nd April 2016 and total number of bins harvested per hectare – the number of bins in the prentices (in italics) are calculated per ha since the actual harvested areas are not equal with 0.56 ha control area and 0.88 ha under the environmental cover.*

	11.04.2016	22.04.16	Bins per ha
Control	0.5 (*0.9*)	0.4 (*0.7*)	1.6
Netted	5 (*5.7*)	19 (*21.6*)	27.3

overall. The increase in yield for the netted area is 6 times more at the first harvest and 30 times more at the second harvest.

Harvest fruit quality (Table 4) was in general very similar between fruit from the control block and the netted area, with similar starch readings and soluble solids concentration (SSC). Firmness readings (kg) showed a slight increase in firmness at a higher SSC for fruit harvested from the netted block; suggesting that the fruit might be slightly better in quality. The amount of sunburn found on fruit was much less under the netting with only 6% compared to 1/3 of fruit damaged (33%) in the control block.

Table 4 *At harvest fruit quality assessments for fruit from the control block and the netted area harvested on 11th April 2016 performed on 20 random fruit from each block only sun damage was assessed on 100 random fruit – starch pattern index (SPI), soluble solid concentration (SSC – brix), sun damage (%) and fruit firmness (firmness - kg).*

	SPI	SSC (Brix)	Sun damage (%)	Firmness (kg)
Control	4	13	33	8.29
Netted	4	14	6	8.58

The results at harvest confirm that for production of apple fruit in a high temperature climate like the Riverland area it could be very advantageous to have a shading and protective netting.

3.5 Fruit pack out at harvest and post storage (Pack-out)

Pink Lady ™ is expected to have a certain amount of pinkish red blush to be marketed successfully and at the best possible price. Specific fruit size was not recorded; however, notes were taken if trees presented with extremely small or large fruit or if the overall fruit size was very uneven throughout the tree. Ultimately the goal of production is to maximize fruit quality at the highest possible quantity. Since quantity and quality are somewhat negatively correlated maximising "yield" in the case of apples refers to having a balance between vegetative growth of the trees and the amount of fruit left to ripen on each tree. Netting may be of benefit to ensure that more of the fruit at the right size remain unblemished and undamaged from the sun. Having fruit with no to very little damage is important for the fresh market. Fruit sold as fresh fruit any time of the year will be more profitable than having to send fruit to juice production or canning. Any fruit not sold as fresh, most likely will hardly even make enough money to cover the costs of production.

If large amounts of fruit with good quality are produced then some of the apples can be stored in a cold room at between 2 to 4°C. In large apple producing areas fruit often are stored up to 12 months in controlled atmosphere (CA) storage.

4. Conclusions and recommendations

An advantage in a hot climate like the Riverland is the reduction of direct solar radiation under the netting. Diffusion of light has many advantages for the trees the most important being less direct light equals less heating of exposed surfaces (Amarante et al., 2011; Healey et al., 1998; Jakopic et al., 2007; Sinclair et al., 1992; Smart and Sinclair, 1976; Stampar et al., 2002). Sunburn, after only one year of observation, clearly is the greatest challenge and other issues caused by the excessive heating of surfaces including soil. The netting had a positive effect on the reduction of sunburn on fruit and wood. This in the long run will also help the trees and ensure an enhanced longevity of the orchard compared to trees which are exposed to sunburn on the wood year in and year out.

The effectiveness of netting during dormancy and further tree adoption to the netted environment will only become clear after a longer time-period under the netting. After less than one year under the net not all the potential impacts may be realised. Many of the tree responses have not been investigated in first year of the study as some of the critical growth stages had already been reached by the time this study was undertaken. Effects of the netting on tree performance such as water use have not been scientifically investigated. Further research to understand and evaluate the overall potential that netting has on improving apple production in the Riverland will be performed in the next two seasons.

To determine the effects of the netting on WUE, irrigation scheduling and photosynthetic activity we recommend that the irrigation system between blocks is separated. Further research could investigate the effects of lower soil temperature on evapotranspiration and tree water use and could comprehensively compare water use efficiency of a netted vs. an un-netted orchard. Pollination/fertilisation and nutrition changes between the control and the netted area are also areas that could be investigated in an additional study. The effects of reduced wind speed on pollinators and hence flower pollination and fruit set could also be of interest especially if wind during the pollination period historically had an effect on bee flight and visitation.

Some limitations to this study are listed below.

- The short period of adjustment of the trees under the environmental netting – netting was only applied in March 2015. Long-term effects of the netting can only be captured after a prolonged period of time (exact time frame is unknown but most likely around 3 to 4 years).
- Irrigation amounts are currently not adjusted to needs of the plants outside or inside the netting. Only by splitting the irrigation system will a true evaluation of the effects on WUE be possible and the trees overall less stressed. It appears that irrigation is not adequate for plants outside the netting and potentially too much irrigation is applied to the trees under net.

Through the investigations undertaken in season 1 of this study the following recommendations are made.

- Irrigation system be separated into netted and un-netted areas and water applied according to plant needs so that any 'true' water savings can be captured. Separating the irrigation outside and inside the netted area will not only result in less water use overall, but possibly will increase quality due to higher specificity of water monitoring and adjustment to the actual environmental conditions present in each block. The following parameters could be measured in the remaining two seasons to assess possible improvements or shortcomings of the netting:

- Stem and leave water potential readings (pressure bomb) – plant water status
- Pollination, fertilisation and fruit set measures
- Fruit size earlier in the season
- Pest and disease assessments
- Nutritional requirements between blocks

5. Acknowledgements

Authors would like to acknowledge Fergus McLachlan and Rick England at Rivercorp for allowing the study to take place on their property and funders of the project Natural Resources SA Murray-Darling Basin and Primary Industries and Regions, South Australia. Thanks to Mark May (DEWNR) for providing critical information and guidance on the report. Thanks also to Trevor Sluggett and Peter Keynes from Agri-exchange and Peter Buss and Rob Stevens from Sentek for providing information on the Sentek soil moisture probes.

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7. Appendices

7.1 Supporting background information

Different plants either native or cultivated have a certain climate range they prefer. Plants in general survive between just below freezing (-2 °C) and about 45 °C (Fig. 15). Active growth generally happens between about 2 °C and 30 °C (Went, 1953). Temperatures below or above this range are detrimental to growth and the plant as a whole depending on the time of year and the status of the plant. A dormant plant can endure more extreme temperatures without suffering damage than an actively growing plant (Williams et al., 1979). Nevertheless, temperatures outside the optimum range can limit normal growth, reduce fertility and fruit bearing, as well as lessen fruit quantity and quality.

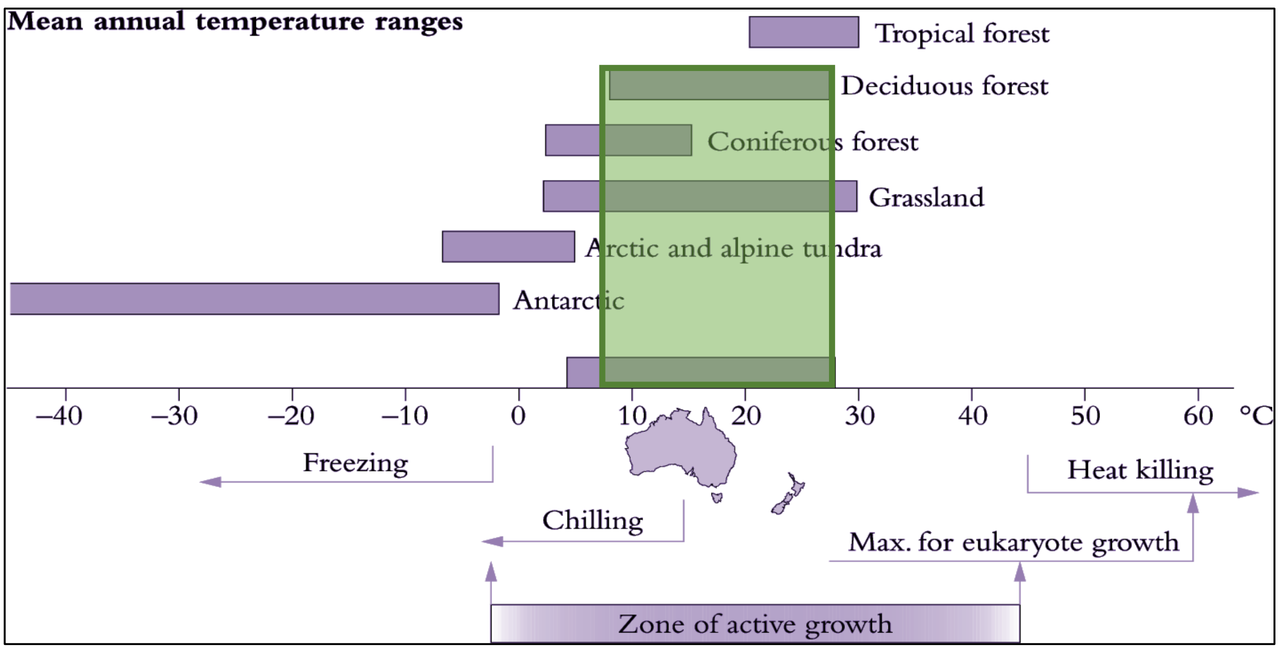

***Fig. 15** Mean annual temperatures in Australia and New Zealand range from 28°C in the north (tropical forest) to 4°C at higher elevations in the south. Temperature extremes are an important factor in survival and growth of many species, with heat stress (>45°C) and freezing temperatures (<-2°C) common to some areas. Active growth is normally limited to temperatures 0°C to 40°C, but many subtropical species will be chill damaged at 10—15°C and many temperate species will not survive long periods of temperatures higher than 30°C (http://plantsinaction.science.uq.edu.au/book/export/html/131)*

Apple trees actively grow between about 8°C and 28°C indicated by the green box in Fig. 15. Damage through cooler temperature is unlikely to occur unless the ambient temperature falls below freezing (approximately -2°C), but temperatures outside the optimum will slow growth and development (Stanley et al., 2000). Fruit quality is also affected by extreme temperatures and the effects of excess fruit temperature are explained below. Choosing the right plant material and effective management practices are essential to guaranteeing best possible fruit quality.

7.2 Water use efficiency

Ever increasing temperatures and the duration of hot weather during fruit production months, require a more vigorous assessment of water use efficiency (WUE) or agronomic water use efficiency (AWUE). AWUE is the amount of marketable fruit produced with a certain amount of water being applied (Naor et al., 2008). Optimisation of AWUE therefore aims to produce the highest amount of fruit possible with the lowest amount of water needed. Netting can optimize WUE by lowering leave surface temperature (Shahak, 2008, 2012; Sinclair et al., 1984) and photo stresses from excess sunlight by lowering the amount of light transmitted though the netting and therefore reducing the total amount of light intercepted and absorbed by the plant (Shahak, 2008, 2012). Reduced wind speed within the netted area can potentially have a positive influence on plant performance but has not be characterized thus far.

WUE is also used to determine the amount of carbon assimilated during photosynthesis (molar ratio of net photosynthesis) per litre water usage of the tree (Wibbe and Blanke, 1995). For apple trees this relationship of water used to accumulate carbon is “better” if all fruit are dropped before mid-growing season (Wibbe and Blanke, 1995), meaning that more carbon is stored per litre of water absorbed by the roots. However, without fruit this “WUE” is economically meaningless, since no one except the nursery industry, grows apple trees without the fruit. Therefore, from this point forward WUE will refer to the amount of water used to produce a certain amount of fruit.

Mature fruit including apples generally contain approximately 85% water (Agriculture.Victoria, 2013), therefore supplying sufficient water to the tree is important to guarantee the desired fruit quality and size. Unfortunately, only about 1% of the supplied water is retained in the fruit itself. Most of the water supplied to a tree escapes in the form of water vapour. Woody/permanent plant parts such as stem, leaves, shoots and roots accumulate only about 0.5% of the overall water applied during the season (Agriculture.Victoria, 2013). Hence, 98.5% of the water taken up by a tree will be released to the atmosphere as vapour.

Plants, especially those bearing fruit, are often highly susceptible to water stress and can drop all fruit to the ground for the benefit of the survival of the tree (Fig. 28 – subliminal martial) (Boland et al., 2002). During the growth and fruit development of apple trees, not all stages are equally susceptible to water stress (Boland et al., 2002). For example, during budburst and flowering water stress can be detrimental (Boland et al., 2002). The number of flowers that are successfully fertilised and number of growing leaves to support the fruit during ripening are important (Boland et al., 2002). In addition, after flowering when fruitlets start to form the number of cells formed during cell division is critical for the final fruit size. During this phase water should be readily available (Boland et al., 2002). This phase is followed by rapid shoot growth and constant fruit growth (McGuckian, 2013) during which water availability determines the amount of shoots which grow to full length and the leaf area available for light interception and shading of the fruit. Fruit growth also heavily relies on water. Phase three (Fig. 28 – subliminal martial) is marked by fruit filling – the cells within the fruit fill with water and sugar and the fruit size increases rapidly (Boland et al., 2002). Furthermore, at this stage permanent structures such as roots and shoots grow and buds for the coming year are formed. Water stress or low water availability at this stage influences not only current seasons growth and development but also determines bud development for the coming season (Boland et al., 2002; McGuckian, 2013). Water availability after harvest is only critical if postharvest applications of fertilizers are applied. Otherwise, water supply can be slowed down and in the Riverland this can be used to induce dormancy through some water stress.

Soil moisture measurements (section 3.2.1) are an important tool to guarantee the optimal WUE. Ideal water status of the plant will provide enough water to maintain the vegetative parts of the plant, the fruit of the current season and bud development for the coming season. For apples a general rule of thumb is to keep the soil moisture at a level at which water is relatively readily available (Black et al., 2008). This means keeping a level of moisture that stays within field capacity (water is about to drain to lower soil) and half way to permanent wilting point (Fig. 16).

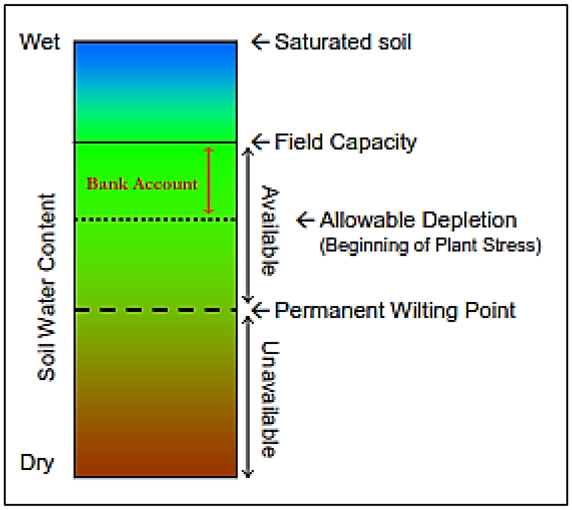

***Fig. 16** Soil water content from saturated to dry. Optimal levels for plant growth are between field capacity and allowable depletion (Black et al., 2008)*

7.3 Netting effects on fruit quality

The use of nets is not only done to prevent hail or bird damage, but can also have other beneficial effects on fruit quality such as reduction in sunburn, better and more even colouring of the fruit, as well as improvement of fruit size.

7.3.1 Sunburn

Sunburn is defined as the damage to fruit caused by exposure to solar radiation (direct sunlight) (Fig. 3). Sunscald on the other hand is defined as injury to the bark and underlying tissues caused by freezing (Schrader et al., 2001), which happens on sunny winter days when the sun heats up the surface of the tree

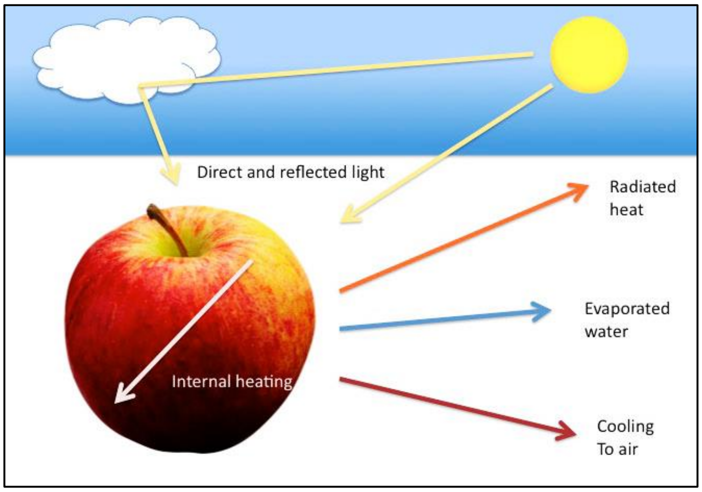

***Fig. 17** Schematic of how sunburn is caused on apple peel showing the effects of evaporation, sunlight as well as air temperature (Schrader, 2014)*

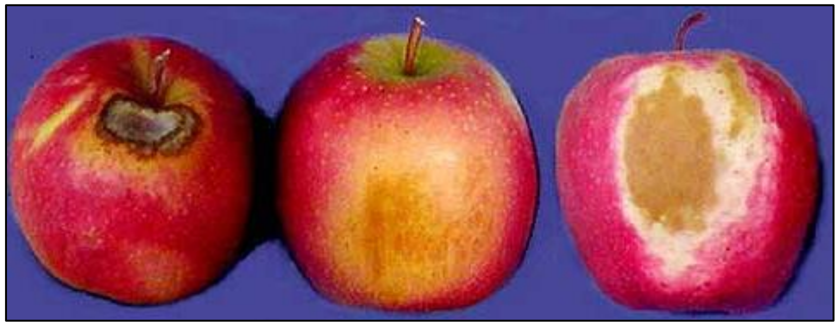

Fig. 18 *Damaged to the apple peel though sun damage, left to right: sunburn necrosis, sunburn browning and photo-oxidative sunburn (Picture from Larry Schrader) (Agriculture.Victoria, 2011)*

and "melts" the underlying tissue which than freezes again and gets damaged. We therefore use the term sunburn to describe this fruit disorder on apple fruit skin caused by increased surface temperature though high and excess radiation.

The skin blemish disorder "sunburn" can be divided into sunburn necrosis and browning (Fig. 18), both caused by heating of the skin to very high temperatures, or photo-oxidative sunburn caused by excess radiation (Agriculture.Victoria, 2011).

In the context of future climate change and associated rising temperatures, increased risk of sunburn damage is highly likely (Darbyshire et al., 2015). Fruit surface temperature can rise above air temperature under certain conditions such as direct sun exposure (Ferguson et al., 1998; Kliewer and Lider, 1968; Smart and Sinclair, 1976) (Fig. 19). At temperatures of 45°C and above enzymatic functions start to be out of balance and eventually will seas all together which has detrimental

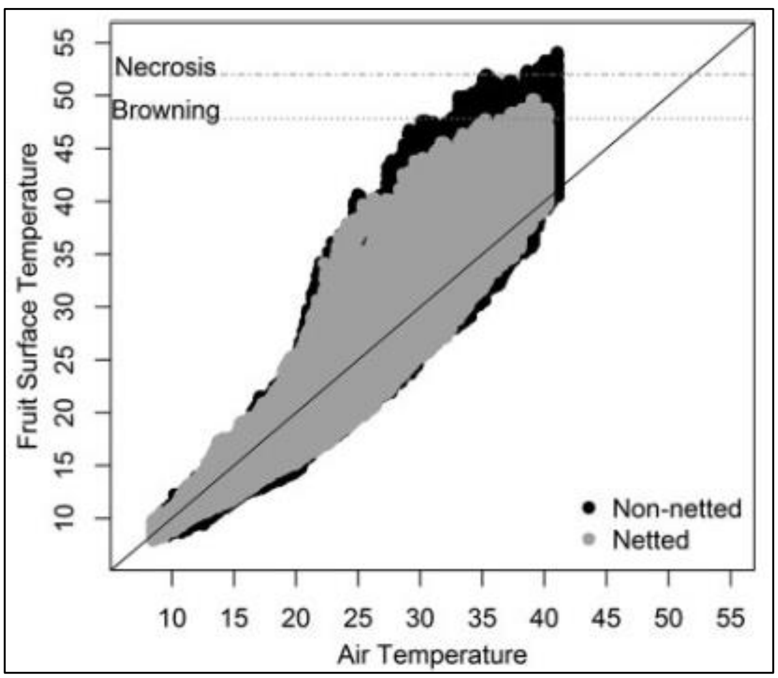

Fig. 19 *Fruit surface temperature (°C) (FTS) recordings and related air temperatures (°C). Necrosis and FST thresholds represent 52 and 47.8°C, respectively (Darbyshire et al., 2015).*

consequences for the cell and the organism. If the plant is exposed to high temperatures for a prolonged time it can have detrimental impact on plant and/or fruit development (Woolf and Ferguson, 2000). Leaves don't often get as heated as fruit due to the fact that the leaf relies on the cooling effects of evaporation (Ferguson et al., 1998). The fruit on the other hand functions as a kind of heat sink with flesh and skin temperature reaching far above ambient. Fruit also retain heat much longer than thin leaves not only due to the much lower rate of transpiration and therefore less transpiration cooling, but also because of the high water content and its low heat transfer capacity.

Sunburn necrosis (Fig. 18) is a sunken dark patch on the side of the fruit exposed to the sun. In severe cases the patch can have blackened or necrotic areas on the surface of the apple. Sunburn is caused through high fruit surface temperatures (FSTs) of 52 ± 1°C for as little as 10 minutes (Agriculture.Victoria, 2011). Where the temperature reaches these levels the cells of the skin as well as few layers below die due to temperature stress and cause a necrotic dead area (Darbyshire et al., 2015). The surface area of fruit which are exposed directly to sunlight can reach much higher temperatures than ambient air, therefore reaching 52°C on the surface of the fruit on a 30°C or higher ambient temperature clear day sunny (Fig. 18). Problematic for the situation of the fruit is that only a very short period of such high temperature is required to cause severe damage. Some fruit are exposed to direct sunlight daily and the same areas are exposed repeatedly, therefore, in areas with high air temperature and high sunlight interception sunburn caused by high FTSs are very likely to occur (Amarante et al., 2011). Environmental netting in the right colour, such as black or grey, can help reduce the amount of sunlight that directly hits the fruit surface (Shahak, 2008, 2012; Shahak et al., 2004; Shahak et al., 2008b).

The apple surface can also show yellow, brown or dark patches at the sun-exposed site (Fig. 18 middle fruit). This browning is caused by skin cells being damaged through temperatures between 46 and 49°C (Agriculture.Victoria, 2011; Darbyshire et al., 2015). The cells do not die at first, and most of the damage is superficial, but lower layers can show damage after cold storage. The difference in sunburn necrosis is mainly the extent of the damage. White bleached patches on the apple skin on the sun-exposed side can later can turn brown or even necrotic after photo-oxidative stress. This photo-oxidative sunburn (Fig. 18 and 20) is also caused by excessive sunlight but at lower FST (<45°C) and mostly happens when formerly shaded fruit are exposed to direct sunlight. For example bending of a branch due to the increased fruit load during fruit development (Agriculture.Victoria, 2011). A shade adapted fruit surface is not well equipped to withstand a high light environment, the skin cells are not use to the stresses caused by sunlight. This can result in surface cells bleaching by the sunlight and the hence skin appears whitish.

Fig. 20 *Apples with severe and onset of sun damage or sunburn – taken on the 17th of March 2016 in Loxton.*

Fig. 21 *Apple tree stem and branches with severe sun damage or sunburn – taken on the 17th of March 2016 in Loxton.*

Damage through excessive sunlight is not strictly restricted to the fruit surface but can also occur on exposed wooden parts (Fig. 21). The wood can heat to temperatures outside the optimal range, start discolouring, and slowly die. The surface at first will seem raw as in Fig. 21 with a smoother surface. Eventually the bark will show signs of damage and water and nutrient flow can be restricted.

In the Riverland, high temperatures in the summer time are a common problem and reoccurring event. Table 5 shows the average monthly maximum temperature in Loxton over the last 31 years. Average high temperatures of 28 to 32°C indicate that many days are above the ideal temperatures to prevent sunburn. If the air temperature is close to 40°C (generally measured in the shade) the likelihood of exposed fruit areas experiencing sunburn damage either though excess heat (FST above 45°C) or initially though high photo-oxidative stress is very high. Increased temperature of the surface compared to the air temperature (Fig. 19). The red and yellow line indicate that FST can reach critical values without netting with air temperatures between 29 and 35°C (Darbyshire et al., 2015).

Table 5. *The 31 year monthly average maximum temperature (°C) at the Loxton Research Station for the spring and summer months (BOM, 2016).*

Statistic	Nov	Dec	Jan	Feb	Mar
Mean (°C)	27.6	29.8	31.9	31.4	28.1

From what we know about FST, direct sunlight and high air temperature influence the likelihood of the development of sun damage on fruit and the permanent wood structure. It can be assumed that netting will have a positive effect on fruit quality through a reduction of sun damage.

Table 6 *Risk factors for the development of sunburn (Agriculture.Victoria, 2011).*

Shaded air temperature:

- 40°C = high risk of a necrotic patch;
- 35°C = high risk of browning damage;
- 30 to 35°C ambient temperature =
- Damage is variable, depending on wind, sunlight intensity (cloud cover), humidity and level of fruit acclimatization to sunlight;

Other factors that increase sunburn:

- Sudden movement of fruit from shade to direct sunlight;
- Modern orchards with dwarfing rootstocks and good light penetration;
- Fruit positioned with a westerly aspect;
- Water stress on hot days.

7.3.2 Wind and other abiotic stresses

Damage occurs through other abiotic stresses such as wind and other extreme weather events that impact on fruit quality and the survival of the orchard. If wind constantly moves the fruit along the trunk or a branch, rough scald like areas can form on the skin (Fig. 22). The flesh of the fruit generally remains undamaged but means that fruit is only sold for processing or juicing not for fresh consumption. In some situations, very strong winds can cause dramatic damage to individual trees or whole orchard rows (Fig. 23).

Fig. 22 *Fruit damage caused by wind (http://www.fruitnet.com/eurofruit/article/16329/gales-hit-nelson-fruit-crops)*

Fig. 23 *Broken branch on an apple tree, damage caused by strong wind (https://murtaghsmeadow.wordpress.com/tag/wind-damage/)*

7.3.3 Colouration

Apple fruit colour is one of the main factors determining the class and therefore the price of the fruit (Doerflinger et al., 2015; Saure, 1990). The pigments causing red colouration in apple skin are mainly anthocyanins. The genetic ability of the fruit to colour is the main factor followed by light (Iglesias et al., 2012; Iglesias et al., 2008), temperature (Hunsche et al., 2010) and fruit maturity. Temperature is important and not only during the day but also (foremost) during the night. This might also be connected to the ability to react to ethylene (Blankenship, 1987; Iglesias et al., 2012; Iglesias et al., 2008). Night temperatures around 11°C increase red colouring whereas temperatures around 22°C slow down the development of colour (Blankenship, 1987). The exact pathways involved in colour development and bleaching are very complicated and are outlined in the literature (Lin-Wang et al., 2011) but it is clear that warm/hot nights have a bleaching effect and therefore a negative effect on colour development. Unfortunately, it is unlikely that the netting will sufficiently influence the temperature at night to have an impact on colour development and retention. A certain effect of netting is the scattering of light or diffusion of light and this leads to more light interception (Gu et al., 2002; Günter et al., 2008; Healey et al., 1998; Stamps, 2009). Environmental netting affect the scattering of light within the canopy, which ultimately can lead to more even colouration of the fruit (Shahak, 2012; Shahak et al., 2004; Shahak et al., 2008b). If light is scattered more fruit are likely to be exposed without being exposed to excess amounts of light which could lead to sunburn. Also scattered light is less intense than direct sunlight (Gu et al., 2002; Günter et al., 2008; Healey et al., 1998; Stamps, 2009) and therefore, has less capacity to heat the fruit surface. Unfortunately, screens above trees and crops have been shown to decrease light penetrability or in other words increase shading over time due to accumulation of dust (Tanny, 2013). Banana plant covers decreased the transmission of PAR (plant available radiation) from 90% to about 75% throughout the summer due to dust accumulation on the netting (Möller et al., 2010). Therefore, the shading effect of the installed netting should be monitored to ensure that this effect stays within the reduction wanted.

7.3.4 Fruit size

Fruit marketed as fresh fruit not only has certain criteria on colour but also the price is highly influenced by the size of the fruit. Genetic factors and growing conditions influence fruit size. Genetic constrains limit the average fruit size of certain cultivars, due to the number of cells and cell divisions early in fruit development (just after the initiation of growth after flower fertilization). Growing conditions, such as water availability, temperature and sunlight all influence fruit size development during the season. However, the most important factor of fruit size most likely is the number of cells developed in the early stages. Therefore, growing conditions at that point are most influential (Bepete and Lakso, 1998; Grappadelli et al., 1994). The other important factor is the practice of fruit thinning. The lower the amount of fruit on the tree the higher the likelihood of achieving maximum fruit size. Weather events occurring around the time when thinning chemicals are applied have a vast influence on the successfulness of a thinning application (Bepete and Lakso, 1998).

7.3.5 Diseases and Pests

Research conducted in Brazil found an increase in the incidence of apple scab on trees grown under black hail netting, but with no effect of white netting compared to the uncovered control in the cultivars 'Royal Gala' and 'Fuji' (Bogo et al., 2012). The increase in scab incidence may be due to slower drying of leaves and fruit under the black netting and through less intense sunlight and therefore greater humidity.

Due to a decrease in wind speed, other pests such as insects could establish a larger population under the netting, but such effects are yet to be demonstrated. On the other hand, damage to the tree and the fruit through direct sunlight interception is dramatically reduced under the netting and a reduction in wind speed has other positive effects such as a reduced loss of water. Therefore, some of the negative effects may be outweighed by the positive impacts of the netting.

Biotic stresses such as birds or other vertebrate pests such as possums or rats can also cause fruit damage. Many animals and birds feed on fruit and berries typical for their region of origin. But with ever decreasing natural habitats and with an abundance of options and possibilities in a commercial orchard, it is logical that animals will feed on fruit in orchards (Utah State University Extension, 2016). Large swarms of birds can cause devastating damage to the fruit (Figs. 24 and 25) and native Australian birds with extremely strong beaks can even cause damage to the tree structure by cutting off smaller branches (Bomford and Sinclair, 2002). Fruit damaged by birds is generally not usable, even for processing, due to the likelihood of contamination.

Fig. 24 *Damage on fruit caused by birds feeding ([Utah State University Extension, 2016](#))*

Fig. 25 *Damage caused by cockatoos pecking at the fruit ([WWF, 2016](#))*

7.3.6 Weather events

During fruit development, weather besides the availability of water, is one of the most influential factors. Erratic weather events and sudden changes in temperature or storms can have dramatic effects such as loss of fruitful and vegetative buds, flowers and/or the fruit at various stages of development. Much of what happens during the growing season to a fruit can influence the quality at harvest and storage. The outcome, such as marginal quality or non-marketable fruit is determined but what exactly causes the disorders is often not clear.

Fig. 26 *Apple with frost damage (http://www.pressherald.com/2010/09/08/off-and-running_2010-09-08/)*

Some weather effects leave clear marks such as frost damage to fruitlets or buds. Frost damage to the developing bud or flower can result in ring shapes scaring tissue circling the fruit (Fig. 26) causing the fruit to not be marketable as fresh. The scar tissue does not influence the internal quality of the fruit and use for juice or cider is still possible. However, as shown in Fig. 27 the average days of frost or temperatures below 0°C are very low in the Riverland region.

Severe rain can cause flooding of the soil and depletes the roots of available oxygen. Apple trees do not do very well in waterlogged soils (Wilcox, 1993). Short term flooding and low oxygen availability in the soil do not pose much threat to the trees, but overly wet soil during the winter months and especially in early spring are not well suited for apple production (Wilcox, 1993). Depending on the rootstock it can be less of a problem, but overall "wet feet" are undesirable for apples. The rainfall in the Riverland is approximately 270 mm yearly; spread throughout the year (Fig. 27) which is low in comparison to the amount of rain and other precipitation received in other apple producing areas. Also, soils in the Riverland are very sandy and unlikely to become waterlogged. Sandy soils have a good draining capacity due to big pores. This effects its water holding capacity after irrigation and the thermal properties when heating and cooling.

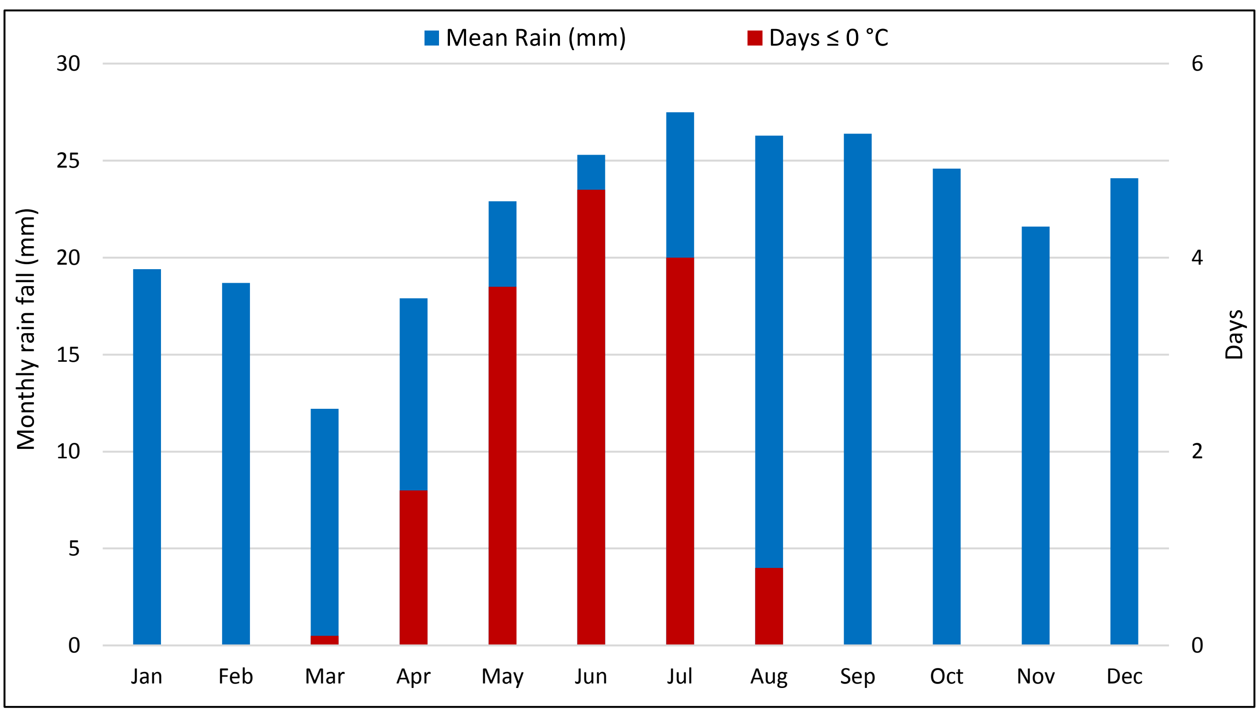

Fig. 27 *Monthly average rainfall and days blow 0°C for the Loxton BOM weather station*

7.3.7 Subliminal material

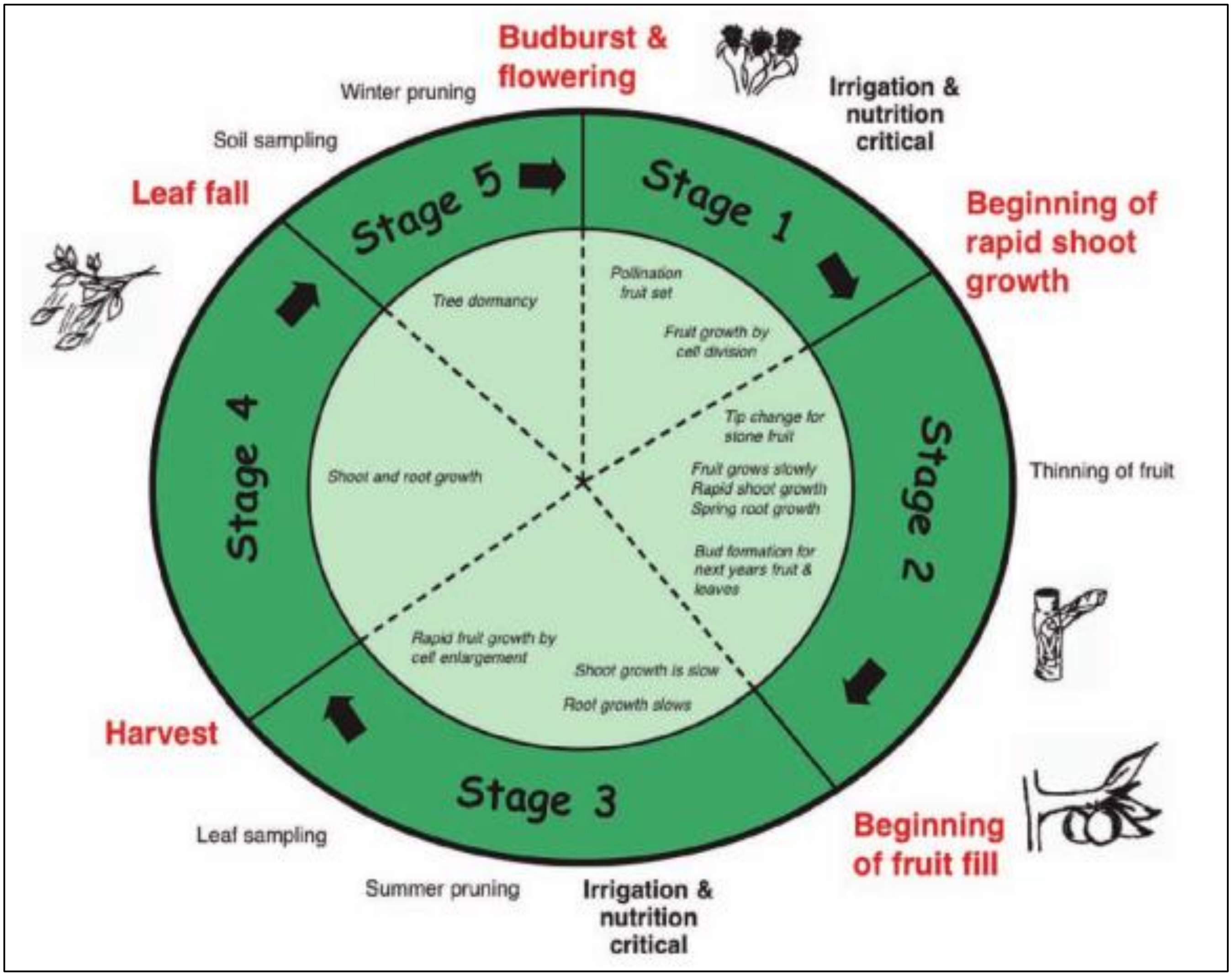

***Fig. 28** Fruit growers guide to irrigation: the growth cycle (Boland et al., 2002).*

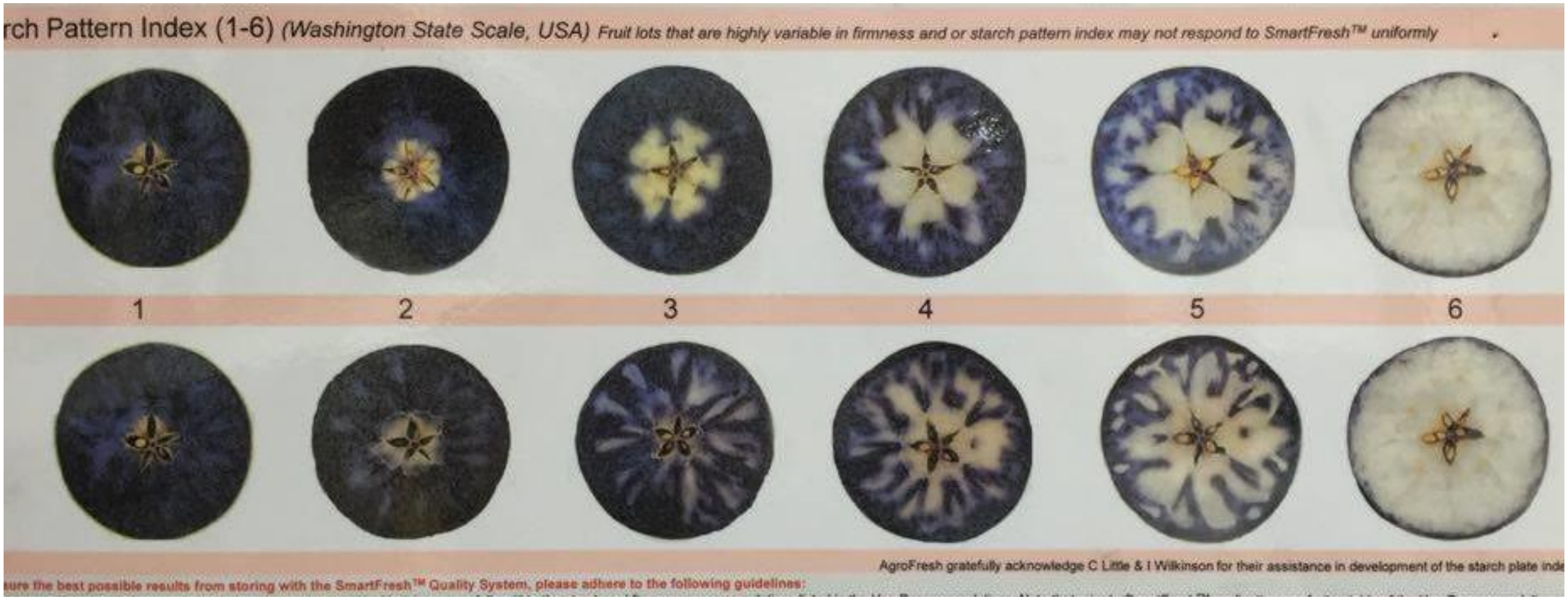

Fig. 29 *Starch chart used and promoted by AgroFresh (http://treefruit.wsu.edu/web-article/harvest-apples/)*

1 = full starch (all blue-black)
2 = clear of stain in seed cavity and halfway to vascular area
3 = clear through the area including vascular bundles
4 = half of flesh clear
5 = starch just under skin
6 = free of starch (no stain)