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

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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 citrus in the Riverland growing region is excessive heat, high solar radiation and strong winds especially early in the season. Environmental netting is one option available to citrus 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 a citrus orchard in the hot Riverland climate. Results to date indicate that environmental netting has little effect on ambient air temperature, "feels like" or apparent temperature and humidity. It does however effect solar radiation, wind speed and soil temperature which appear to reduce fruit damage due to wind and sunburn and alter vegetative growth.

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 may be of advantage due to greater reduction in radiation. 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. The observed orchard is covered with a white netting which also had an effect on reducing direct sunlight.

Effects of the environmental netting on water use efficiency (WUE) are difficult to assess after only one season of observation. In this particular study the difficulty also is that the trees inside the netted area and the control block are not very similar in age and/or tree high. Also the soils of the blocks (under netting and two control, each for Hutton Late navel and Imperial mandarins) are not identical with the control

being lower in sand content compared to the netting. Which in turn will also influence the adjustment of irrigation.

The time the trees have spent under the cover, netting was installed in February 2015, 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. Assessment of pest and disease populations may also be important and need to be monitored.

Overall netting seems to improve citrus tree performance 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 citrus production.

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. Mandarins and oranges combined produce more tonnage of fruit than any other fruit or nut commodity in Australia. Riverland is the third largest citrus growing region in Australia with over 8,000 planted trees and a total tonnage of ~450k citrus is a major industry in South Australia. The citrus industry produces fresh fruit and juice which combined contribute to a nutritious and balanced diet for many Australians. The Riverland is very important for the citrus industry with 6,300 ha of production and is an important contributor to the South Australian economy.

Like most primary production the citrus industry in South Australia is facing ever increasing challenges of land preservation, water conservation, stricter import rules and potential market losses in export countries. To ensure sustainable production new technologies have to be explored in order to secure markets and to ensure a consistent supply of premium quality fruit with superb eating and juicing qualities. Changes brought upon the industry though climate change could be severe and are already becoming increasingly visible (Wachsmann et al., 2014). Therefore, mitigation of extreme changes in climatic factors has become important for open-field agriculture (Wachsmann et al., 2014). To mitigate some of the factors changing though climate change, such as more sunlight and higher radiation (Meehl et al., 2000) different approaches can be taken such as the use of environmental netting. In the Riverland, which already has plentiful sunlight and little cloud coverage in the summer months, a reduction in solar radiation through netting could prove to be a production advantage both in terms of yield and fruit quality.

Environmental netting can reduce the effect of solar radiation through the scattering of light under the netting, which ultimately can lead to more even exposure of the fruit to light (Shahak, 2012; Shahak et al., 2004; Shahak et al., 2008b). If light is scattered more fruit are likely to be exposed within the canopy without being exposed to excess amounts of directly intercepted sunlight which could lead to sunburn. Scattering of light therefore not only has a beneficial effect on photosynthesis but also reduces sun exposure of fruit. Unfortunately, screens above trees and crops have been shown to decrease light penetrability or increase shade over time due to the 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). A reduction in radiation of up to 25% (75% light transmission) in the Riverland will most likely still deliver sufficient radiation with the average daily solar radiation in the summer month (beginning of November 2015 to the end of March 2016) being 27.7 kW/m^2 day. A reduction by 25% will mean still about 20 kW/m^2 per day (Ribeiro et al., 2006). The netted area only displays an average reduction of 13.4% to 24 kW/m^2 day this season at the Payp side.

Other beneficial effects of environmental netting are the reduction in wind speed. Wind can be a major contributor to losses in citrus quality. Rubbing of the skin of one fruit onto another object can cause scaring and discolouration of the peel (Albrigo, 1976). This in turn means the fruit is lower quality or might not be able to be marketed as a premium or fresh fruit. Traditionally wind breaker hedges and tree rows are planted on the side(s) of most wind exposed areas of the orchard. But not all sides of the orchard can be surrounded by trees or hedgerows. Additionally, insects (Lewis, 1970), birds and other animals (Pollard and Relton, 1970) can find nesting and housing within such hedgerows (Forman and Baudry, 1984) which in turn increases pressure on the orchard. Netting all around or at least mostly could have a greater effect on slowing down wind speed than a wind-breaker-hedge alone. Hedgerows cause turbulences in the wind flow and only reduce wind speed for a certain distance from the hedge (Forman and Baudry, 1984), whereas the top cover of the netting slows down the turbulence and allows for a greater reduction in overall wind speed.

Problematic in many growing regions around the globe is hail (Jackson, 1999). Netting with the right specifications can be very effective in protecting the plants from hail (Scott, 1988; Whitaker and Middleton, 1999). Hail effects not only the fruit but can also cause severe damage to the permanent tree structures causing devastating damage to the orchard. Netting can prevent some of the damage (Scott, 1988) by not letting the hail to penetrate though the netting and therefore preventing damage (Gordon, 2013). The netting needs to be designed in such a way that the hail can be released though at some safe point to prevent the whole structure from collapsing.

Netting not only can be used to alter effects of abiotic stresses such as high light and increased evaporation (water loss) but also to mitigate some of the effects caused by biotic stressors such as birds. Netting has been found to very effective against birds, if the netting is controlled and well maintained (Bomford and Sinclair, 2002). Even though the costs for netting are higher than the other means of bird protection, some beneficial effects have been detected in other growing regions in Australia and internationally (Bomford and Sinclair, 2002).

Understanding the changes in climate and weather patterns due to the netting will help determine which quality parameters, tree components and other factors are most effected by the nets, either positively or negatively. Therefore, this report will investigate the use of environmental netting on the production of Hutton Late Navel oranges and Imperial mandarins in a hot inland growing region such as Loxton, Riverland.

2. Methodology

This report looks at a comparison of netted and un-netted (control) blocks of Hutton Late Navel oranges and Imperial mandarins to assess the influence of environmental netting on citrus. Blocks were chosen due to their relative close proximity on the same property.

2.1 Site description

The four orchard blocks have some similarities and some very obvious differences. For all four sites – control and netted, Hutton Late Navel oranges and the Imperial mandarins irrigation is setup with two dripper lines. The drippers are 2.3 L/hr and spaced 0.9 m apart, therefore a total of 3700 drippers/ha. This setup has the capacity to deliver 8.52 ML/hr/ha (mega litres per hour and hectare), this converts into 8.52 mm of irrigation per hour. In this report precipitation as well as soil moisture will be presented in mm. mm of water: 1 mm = 1 L/m^2 or on a per hectare basis 100 mm or 1 ML/ha (mega litres).

2.2 Cultivars and the specifications of each block

While the same cultivars are being investigated in this study there are some important differences between blocks that need to be outlined from the start as they influence how results are interpreted. This study is an observational case study aimed at providing some basic comparisons between netted and un-netted citrus. Differences in the layout of the blocks, age of trees, plant density are important to know to understand how they influence the yield and performance of the trees and the orchard block as a whole (Table 1).

Table 1 *Site description for the four citrus blocks at Pyap citrus, Loxton, for the Imperial mandarins and the Hutton Late Navel oranges.*

Cultivar	Treatment	Planting year	Rootstock	Planting density	Soil type
Imperial Mandarins	Un-netted (Control)	1970/ top worked 2008/ interplanted 2012	Sweet Orange	333 trees/ha 5m x 6m – interplanted in 2013 to 666 trees/ha to 2.5m x 6m	Sandy loam
	Netted	2005	Carrizo	617 trees/ha 2.7m x 6m	Sand
Hutton Late Navel	Un-netted (Control)	1968/ top worked 2008/ interplanted 2013	Sweet Orange	333 trees/ha – interplanted in 2012 to 666 trees/ha	Sandy loam
	Netted	2008	Rough Lemon	617 trees/ha 2.7m x 6m	Sand

2.2.1 Hutton Late Navel Oranges

Navel and Navelina are seedless oranges that take their names from the Navel protuberance at the end, which contains a tiny embryonic fruit. They have thick, pebbly skins and very sweet juicy flesh (Growers, 2012). The citrus Hutton Late Navel are a sub-cultivar in the range of Navel oranges and are in general harvested in late July until November (in Australia) and generally are placed in the market place in Australia and Asia (Oranges). They are ideal for fresh consumption due to their seedlessness and sweet juicy flesh.

2.2.1.1 Control oranges

The un-netted block (Hutton control) was originally planted and established as a Sweet Orange block in 1968 with Hutton late navel grafted in place of Sweet Orange in 2008. The original spacing within the row of 5 m was interplanted in 2013 with Hutton Late Navel on Rough Lemon, to increase the planting density from 333 trees/ha to 666 trees/ha. The spacing between rows is 6 m. The soil in the block is classified as sandy loam.

2.2.1.2 Netted oranges

The netted block of Hutton Late Navel (Hutton netted) was planted as a nursery plant union with a Rough Lemon rootstock in 2008. The planting density in this netted area is 617 trees/ha with a tree spacing of 2.7 m and a row width of 6 m. The soil type in the area is classified as sandy.

2.2.2 Imperial Mandarins

Imperial Mandarins belongs to the citrus classified as "Easy Peeler" varieties. These varieties have an airgap between the rind of the peel and the flesh of the fruit allowing for extremely easy peeling of the fruit. Imperial mandarins are the first of the easy to peel varieties to be harvested in early June through to late August in Australia (Siebert). This has the advantage of being the first on the market. Imperials are therefore the most popular mandarin variety because they are the first to be harvested each season allowing great access to the market. They are a golden-orange mandarin, and one of a handful of popular citrus varieties that have originated in Australia. The variety was first recognized as a cultivar in Sydney in 1890 (Mandarins). Imperials are easy to peel, have very few seeds, and can be enjoyed as a perfect portable snack.

2.2.2.1 Control mandarins

The un-netted (control) block of Imperial Mandarins are grafted to a Sweet Orange rootstock which was originally planted in 1970 (top worked to Imperial Mandarins in 2008). The original spacing within the row was 5 m and in 2012 Imperial Mandarins on Carrizo were interplanted to increase the planting density from 333 trees/ha to 666 trees/ha. The spacing between rows is 6 m. The soil in the block is classified as sandy loam.

2.2.2.2 Netted mandarins

The netted Imperial mandarin block was planted in 2005 as grafted nursery plants with the rootstock Carrizo. Trees are 2.7 m apart within the rows and the rows are 6 m wide (617 trees/ha). The block is planted on sandy soil.

2.1 Environmental netting

The enclosure has netting on three sides with natural vegetation functioning as a wind block on the south facing side of the enclosed area. The netting is at a height of 6m and is a white 20mm^2 quad weave poly net. The quad weave means that there are 4 lighter cross filaments within the main 20mm^2 net weave. The sides are netted with a tighter weaved netting with 8mm^2 quad weave in a black colour. The netting over the two netted blocks spans a much wider area than each of the two blocks being studied as it includes other types of citrus grown in the commercial orchard.

The netting was installed by Elite Netting and installation was completed on 29th May 2015.

2.2 Data collection and measured parameters

For comparison of the performance of the control and the netted areas certain parameters are important. Comparing yield is difficult as there are great differences between the well-established older trees outside in the control blocks interplanted with much younger trees whose yield will be lower due to less leaf area and overall smaller trees. Therefore, comparison of yield purely based on area will not present the full picture. Consequently, other measurements of quality and improvement with or without the netting have been performed and will be the focus of the comparison.

2.2.1 Soil moisture

Establishment of differences in soil moisture outside and under the netting can give insight into the difference in respiration inside and out of the netting. Soil moisture is monitored with the use of Sentek

EnviroSCAN probes (Fig. 1). The measurement is based on electrical flow between two sensor parts. Data interpretation is based on a calibration for Murray soils and can be adjusted over time depending on the data output.

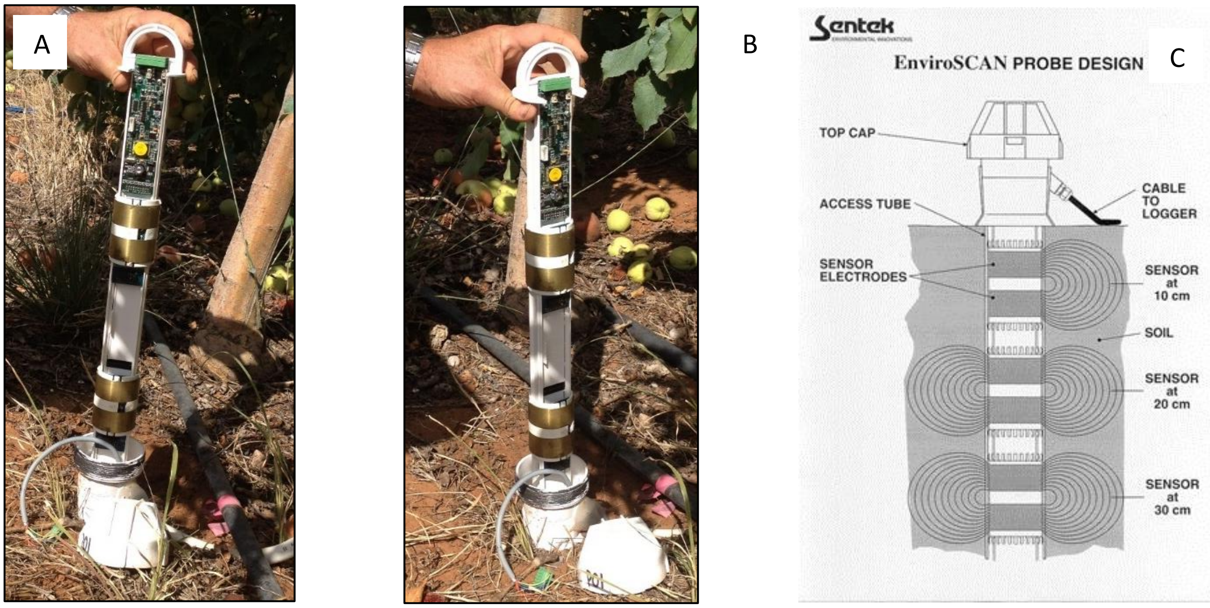

Fig. 1 *Soil moisture sensor EnviroSCAN by Sentek installed the apple orchard (A and B) – the measurements are performed between 5 and 15 cm, 25 and 25 cm and so forth, the 10 cm span measures the conductivity of the soil in that region (how it is installed: http://www.sentek.com.au/products/enviro-scan-probe.asp#enviroscan) – (C) a schematic of how the sensor measures the soil moisture.*

Interpretation of the soil moisture data needs to take into consideration the soil type. Since depending on the soil water distribution is very different (Fig. 2). The soil moisture probe (EnviroSCAN) is generally installed approximately 10 cm form the dripper line next to a dripper. This is done to ensure the correct measurement of the soil moisture as it would be perceived by the majority of the roots.

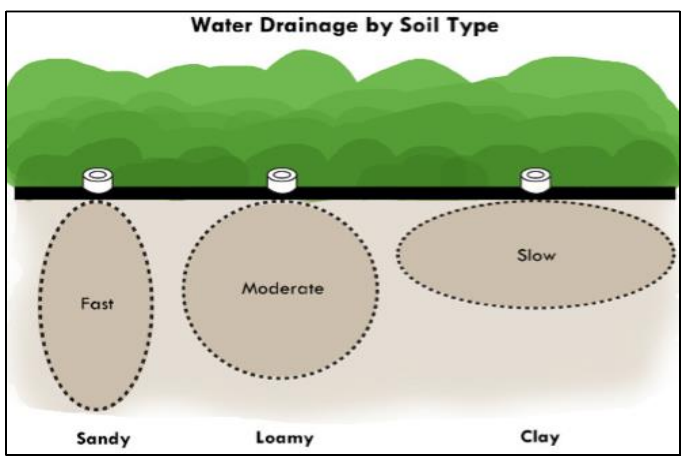

Fig. 2 *Soil wetting profile depending on soil type and dripper output speed (https://www.dripdepot.com/article/know-your-soil-type)*

Wetting ability and the pattern of the wetting profile changes with the soil type and the length of each irrigations cycles (Fig. 2). 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.

The EnviroSCAN reaches down 80 cm in the Hutton Late Navel blocks and even 110 cm in the Imperial mandarin blocks. Reaching this far down into the soil ensures that the probes reach into the sub-soil areas and therefore not only monitor the irrigation of the upper soil profile but also monitor water runoff beyond the root zone as well as over watering. The lower sensors also sense whether longer irrigation cycles can reach the lower profiles of the soil. Occasional irrigation down into the subsoil layers can have beneficial effects for the overall wetting profile and allow root growth into lower sections, depending on soil structure and profile this can be desirable.

2.2.2 Weather data

Climate as a whole is important for growing horticultural crops and for the comparison of the control and netted citrus orchard areas it is important to understand how the netting effects such climatic parameters. Therefore, a station was installed under the cover to compare with an already installed station outside the netted area.

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.

2.2.3 Tree and fruit assessments pre-harvest

Fruit quality assessment before harvest (pre-harvest) while the fruit are still on the tree allows for a visual comparison of performance. An estimate of the number of fruit per tree can be evaluated based on tree size and health. This information is generally lost after harvest when fruit form many trees are combined in bins and no tracing back to certain trees is possible.

During a site visit on 18th of March 2016 20 orange trees and their fruit and 15 mandarin trees and their fruit from both netted and control trees were assessed. Each tree was photographed to estimate leaf area index (LAI) and canopy porosity using the VitiCanopy App (De Bei et al., 2016). The assessment of tree health of each tree was visually assessed and evaluated for damage of permanent tree parts (wood and leaves) and fruit.

General tree evaluations focused on comparing trees to each other to determine whether a tree had average amount of fruit, how the fruit appeared in their development overall, colour, size and whether there was any skin damage (wind/sunburn) on fruit and/or wood of a given tree.

2.2.4 Fruit quality at harvest and post storage (Yield)

Fruit quality at harvest will be measured in July 2016 and will presented in the future reports.

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

Assessment of fruit pack out at harvest and post storage will be presented in future reports.

3. Results

3.1 Soil moisture

Detection of soil moisture can be used to extrapolate plant water use and water use efficiency. The only drawback in this case is that the soil moisture sensor data only reflects soil moisture and no further aspects of plant transpiration, evapotranspiration off the soil surface and other environmental factors effecting water uptake and water use of the plant. Therefore, the data presented has to be seen with its source in mind and interpreted accordingly. 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. The soil type outside the netting for both citrus areas is sandy loam, whereas the trees under the netting grow in a sandy soil. Therefore, the water holding capacity differs between the areas. Sand cannot hold on to as much water as the sandy loam and therefore irrigation needs will be different. The comparison between the netted and the control blocks must be undertaken with consideration of the difference in soil.

Soil moisture is different between different sections or horizons within the soil profile (Jabro et al., 2005). The Sentek EnviroSCAN set up in the four blocks are equipped with 4 sensors reaching a depth of 80 cm in the soil.

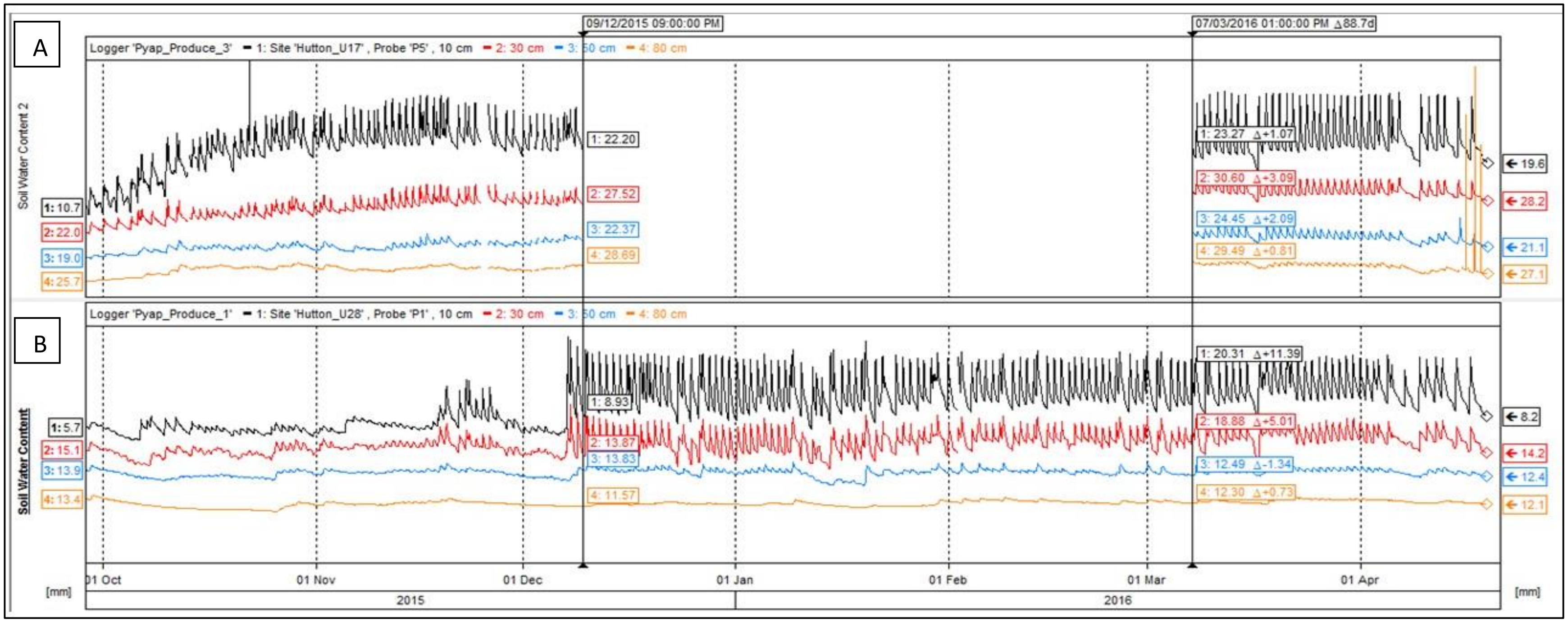

Fig. 3 *<u>Hutton Late Navel</u> soil moisture sensor readings in mm at 10 cm (black), 30 cm (red), 50 cm (blue), and 80 cm (yellow) at Payp form the sensors placed under the environmental control (A) and netted block (B)*

The Hutton Late Navel oranges have very different soil moisture profiles in the control block (A) and the netted area (B) (Fig. 16). Unfortunately, an outage caused the sensors in A to not record data between 09th December 2015 and 07th March 2016. Therefore, a comparison over the whole season is not possible. It becomes clear even with the short time span of comparison, that the water holding capacity of the sandy loam in the control block is much higher compared to the sandy soil under the netting; with 22.3 and 8.9 mm at 10 cm soil depth at control and under the netting respectively (Fig. 3). Similarly, in the lower soil profiles the sandy loam in the control block has a soil moisture within the low and mid 20 mm range, whereas the sandy soil under the netting only holds about 10 to 13 mm moisture. The amount of measured moisture in the lower soil profiles, especially at 80 cm, is of significance for irrigation scheduling and monitoring of water flow. In both blocks control as well as under the netting (Fig. 3) the 50 cm (red) horizon clearly still receives plenty of water with each irrigation and decreases with plant water use. Under the netting the 80 cm (yellow) horizon does not fluctuate as much with irrigation and root water uptake seems less from this area. But the trees under the netting are less established compared to the trees in the control block. Sandy soil can hold less water compared to soil with more other components (Doran and Parkin, 1994), outside the netting in the control block the soil is less sandy. Nevertheless, the sandy soil under the netting has less water leaching into the lower soil profile indicating good water management with sufficient irrigation without having excessive water leach into lower soil profiles at which point it would no longer be plant available.

In comparison the Imperial Mandarin blocks show a more similar water holding capacity outside and underneath the netting (Fig. 4). Here also the control block had a short time period without recording (22nd December 2015 to 07th January 2016). Nevertheless, overall the soil moisture is more similar in the blocks than in the Navel oranges (Fig. 3). The lower soil profiles 80 (yellow) and 110 cm (green) received plenty of water between 25th January 2016 and 08th February 2016 with good deep irrigation but little retention of the water. This could indicate leaching of the excess water into even lower soil horizons (Fig. 4 A blue circle) or water uptake by roods, as indicated by the staircase shaped curve indicating uptake and refill. Whereas deeper irrigation was done on 30th January 2016 under the netting and the lower soil profiles retained a higher soil moisture after that which was increased from 19.5 and 17.5 mm to 25.1 and 29.8 mm for 80 and 110 cm respectively (Fig. 4 B red circle). Increasing soil water content in lower soil areas is a long process and has to be done carefully in order to avoid water leaching beyond the rooting zone. As can be seen the water table was raised in the lower horizons and remained higher throughout the remaining season (Fig.4 B).

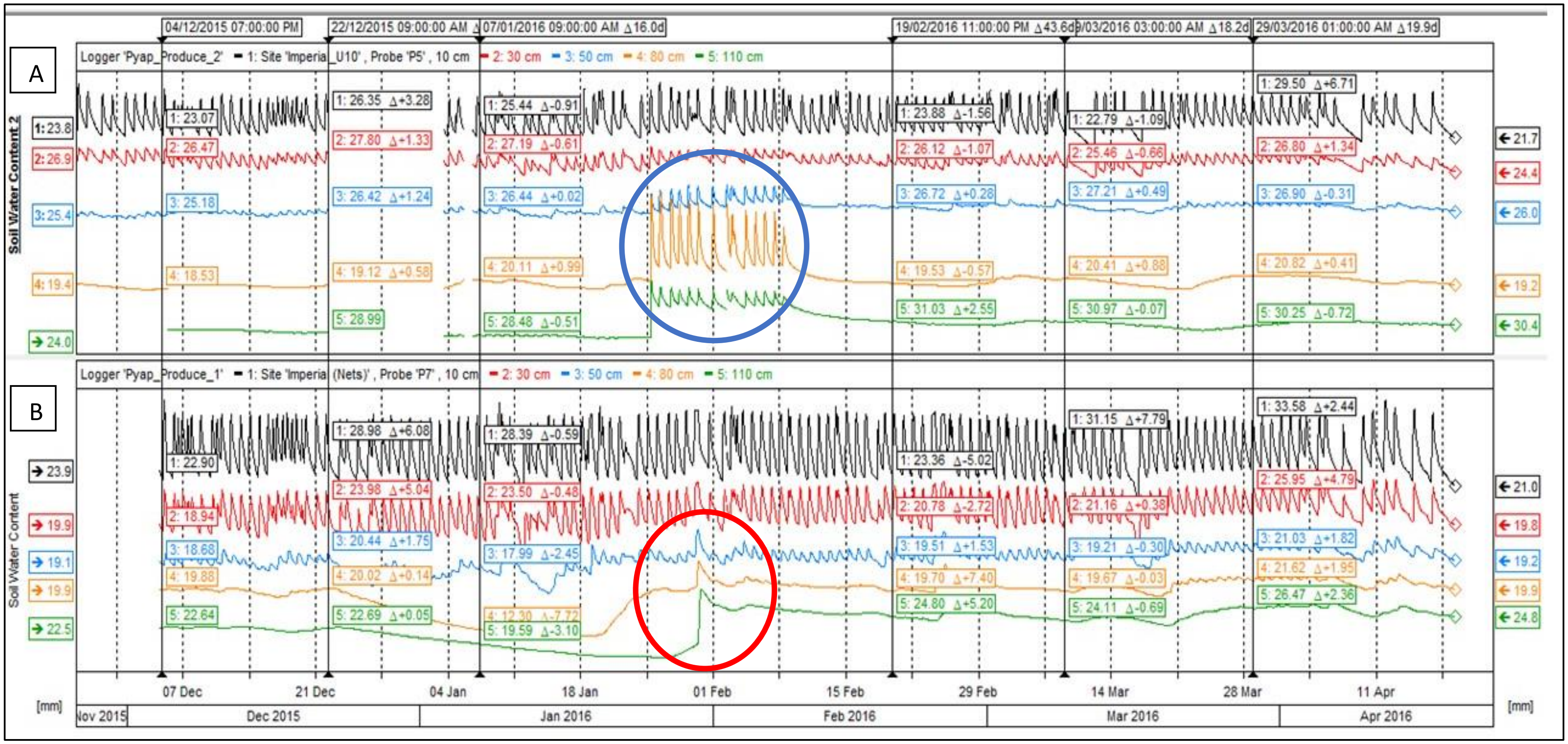

Fig. 4 *Imperial mandarins soil moisture sensor readings in mm at 10 cm (black), 30 cm (red), 50 cm (blue), 80 cm (yellow) and 110 m (green) at Pyap form the sensors placed under the environmental control (A) and netted block (B); the blue circle indicates excessive changes in soil moisture in the lower soil horizons at 80 and 110 cm in the control block, and the red circle marks a steep increase in soil moisture of layer 80 and 110 cm of the netted block.*

Interesting in terms of production is how much water is applied and retained within the measured soil horizons (Fig. 5). Between 10 and 110 cm the soil profile in the period from 04th December 2015 to 17th April 16 the control area (A) received approximately 1300 mm (1.3 hL) whereas inside the netting about 2.4 hL was applied (2380 mm). Unfortunately, in the control block (A) between 23rd December 2015 and 03rd January 2016 no data was recorded. In this time period about 202 mm water were added and detected by the sensor in the soil. The difference of more than 1000 mm or 1 hectolitre (hL) in total cannot be explained by that short outage of the data logger, but can be explained by the difference in soil moisture retention.

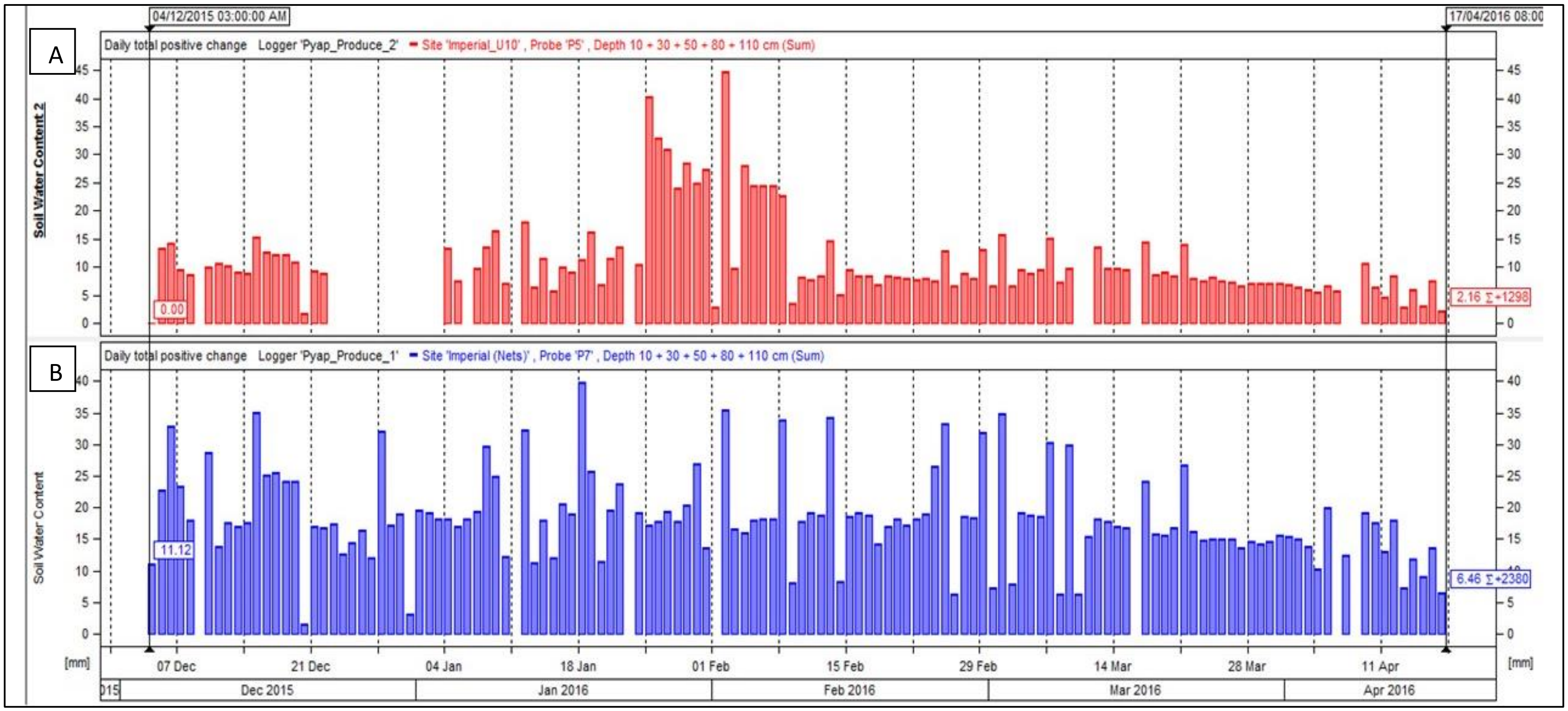

***Fig. 5** Total positive daily change in soil moisture (mm) in the Pyap un-netted control (A) and the netted (B) Imperial Mandarin blocks – with a total daily positive change in soil moisture between 04.12.15 and 14.04.16 of control (A) 1298 mm and netted area (B) 2380 mm – during the not recorded time 23.12. to 03.01. in the control block, 202 mm soil moisture were added to the netted area.*

The positive changes in soil moisture are well reflected in the graph above with lower soil moisture on the days when no irrigation was applied. Another example is the significant increase on 1st of February 2016 (Fig. 5) which coincides with a deep irrigation (Fig. 4). Accurate irrigation is important to guarantee not only even watering of a block, but also that the site of soil moisture assessment is representative of other parts of the orchard in order to ensure correct estimation of needed irrigation. Irrigation precision is therefore based on even output of water along the irrigation line. If some drippers deposit water more or less than others due to changes in pressure, blocking of dripper lines or dripper holes, or any other reasons, the irrigation water is not delivered evenly throughout the block. This becomes especially challenging and important if irrigation scheduling is based on sensor data delivering information about soil water content (soil moisture in mm). This is generally a very good way to ensure sufficient irrigation without using unnecessarily high amounts of water.

The soil type also is important for distribution of water in the soil (Figs. 1 and 2). Depending on the ratio of fine particles (clay) and larger particles (sand) in the soil the water holding capacity (field capacity) is very different. Sandy soils need more frequent irrigation with less water applied in each irrigation treatment compared to soils rich in clay (Doran and Parkin, 1994). Sine sandy soils have big particles and therefore larger soil pores which cannot hold large amounts of water due to limitations of capillary tension of water in the pores. But the water present in these sandy soil types is easily plant available. Both these aspects have to be kept in mind when irrigation scheduling is done. Precision irrigation therefore needs to be done based on measurements of soil moisture, weather considerations such as coming up heat waves, as well as the soil type in mind. Leaving any of those aspects out of the consideration of when and how much to irrigate can lead to under or over irrigation and therefore either risk drought or wasting water.

3.2 Weather events

Climate and seasonal weather are important factors for production of horticulture crops outside of a controlled environment (greenhouse). Indications are that under current climate change conditions night temperatures might rise faster than day time temperatures. Which can have great implications on production of fruit and vegetables in many regions (Alward et al., 1999; Franz et al., 2004). The difference between day and night temperatures can be important for crop quality as well. Lower night temperatures mean less respiration and higher retention of soil moisture and carbohydrates within the plant (Gifford, 1995). The day and night temperature from the Pyap weather stations, both outside the netting and under the netting, are as shown in Fig. 6.

Day and night time temperatures are generally very similar outside the netting (control) and within the environmental enclosure (netted) (Fig. 6). Only between 28th January and 28th February 2016 is there a clear visual discrepancy between the two weather stations with much higher maximum and average temperatures as well as day and night temperatures at the control station compared to the netted area (Figs. 6 and 7). This appears to be due to an incorrect temperature measurement of the outside sensor which is also demonstrated when compared to the Loxton Bureau of Meteorology (BOM) weather station (Fig. 8).

Temperatures below 12 °C can cause damage on citrus fruit in storage and if still on the tree may induce the production of cold shock proteins. The tree may suffer some minor injuries if the temperature drops suddenly below a critical cold temperature (about 8 °C) and fruit can also be damaged on the tree. Only a few nights in April had low temperatures close to 8 °C (Fig. 7) and at that point the tree should be acclimatised to lower temperatures due to the shorter day length (Nijjar and Sites, 1959).

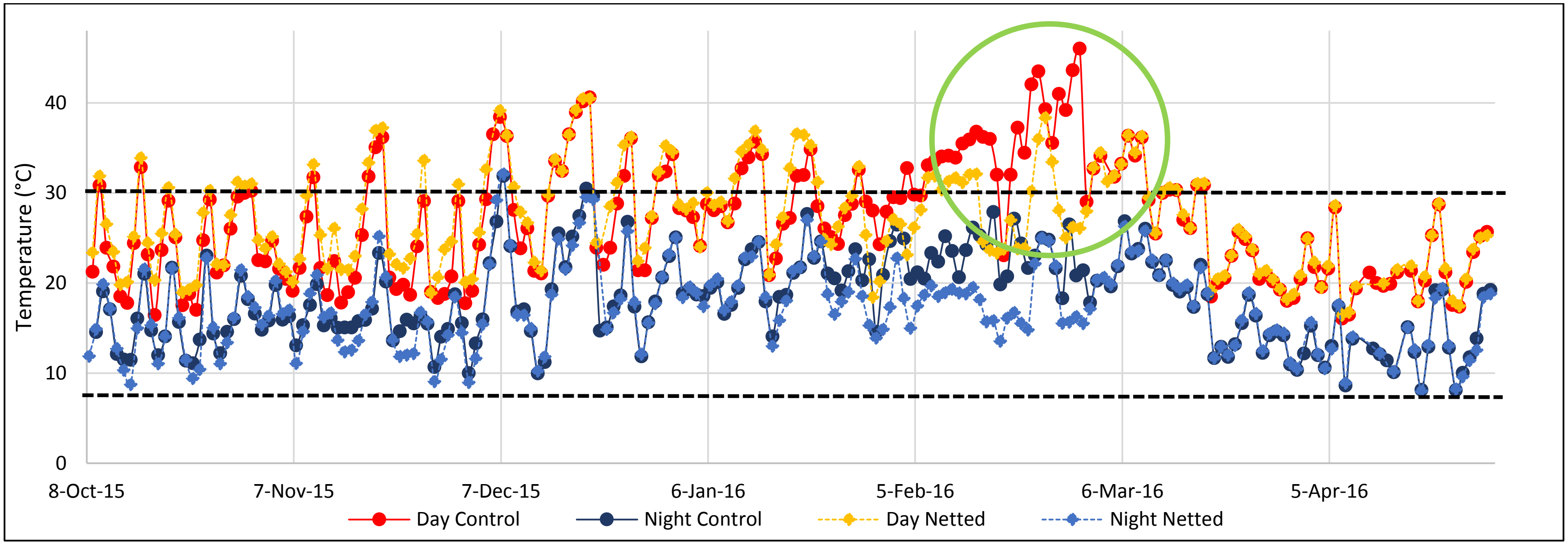

***Fig. 6** Comparison of day (average temperature between 9am to 8pm) (red and yellow) and night (average temperature between 9pm to 8am) (blue) temperatures (°C) in the control block and under the netting (both stations are centrally located to the mandarin and orange blocks) – 8th October 2015 to 28th April 2016 – data from NRM Board (2016)*

Daily average and maximum temperatures between the netted and the control area generally differ very little (Fig. 6). The greatest difference again was observed between 12th and 29th of February 2016 with a huge spike in the day maximum temperatures measured to be over 60 °C outside the netted area, such high ambient temperatures can cause severe damage to the trees and fruit and at direct sunlight can be even higher. Hopefully theses temperatures are an artefact of high light and high ambient temperature heating the weather station beyond the ambient temperature. Also the temperature under the netting reached almost 45 °C (43.3 °C) on 23rd February 2016. Such high temperatures stress the trees and sufficient irrigation is needed to prevent long term damage (Guo et al., 2006).

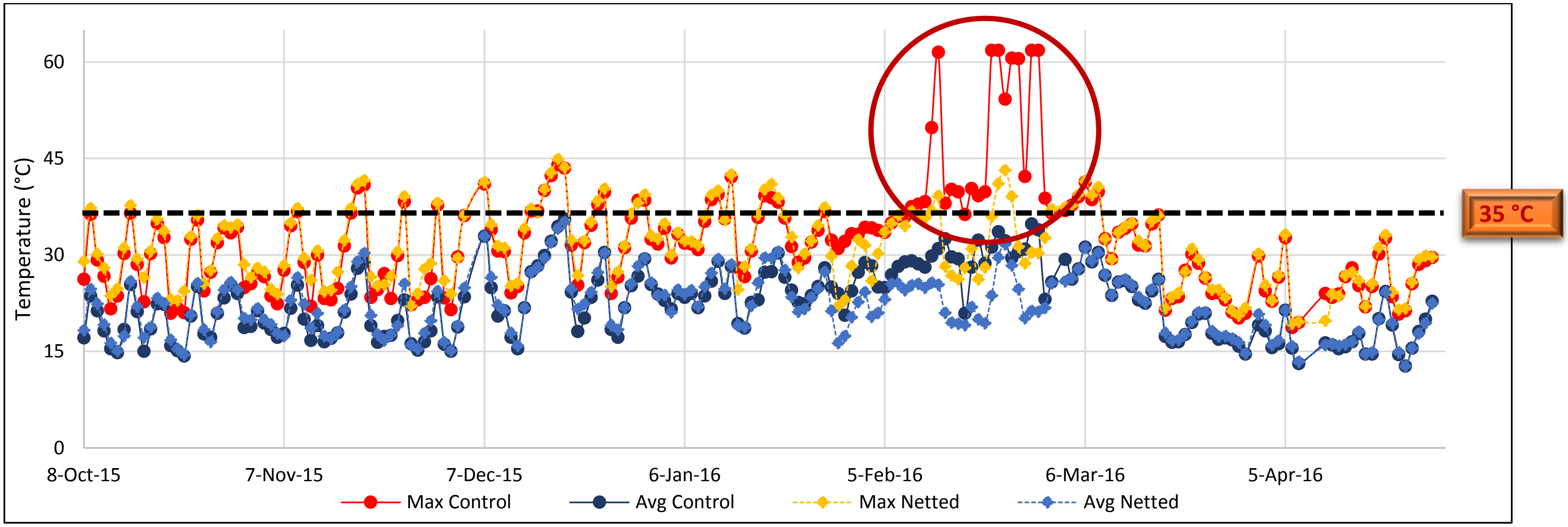

Fig. 7 *Daily average and maximum temperature for uncovered (control) and netted area at Pyap, from 8th October 2015 to 28th April 2016; the black line indicates 35 °C – data from NRM Board ([2016]).*

The comparison of the control weather station with BOM data (Fig. 8) (netted data not shown but very similar to BOM data) and the calculated day temperature shows that the high temperatures measured at the Pyap weather station are most likely some irregularities in the measurement rather than orchard experiencing temperatures over 60 °C.

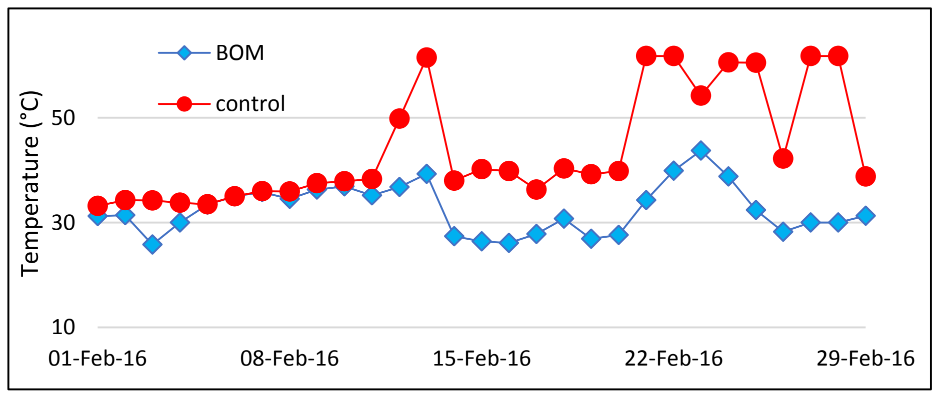

Fig. 8 *Comparison of measurement of maximum ambient temperature (°C) at the control weather station (control) at Pyap and the BOM weather station at the Loxton research station (http://www.bom.gov.au/climate/dwo/201601/html/IDCJDW5031.201601.shtml)*

Rain events and radiation (solar) recorded for Pyap weather station outside (control) and under the environmental cover (netted) are shown in Fig. 22. The amount of rain collected by each of the two weather stations is very similar over the time period form 8th October 2015 to 28th April 2016 indicating little effect of the netting on precipitation. Solar radiation (W/m^2) on the other hand is greatly affected by the netting. Reducing the total light penetrating into the canopy by 14% to only 86% of the solar radiation outside the netting. Over the time period of approximately seven months (October to April) this equals 707 kW/m^2 or an average daily reduction of 3.6 kW/m^2. Reduced direct sunlight can have dramatic effects on fruit health especially for sun burn. Which is caused though excessive heating of the fruit surface. The white netting reduces radiation less than a different colour like black netting (Shahak, 2012; Shahak et al., 2008a).

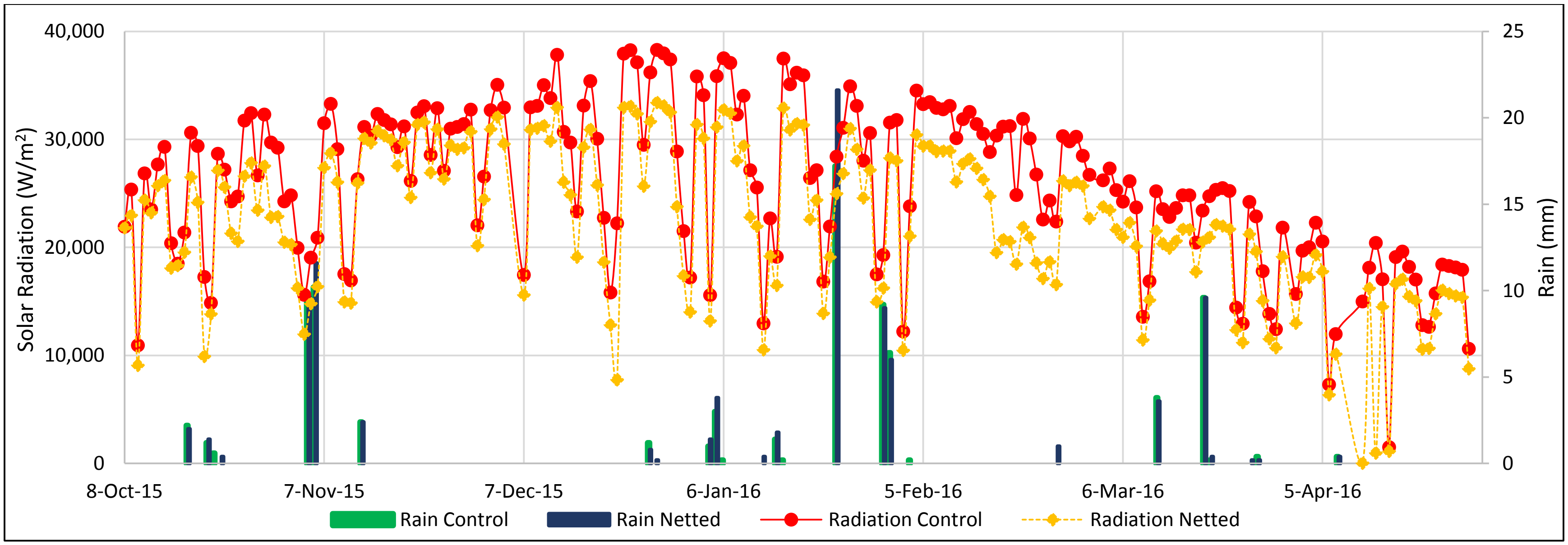

Fig. 9 *The daily solar radiation (W/m^2) and rain fall (mm) for Pyap weather station and the weather station under the environmental netting (netted – Trial 2), 8th October 2015 to 28th April 2016 – data from NRM Board (2016)*

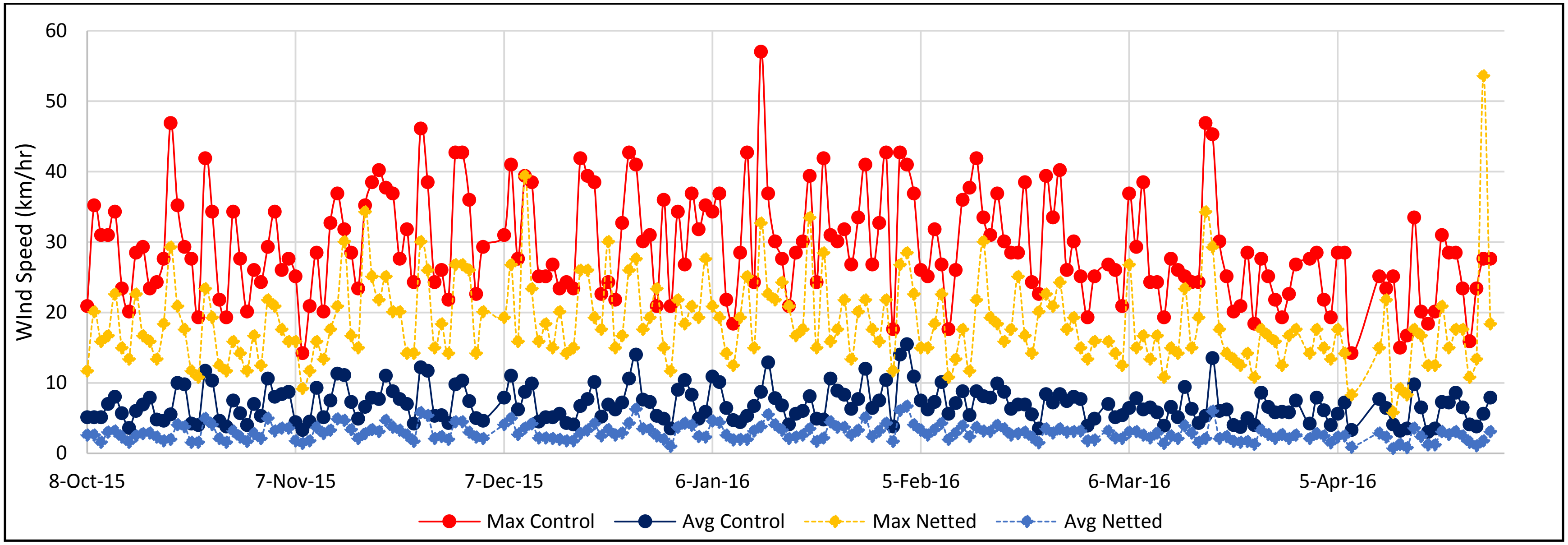

Fig. 10 *The wind speed (km/hr) measured as daily maximum and average for the control area and under netting (netted), 8th October 2015 to 28th April 2016 – data from NRM Board (2016)*

Wind also can have a negative effect on mandarin and orange fruit development though causing skin blemish (Fig. 6, 7 and 13). Therefore, the effects of netting on wind speed can have effects on fruit quality and the amount of fruit that can be used for the fresh market. The average wind speed is in typical reduced by 4.0 km/hr though the netting and the daily maximum is lowered by about 11 km/hr (Fig. 23). Especially on very windy days the effect of the netting is remarkable and the reduction can be up to 75% under certain conditions. Lower wind speed means less movement of the fruit and leaves, which in turn means less rubbing of the fruit against another surface, being either stems, branches, or leaves, which therefore leads to less damage on the fruit though wind.

Not only the air (ambient) temperature but also the temperature of the soil can influence the development of trees as well as the fruit as such. Higher amounts of direct sunlight intercepted by the soil will increase the temperature similar to that of fruit surface. The temperature of the soil will change depending on the depth of measurement and therefore will have different effects on different parts of the root system depending on rooting depth and pattern. The weather stations have the soil temperature sensors at 150 mm soil depth. Problematic can be, that if irrigated with trip systems the main root system is concentrated around the area which gets wetted and, therefore, can be shallow and concentrated in a small soil area. Shallow root systems are not only in danger of high soil temperature but also of salt crusting around the irrigated soils zone.

Soil temperature influences water loss from the soil as well as root health. Extreme soil temperatures can damage roots. During the growing season in the Riverland effects of soil are mostly though heat and water availability which is regulated though irrigation. In other regions low soil temperatures in the spring can slow down the initial growth or retard growth. In the Pyap orchard the environmental netting had a positive effect on soil temperature with reduced maximum temperatures in average by 5.2 °C (Fig. 24). Under the netting the average and minimum soil temperature is in general slightly warmer than in the control area and stays more consistent thought the season. On 17th December 2015 the max soil temperature in the control orchard reached 51.9 °C compared to only 39.6 °C under the netting. Prolonged exposure to such high temperatures can certainly cause damage to the root system. The soil temperature development at the control station also agrees with the statement that the extremely high temperatures measured in February are most likely due to some interference with the station.

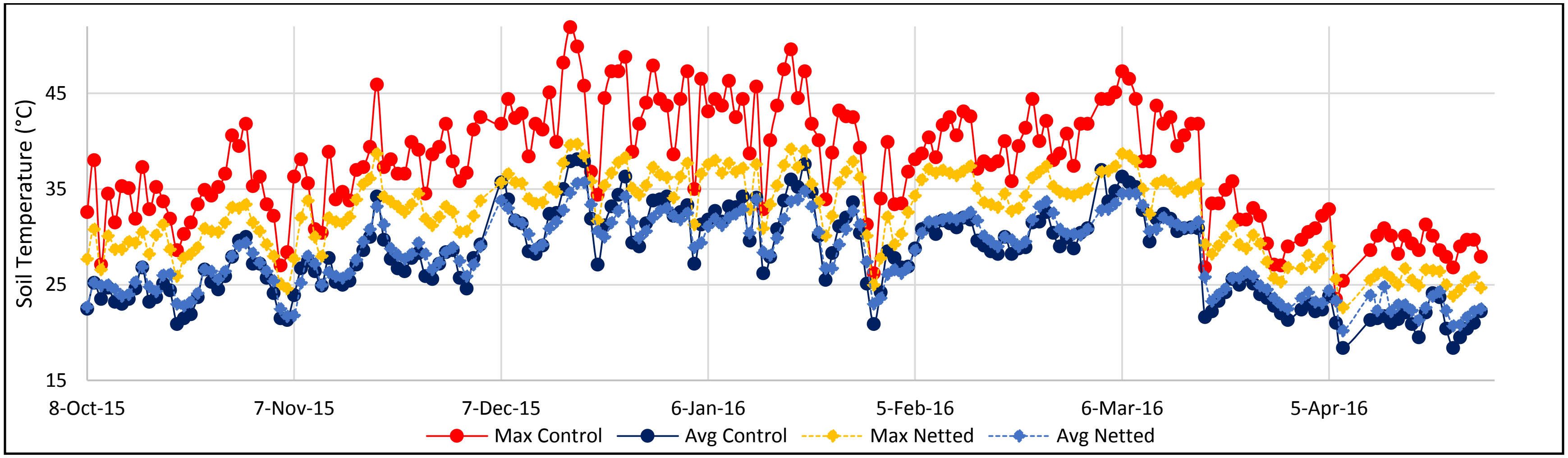

***Fig. 11** Daily maximum and average **soil temperature** (°C) for the uncovered control plot and the netted part of the citrus orchard (Payp), 8th October 2015 to 28th April 2016 – data from NRM Board (2016)*

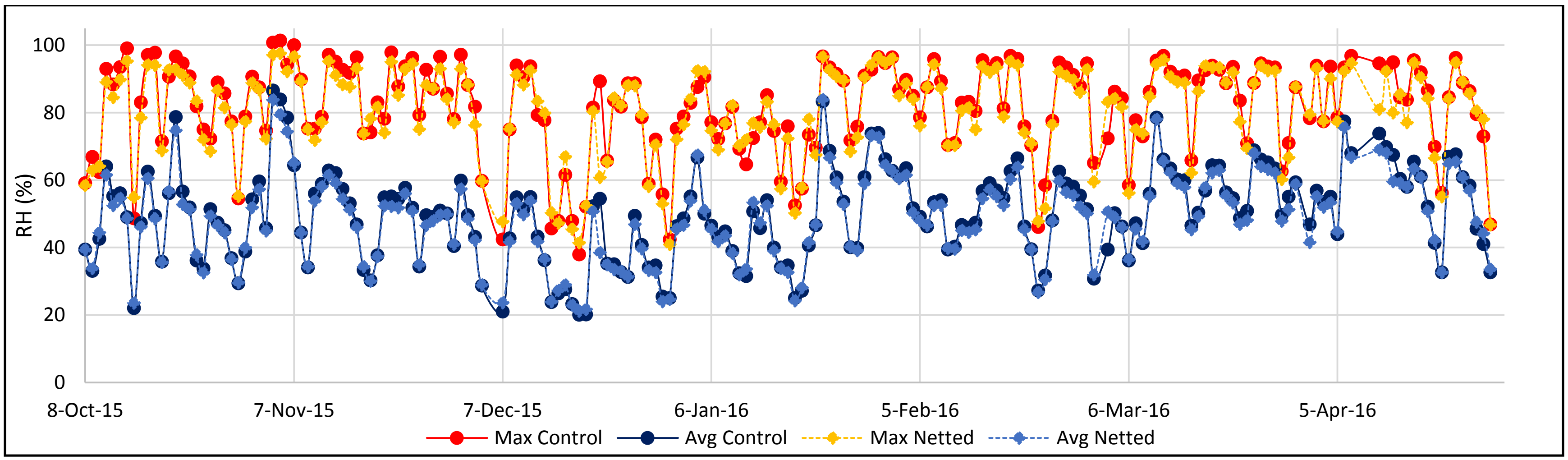

***Fig. 12** Maximum (Max) and average (Avg) **Relative humidity** (RH, %) for the uncovered control and the netted citrus area at the Payp citrus orchard, 8th October 2015 to 28th April 2016 – data from NRM Board (2016)*

Relative humidity (RH, %) is an important indicator for the amount of photosynthesis that can be performed within the orchard. If the RH is very low the VPD (vapour pressure deficit) is very high, meaning the difference between the humidity/water within the leave and outside the leave is very high. Water as evaporation/vapour escapes faster from the leave if the humidity outside is very low. Which in turn leads to a closure of the stomata and therefore reduced uptake of CO_2 and ultimately less photosynthesis. The effects of the netting on RH (Fig. 25) are overall very low. With no improvement on maximum or average RH compared to the uncovered control area.

Overall there are limited measurable effects of the netting on micro climate. The ambient and apparent (data not shown) temperature is little changed though the netting. This is mainly due to the fact that the calculation of perceived or apparent temperature only considers current RH and wind speed to calculate the adjustment of ambient (http://www.bom.gov.au/info/wwords/).

3.3 Tree and fruit assessments pre-harvest

Preharvest fruit and tree assessment was done on 18th March 2016. For the Hutton Mandarins 20 trees each under the net and the control were photographed for LAI (leave area index) and scored based on simple tree and fruit parameters. Fruit damage was assessed as approximate amount of fruit damaged with wind damage and/or sunburn in percentage of fruit on the tree. New growth or vigour was scored on a scale from 1 to 5 with 1 being very little new growth and 5 being very vigorous. Gall wasp damage and infection with Leave Minors was only visually assessed as for there was an infection or non.

Growing conditions under the netting are more favourable for growing Hutten Mandarins as well as Imperial Late Navel oranges. This may be due to the fact that already in March there were great differences in the fruit quality between inside and outside the netting. Sun damage for one was much lower under the netting, but mostly wind damage was drastically reduced (Table 1). Wind damage is often already establishes early on during fruit development (Albrigo, 1976). The young fruitlet rubs against another fruitlet, the bark or even a leave, the skin gets damaged and with increasing surface area, during growth, the area of damage growth as well (Albrigo, 1976). Reduced wind speeds were found within the netted area compared to the control (Fig. 23).

Table 2 *Tree and fruit evaluation – 18th March 2016 – for fruit damage (%) including sunburn and wind damage, new growth (scale 1 to 5) and infestation with Gall Wasps and Leave Minors, leave area index (LAI) and canopy porosity.*

	Damaged fruit (%)	New growth (1-5)	Gall Wasp	Leave Minor	LAI	Canopy porosity
Netted Huttons'	5.5	3.4	**minor**	severe	4.20	0.101
Control Huttons'	30.3	2.8	severe	**minor**	4.74	0.078
Netted Imperials'	5.4	3.3	**minor**	severe	4.05	0.110
Control Imperials'	24.0	3.4	severe	**minor**	4.33	0.096

New growth or vigour of the trees was relatively similar inside and outside the netted area (Table 1). But the trees did not receive equal pruning and/or irrigation treatments. Also the differences in tree age and rootstock could account for the differences in growth over all. Citrus tree pruning is often adjusted based on previous year's harvest and flush (new growth) (personal communication). Depending on the current fruit set, also sometimes hand thinning can be applied to allow the lower fruit load to grow into bogger fruit (Webber and Batchelor, 1943). Fruit size is mainly a function of leave area to fruit ratio, therefore, less fruit at the same leave area means more photosynthates for the remaining fruit.

4. Conclusions and recommendations

Solar radiation, wind speed and soil temperature were reduced under netting for both mandarins and oranges. In contrast to anecdotal evidence ambient and apparent temperatures and relative humidity both during the day and night were not consistently different under the netting when compared to measures taken outside of the netting. Due to differences in the soil type between netted and un-netted trees it's difficult to infer any changes in soil water holding capacity. Soil moisture content during the observed period was higher under the netting when compared to the control. This may be due to a reduction in soil temperature and hence evaporation under the netting. A reduction in solar radiation and wind speed appears to have significantly reduced the levels of fruit damage caused by sunburn and wind for both mandarins and oranges. A greater amount of new growth was also observed on orange trees under the net. While canopy porosity was greater under net and leaf area lower. Assessments of gall wasps under netting revealed that they were less than outside of the netting while the presence of leaf miner was greater under netting. These differences suggest that the approach to management may need to be adapted to the netting environment to respond to changes in pests and diseases and changes in overall plant growth. The limitations of this study have been outlined in this report and need to be carefully considered when interpreting the data presented. Despite these limitations there does appear to be some significant changes to tree health and productivity when trees are netted.

Future investigations will assess yield, fruit quality, pack-out and post-harvest storage information as this information becomes available and will be presented in future reports. In the following seasons additional measures at flowering and fruit set and earlier measures of fruit size will be taken to assess netting effects on reproductive development. To assess the effects on plant water status of the trees stem and leave water potential readings (using a pressure bomb) will be taken. Assessments of disease and pest levels and any changes in nutritional requirements will also be made. To determine the longer term effects of netting on citrus performance investigations will continue for the following two growing seasons.

5. Background

The overall effect of netting on citrus trees are not yet well understood. Wachsmann et al. (2014) have explored different netting colours and their effects on different factors of tree performance, water use efficiency and yield of 'Ori' mandarins. Figure 1 shows the findings of Wachsmann et al. (2014) with the triangles indicating the effect of no netting (control), as well as each net colour on the factors investigated. For example water consumption is highest in the control and lowest under white or clear netting, whereas yield has the opposite trend with highest yields found for trees under clear or white netting but lowest for the un-covered control trees (Wachsmann et al., 2014).

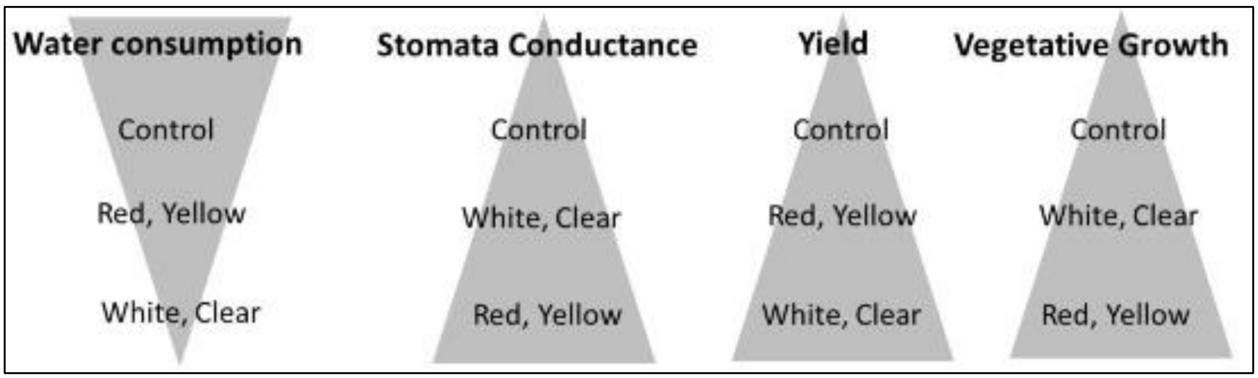

Fig. 13 *The effectiveness of different net colours as well as uncovered control trees on water consumption, stomatal conductance, yield and vegetative growth of 'Ori' mandarins in the central coastal plains of Israel (Wachsmann et al., 2014).*

Differences observed for the different netting colours may be due to differences in light transmission through the net (Shahak, 2008, 2012). Overall the netting, despite the colour, had a positive (enhancing) effect on all measured factors compared to the un-netted control trees, with higher stomatal conductance, higher yield and enhanced vegetative growth (Wachsmann et al., 2014). Increased vigour might not necessarily be favourable under all conditions, and whether or not there will be increased vigour under the netting in Loxton will need to be assessed over the next few years. Most of these effects observed by Wachsmann et al. (2014) could be due to the light scattering effect of the netting allowing for more even light distribution within the tree and therefore higher photosynthetic capacity, which could be a benefit in the high light environment such as the Riverland without over shading the trees.

5.1 Effects of climate on fruit quality

Fruit quality can be defined in two ways: optical/outer quality and nutritional quality. For the purpose of this report we will focus merely on outer quality which can be evaluated based mostly on non-destructive measures such as visual assessment. In this case quality will be defined as a fruit free of blemish which has reached a size marketable in the fresh market segment. All fruit are therefore classified into fresh marketable (high quality fruit), juice (low quality with blemish) and not usable (compost/waste). The higher the amount (percentage) of fruit off a block which can be marketed fresh the higher the quality.

The quality of citrus fruit can be reduced through effects occurring on the tree as well as after harvest (Kays, 1999). The use of white netting has been shown to improve fruit quality in 'Ponkan' mandarins through a reduction in sunscald damage and increased juice content (Lee et al., 2015). Sunscald on the skin of citrus fruit is caused by excessive light and heat of the fruit causing the fruit skin to discolour (Chikaizumi, 2007). If the conditions persist the glade tissue turn brown and thicken and the rind becomes thicker and firmer than usual (Chikaizumi, 2007). Fruit with sunburned skin cannot be marketed as fresh produce.

Fruit surface temperature can rise above air temperature under certain conditions such as direct sun exposure (Smart and Sinclair, 1976). Uneven temperature on the fruit surface and especially high surface temperatures can cause uneven ripening and differences in quality and fruit storability within one fruit and between fruit from one orchard (Woolf and Ferguson, 2000). If the temperature rises above a threshold of about 40 °C damage sunburn can occur.

Also inner quality can be effected; either on the tree or postharvest. The fruit can suffer from granulation, which is the drying of segments caused by the formation of gel within the vesicles (Bartholomew et al., 1941). The granulating segments discolour and have dry pulp with lower total soluble solids (TSS) and titratable acidity (TA) (Goto and Araki, 1983; Hofman, 2011; Nakajima, 1976). Granulation has been found to be aggravated by high temperatures at flowering as well as by cool and dry windy conditions (Ritenour et al., 2004). Tree factors such as excessive tree vigour and severe mite damage also contribute to the drying of segments, as well as the composition of the fruit juice, and advanced fruit maturity at harvest (Ritenour et al., 2004). Therefore, many pre-harvest factors contribute to the disorder even if it happens only after harvest (Lee et al., 2015).

Netting effectively reduces the canopy and fruit surface temperature in apple fruit (Darbyshire et al., 2015) and a similar effect can be expected for citrus fruit. Regardless of netting colours a reduction in direct sunlight has been observed (Middleton and McWaters, 2004), darker colours might have a greater impact on PAR that is transmitted though the environmental cover, and might influence plant light interception and therefore reduce photosynthesis of the leaves. Due to very high light levels and little cloud coverage in the Riverland it is envisaged that the reduction in light will not be detrimental to citrus growing in this environment.

Other events such as hail can damage the fruit through impact, but can also cause the leaves to be damaged and the stem of the tree (Fig. 14 and 15). Damaged trees can be susceptible to secondary infections. Additionally, if fruit are damaged entry points for secondary infections, such as mould fungi, are given (Brown et al., 1978). Damaged leaves will have reduced photosynthetic capacity and will no longer be able to support as much crop and not produce enough storage carbohydrates for the new growth.

Fig. 14 *Hail damage on oranges -*
[*http://www.freshplaza.com/article/130037/Greece-a-lot-of-hail-damage*](http://www.freshplaza.com/article/130037/Greece-a-lot-of-hail-damage)

Fig. 15 *Hail damage on Mandarin damage on fruit and leaves and tree -*
[*http://wwwrockrose.blogspot.com.au/2015/04/stoned-to-death.html*](http://wwwrockrose.blogspot.com.au/2015/04/stoned-to-death.html)

Fig. 16 *Sunburn on citrus -*
[*http://cals.arizona.edu/pubs/diseases/az1154/*](http://cals.arizona.edu/pubs/diseases/az1154/)

Fig. 17 *Sunburn on Navel orange -*
[*https://freshcitrusdirect.wordpress.com/*](https://freshcitrusdirect.wordpress.com/)

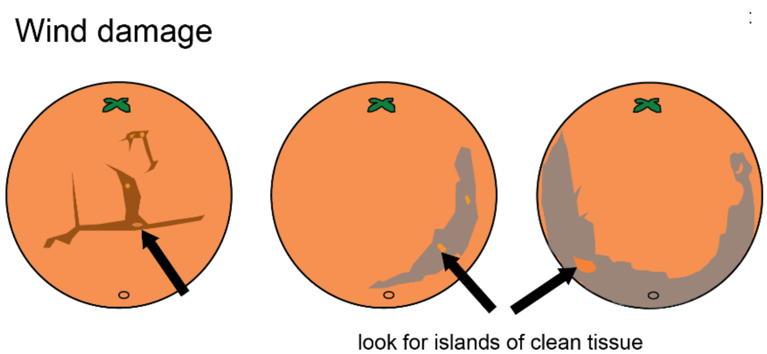

Fig. 18 *Damage caused by wind to citrus fruit surface -*
[*https://www.agric.wa.gov.au/citrus/thrips-citrus*](https://www.agric.wa.gov.au/citrus/thrips-citrus)

Fig. 19 *Wind damaged fruit -*
[*https://freshcitrusdirect.wordpress.com/*](https://freshcitrusdirect.wordpress.com/)

Sunburn of citrus skin is a major blemish causing great losses for the citrus industry. It is caused bt prolonged periods of heat and direct sun radiation exposure of the citrus skin (Fig. 16 and 17) (Ladaniya, 2008a, b). The fruit peel is damaged and the peel discolours. The fruit dries out through the damaged peel and often does not ripen. It may be better to remove the fruit while it is still green to reduce fruit load and increase the sink strength of the remaining fruit. Reduction of heat and direct sun exposure can dramatically reduce the risk of sunburn on fruit (Smart and Sinclair, 1976).

Wind damage (Fig. 18 and 19) damages the fruit peel/skin through abrasion with leaves and woody parts of the plant (Gravina et al., 2011). Peel surface blemish does in theory not affect the internal quality of the fruit but a very competitive market and consumer demand for blemish free fruit makes wind damaged fruit not marketable as fresh. Use for juicing is still possible but with a significant loss to orchard profits.

Frost and lower temperatures can be a threat to citrus. Cold in the biological sense is defined as a temperature at which chemical processes are retarded (Sakai and Larcher, 2012). Frost on the other hand is the process of solidification of water (Sakai and Larcher, 2012). Therefore, the definitions for biological processes and plant survival and meteorological definitions of frost might not always be exactly the same. Most important for the survival of a plant is the level the temperature sinks to during a frost event, the duration of the event, the time of onset of frost and whether the frost is only above ground or also penetrates into the soil (Sakai and Larcher, 2012). Citrus as a plant originated in the tropical and subtropical regions is sensitive to low temperatures. Generally citrus is not very frost hardy and likes to grow at about 10 °C and above. Temperatures at and around freezing therefore are not a great condition for the tree. But in the Riverland days below 0 °C are rare (Fig. 8).

Anecdotally environmental netting can keep the temperature about 2 °C higher in a frost event (personal communication) and has been reported for apple orchards in Australia (Gordon, 2013). Therefore, if the ambient temperature outside the netted area falls just below freezing (~-1 °C) the additional 2 °C might keep the temperature above freezing inside the netted area. This can be the difference between damage and no damage to the buds on a tree.

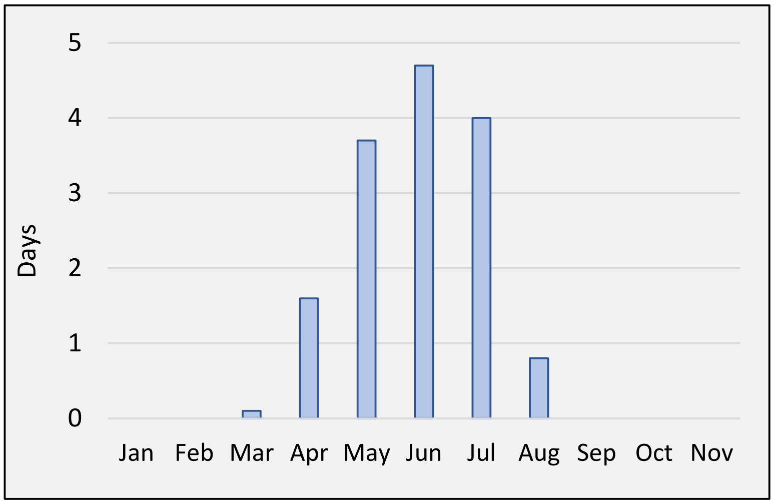

Fig. 20 Mean number of days ≤ 0 °C recorded between 1983 and 2016 at the Loxton Research Center BOM weather station (http://www.bom.gov.au/climate/averages/tables/cw_024024.shtml)

5.2 Tree growth

Tree growth is influenced by many factors and is often most importantly regarded in the senses in which it influences fruit set, development and final yield. All effort put into growing fruit trees is to get the best possible yield with the largest fruit and the best marketable quality.

In the 1970's fruiting patterns of citrus trees was an important research field, with research focused on the effects of the number of flowers and the type of inflorescence on the likelihood of fruit set and fruitlet retention on the tree. Goldschmidt and Monselise (1977) constructed a model showing the importance of leave area and new growth as well as the need for mixed inflorescence – flowers and leaves from the same bud – for the survival of the fruit on the tree. Citrus trees set many folds more flowers than will remain on the tree as maturing and mature fruit.

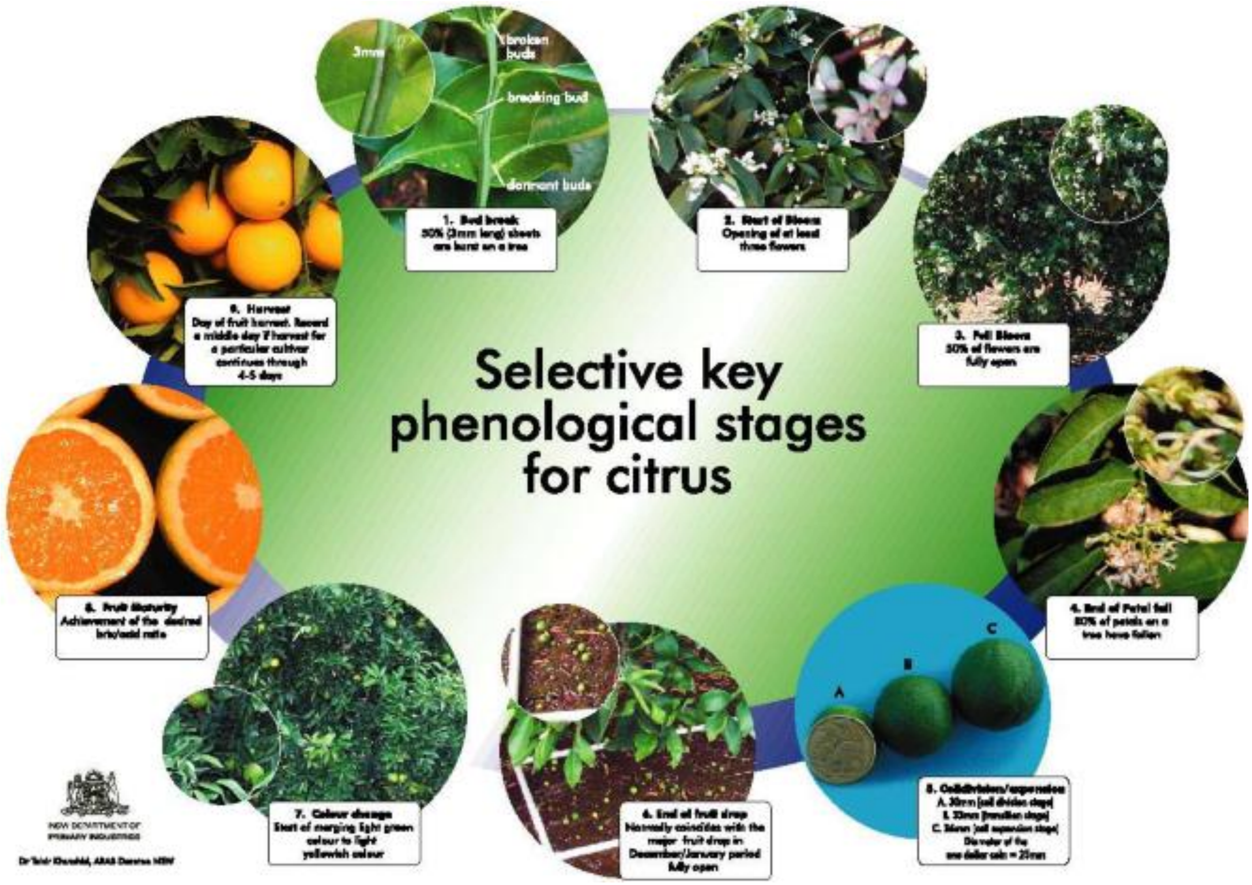

Fig. 21 *Key phonological stages of citrus development from (1) Bud break to (9) mature fruit (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/144980/Tahir-Khurshid-NSW-DPI-Climatic-effects-on-Citrus_-TK.pdf)*

Vegetative growth and the development of flower buds (Fig. 10) for the next season are important aspects of fruit tree development which need to be carefully managed in order to guarantee good flower development for the next season, and therefore, the potential for good fruit set and yield. The initiation and induction of flower buds (May and June), which will bear in the coming season, happen whilst fruit from the current season are still maturing on the tree (May) (Citrus.Australia). Therefore, careful stress management and management of nutrients during this period determines the amount of flowers and potential yield in the following season.

FLOWERING - INITIAL SET (June - October)

- Apply 40% to 50% of annual nitrogen in two split applications at bud swell.
- Apply 50% (fertigation) or 100% (banding) of annual phosphorous before and during bloom.
- Apply 30% to 40% of annual potassium.
- Apply Nitrogen – Phosphorus and Potassium mixes between September and November.
- Zinc is critical, apply foliar sprays as required.
- After fruit set apply magnesium and manganese foliar sprays as required.
- Adding low biuret urea (0.5%) to sprays with zinc and manganese helps uptake.

STAGE 1 FRUIT GROWTH (November - December)

- Apply 25% of annual nitrogen in November after fruit set and at the end of the vegetative growth flush.
- Calcium nitrate is preferable to ammonium nitrate and urea as these forms of nitrogen compete with the uptake of calcium leading potentially to albedo breakdown issues.
- If fertigating, apply the remaining phosphorous (50%) at monthly intervals from October onwards.
- Ensure adequate supply of calcium to reduce albedo breakdown.
- Apply 30-50% of annual potassium after fruit reaches 10mm in size.
- Apply foliar micronutrient sprays as needed.
- Experience shows that foliar sprays of potassium phosphite or MAP in November will improve fruit size.
- Potassium nitrate sprays should be applied at 1% to 3%.

STAGE 2 FRUIT GROWTH (January - April)

- Nitrogen is still important at this time - apply 25% of annual requirement (adjusted for crop load) throughout this period. Be aware that high levels of nitrogen will delay maturity.
- Ensure adequate nitrogen levels of carbohydrate reserves for next season's flower initiation in winter. This will help to reduce biennial bearing and give balanced crops.
- Potassium continues to be important - apply 30% of annual requirement after the final fruit drop stage in January and February.
- The nitrogen: potassium ratio is important - ideally ratios should be 2:1.

Fig. 22 *Guideline for nutrient application to produce the best possible quality of citrus fruit as advice by Citrus Australia (http://www.citrusaustralia.com.au/LiteratureRetrieve.aspx?ID=46885)*

Applications of nutrients may also be influenced by enclosing the trees with environmental netting. Nutrient management will have to be adjusted to the growth pattern of the trees according to the light levels and the growth of the trees. Generally, though the application of nitrogen as well as water the rate of growth can be managed (Alva et al., 2006). Also how much and when a tree is pruned can have an effect on tree growth and vigour (Webber and Batchelor, 1943). Potentially changes in management have to be made compared to the un-netted control trees after several seasons under the environmental netting. But such observations can only be made after a longer establishment time. Thus far there is no research considering changes in nutrient management for netted and un-netted trees. Therefore, whether or not there are any implications that might warned a change in nutrient management or not remain to be seen over time.

5.3 Pest management

Pest management in general should focus on how much is needed to guarantee good fruit development and what is needed to ensure survival of the tree. Reduction of wind speed and slight changes in overall microclimate under the netting can have an influence on pest development and pest pressure. This has been found in other crops but has so far not been shown in citrus. For example Shahak et al. (2008a) found that in bell pepper production the colour of the netting had varying effects on pest control with lower incidences of white fly under yellow netting compared to black and reduction of lower cucumber mosaic virus carrying aphids under yellow, pearl or white netting again compared to the black netting. The management of pests might therefore have to vary between the netted trees compared to un-netted blocks. The development of pest populations under netting will have to be monitored to ensure best possible management strategies.

Birds in an orchard can always cause damage to fruit. In some settings this can be enhanced due to the surrounding habitats or the fact that natural habitats are disappearing due to urban expansion or agriculture/horticulture use (Tracey et al., 2007). Abandoned orchards in close vicinity to a managed orchard can increase the pressure through pest organisms of many kinds including birds. Damage caused by birds and vertebrate pests such as rats and possums are through the peel by wounding and allowing other organisms such as mould to enter. Any damage to the rind and peal can allow for the entry of secondary infection with mould fungi (Singha et al., 2015). Excluding vertebrate pests from the orchard through environmental netting can be a way to not only lower the pressure though birds and other possible feeders it also reduces the entry points for certain fungal infections into the fruit due to less damage on the peel.

Fig. 23 *Bid damage on mandarin fruit peel – (http://www.lauriemeadows.info/season/winter/season_Winter.html)*

Fig. 24 *Damage caused by vertebrate pest such as possum or rats - https://www.agric.wa.gov.au/pest-insects/citrus-pests?page=0%2C4*

Fig. 25 *Bird eating Nashi fruit - http://rodrepel.com/blog/blog/category/uncategorized/page/70/*

5.4 Water use efficiency

Ever increasing temperatures and duration of hot weather during the summer and fruit production months, require a more vigorous assessment of water use efficiency (WUE) or agronomic water use efficiency (AWUE). WUE is defined as being the amount of marketable fruit produced with a certain amount of water being applied (Naor, 2006). Optimisation of WUE therefore aims to produce the highest amount of fruit possible with the lowest amount of water needed. Netting in that regard can be used to lower leave surface temperature and photo stresses though excess sunlight (Shahak, 2008, 2012; Sinclair et al., 1984). WUE sometimes 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).

Mature fruit generally contain approximately 85% water (Agriculture.Victoria, 2013), therefore supplying sufficient water to the tree is important to guarantee the desired quality. Unfortunately, only about 1% of the supplied water is actually retained in the fruit itself. Most of the water supplied to a tree escapes in form of water vapour and is not retained at all (Chavarria and dos Santos, 2012). 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 re-released to the atmosphere as vapour (Chavarria and dos Santos, 2012).

Irrigation scheduling therefore has to be done based on many factors to ensure optimization of WUE. The water applied has to be sufficient to maintain photosynthetic activity during the day. The weather of a given day dramatically influences the ability of a plant to draw water from the soil. The higher the vapour pressure deficit (VPD) the less water vapour is in the air surrounding the leaf and the more water vapour will escape the leaf as it draws in carbon dioxide (CO_2) (Camacho-B et al., 1974; Elfving et al., 1972). If sufficient soil moisture is available loss of water vapour though the stomata (opened to acquire CO_2) is less dramatic. If the soil is drying out, the plant has to go into a water conserving state. This happens by sacrificing photosynthetic activity by shutting the stomata and no longer being able to assimilate CO_2 into carbohydrates (Syvertsen, 1982).

Water availability from the soil is further dependent on the soil type (Doran and Parkin, 1994). A soil with larger pores such as sandy soils cannot retain large amounts of moisture. The water will simply run down into lower soil profiles though gravitation. Soil mainly composed of smaller particles such as clay can hold large volumes of water but that moisture is not readily available to the plant (Doran and Parkin, 1994). The smaller the spaces between soil particles the stronger the capillary forces with which the water is held in the soil. Therefore, a stronger force is needed to extract the water from the soil. Soils high in clay will have a higher moisture content but also a wilting point at a much higher water content than a sandy soil. Both the control blocks as well as both blocks under the netting have a relatively sandy soil type with sand under the netting and sandy loam outside. Soil with such high porosity needs to be carefully managed in regards to water to guarantee tree survival and minimize fertilizer and nutrient run off.

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