Apple tree and fruit responses to shade netting.

By

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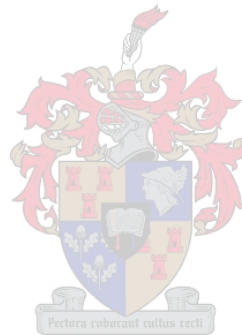
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DECLARATION

I the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or in part, been submitted at any university for a degree.

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Summary

The production of high quality fruit that meet international standards is of vital importance to the South African fruit industry. Detrimental climatic conditions are forcing producers to examine alternate production methods. In this study the effect of protective netting on apple tree (*Malus domestica*) physiology, microclimate and fruit quality was investigated to determine the potential of apple production under netting in the Western Cape Province of South Africa.

The influence of 20% black shade netting on the photosynthetically photon flux density, leaf and fruit surface as well as air temperature was measured on four blush apple cultivars over a two year period in the Koue Bokkeveld area, in the Western Cape, South Africa. Measurements were also taken on leaf gas exchange, including net CO_2 assimilation rate under ambient and saturating CO_2 conditions, stomatal conductance, and transpiration rate. A decrease in light conditions of 22 - 31% was measured under black netting thus reducing the amount of light available to the plant significantly. Leaves under the netting were cooler by 1.7 – 3.9°C on a milder day (11 January 2005) and by 4.3 – 6.2°C on a hot day (28 February 2005) than control leaves. Fruit surface temperature under the netting was cooler by 0.7 - 2.9°C on milder days, and by 4.0 - 5.3°C on a hot day (28 February 2005) than control fruit. Significant increases in CO_2 assimilation, stomatal conductance and transpiration were found under the netting. Netted treatments also showed a lower leaf vapour pressure deficit and tended to be less water stressed having higher leaf water potential than the control treatments. Differences in leaf nitrogen were not significant between treatments except for 'Cripps' Pink' where non netted treatments had higher leaf nitrogen levels than the netted treatments during the 2004 season.

Heat tolerance and the ability to recover after exposure to different temperatures for different lengths of time, was evaluated for the same four blush apple cultivars grown under protective netting. The results showed that fruit taken from the netted treatments had a higher incidence of injury based on chlorophyll fluorescence measurements, and did not recover well at temperatures higher than 45°C. The higher tolerance of the non-netted fruit at 45°C could be due to better acclimation to high light and heat levels than the fruit from the netted treatment.

Fruit quality of 'Royal Gala', 'Fuji', Cripps' Pink' and 'Braeburn' was evaluated for netted and non-netted treatments as well as between five different crop loads as sun-treatments. It

was found that cultivars reacted differently to the altered microclimate under the netting. Significant interaction between net and crop load treatments was found for fruit mass of 'Royal Gala' and 'Fuji'. Fruit mass declined more rapidly with increased crop load under nets than in the open. The net treatment reduced sunburn significantly in all the cultivars except 'Cripps' Pink'. Ground colour was found to be positively influenced by netting on 'Braeburn' and during 2005 on 'Royal Gala'. Blush colour was reduced under the netting for 'Braeburn' and 'Fuji' and unaffected for 'Royal Gala' and 'Cripps' Pink'. Fruit firmness, total soluble solids and titratable acidity, were reduced under nets for most of the cultivars. Netting thus seems to have a positive effect in reducing sunburn damage but a varying effect on other fruit quality parameters, which seem to be cultivar specific.

The influence of black protective netting on vegetative growth was determined by measuring total prunings and trunk circumference. Reproductive bud development analysis was also done. An increase was found in summer prunings for 'Fuji' and 'Cripps' Pink' which was most likely due to the topping of the trees to prevent them from growing into the netting. Seasonal trunk growth was affected significantly for 'Braeburn' with a higher percentage recorded under the netting. Reproductive bud development was higher for the netted treatments and on trees with lower crop loads.

Photosynthetic photon flux density was reduced significantly in a 'Granny Smith' orchard at harvest by black, blue and grey type netting. Sunburn was significantly reduced under the black and blue netting. Fruit mass was higher under the netted treatments during the second season of measurements. Firmness and total soluble solids were lower under the netting. Blush colour was found to be significantly lower under the black netting. Seed viability, ground colour, titratable acidity, starch breakdown, stem end russet and the occurrence of *Fusicladium pyrorum* damage was unaffected by the netting.

 Opsommimg

Appel boom en vrug reaksie op instalering van skadunet.

Die produksie van hoë kwaliteit vrugte wat voldoen aan internasionale standaarde is van kardinale belang vir die Suid-Afrikaanse vrugtebedryf. Ongunstige klimaatstoestande dwing produsente om alternatiewe verbouingsmetodes en sisteme te ondersoek. In hierdie studie is die invloed van skadu-nette op appel (*Malus domestica*) fisiologie, mikroklimaat en vrugkwaliteit ondersoek ten einde die invloed op appelproduksie te kan bepaal vir die Wes Kaap.

Die invloed van 20% swart nette op fotosintetiese foton-vloeddigtheid, blaar en vrug-oppervlaktemperatuur sowel as lugtemperatuur is gemeet vir vier blosappel kultivars. 'n Afname in lig van 22-31% is gemeet onder swart nette. Blare onder die nette was koeler met 1.7 – 3.9°C op 'n matige dag (11 January 2005) en met 4.3 – 6.2°C op 'n warm dag (28 February 2005) as onbedekte blare. Vrugoppervlak temperature onder die nette was 0.7°-2.9 °C laer op matige dae en 4.0-5.3 °C laer op warm dae. Betekenisvolle toenames in CO_2 assimilasie, huidmondjiegeleiding en transpirasie was waargeneem onder die nette. Dit het gepaard gegaan met laër blaar dampdrukverskil. Die netbehandelings was ook geneig om minder waterstremming te toon met 'n hoër waterpotensiaal as die kontrole. Blaarstikstof het gedurende die 2004 seisoen betekenisvolle verskille getoon tussen die net en kontrole behandelings vir 'Cripps Pink'.

Hitte toleransie en die herstelvermoë na blootstelling aan vyf verskillende temperature vir verskillende tydsintervalle is geëvalueer vir dieselfde blosappel kultivars onder swart haelnette. Die data toon dat vrugte verbou onder nette 'n hoër vlak van beskadiging toon met 'n toename in temperatuur oor tyd. Fluoresensiemetings het ook getoon dat vrugte onder l nette   nie in dieselfde mate as die kontrole herstel na blootstelling aan temperature hoër as 45°C nie.

Vrugkwaliteit is geëvalueer vir vrugte onder beskermende nette vir vyf verskillendes vrugladings. Die reaksie was kultivarspesifiek. Betekenisvolle interaksie tussen net en vruglading was gevind vir 'Royal Gala' en 'Fuji'. Vrugmassa het vinniger afgeneem met toename in vruglading vir die nette as vir die kontrole. Sonbrand was betekenisvol minder onder nette vir al die kultivars behalwe 'Cripps' Pink'. Saadkiemkrag het afgeneem vir vrugte verbou onder nette. Vruggrondkleur is verbeter op 'Braeburn' en gedurende 2005 op 'Royal

Gala'. Bloskleur was verminder onder die nette vir 'Braeburn' en 'Fuji' en was wisselvallig op 'Royal Gala' en 'Cripps' Pink'. Vrugfermheid, totale oplosbare vaste stowwe en titreerbare suur was minder in vrugte onder die haelnette.

Die invloed van swart nette op vegetatiewe groei was bepaal deur die meting van totale snoeisels en stamomtrekke. Knopanalises is gedoen om die verhouding tussen reproduktiewe en vegetatiewe groei te bepaal. Die topsnoei van bome onder nette (om te verhoed dat groei tot teen die nette plaasvind) het gelei tot 'n toename in somersnoei op 'Cripps' Pink' en 'Fuji'. Stamgroei het nie betekenisvol verskil van die kontrole nie behalwe vir 'Braeburn' waar die persentasie stamgroei hoër was onder die nette. Reproduktiewe knopontwikkeling was hoër onder die nette en op die bome met hoër uitdun persentasies.

Fotosintetiese foton vloeddigtheid in 'n 'Granny Smith' boord onder 20% swart, 30% blou en 20% grys nette is betekenisvol verminder onder al drie nettipes. Sonbrand was betekenisvol minder onder swart en blou nette en vrugmassa was hoër onder al die netbehandelings gedurende die 2005 seisoen. Bloskleur was minder onder die swart nette en saadkiemkragtigheid, grondkleur, totale suur, styselafbraak, stingelentveruwwing en infeksie deur *Fusicladium pyrorum* was nie geaffekteer deur die gebruik van beskermende nette nie.
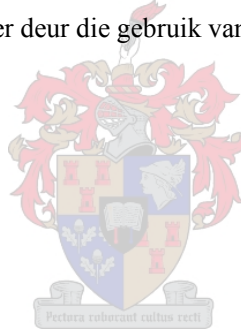
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Contents

Chapter 1:

Literature review

1. Introduction.

South African apple producers have been fighting natural elements such as hail, drought, and high light intensities and high temperatures in order to produce some of the world's best export fruit. The constant development of new technology and agricultural production methods has aided producers in achieving their goals but has also increased the competition from other countries. Protective netting is a promising new technology, which is receiving word wide attention for use in apple production (Widmer, 2001; Leite et al., 2002)

Reasons for the installation of protective netting in South Africa would be to reduce sunburn and hail damage in the areas where these factors lead to severe crop loss. Other underlying benefits accompanying the installation of netting are reduction of wind within the orchard by up to 50 % and more efficient chemical spraying conditions and water use (Middleton and McWaters, 2002). There are, however, negative effects linked to the use of shade netting on production that have been reported from previous studies in apple orchards. These include a reduction in fruit size and a loss in colour (Stampar et al., 2001; Middleton and McWaters, 2002), as well as reductions in total soluble solids (TTS) (Wagenmakers and Tazelaar, 1999). These negative effects do, however, seem to depend on apple cultivar, regional climate, and orchard location and management, since articles with contrasting results have been published (Shahak et al., 2004).

The objectives of this study were (1) to evaluate the effect that protective netting might have on microclimate and gas exchange of different apple cultivars grown in the Bokkeveld, Western Cape Province, South Africa, (2) to investigate the extent of injury on apples grown under protective netting, as determined by chlorophyll fluorescence, when exposed to different temperatures over different time periods, (3) to determine effects that netting and crop load might have on fruit quality in this region, and (4) to evaluate vegetative growth and reproductive potential of apple trees under protective netting.

2. Light and the characteristics thereof

Light has the single largest effect on the growth and development of all plant life on earth. Plants show an ability to adapt to alteration in the availability of light in order to survive changing environments. In understanding why plants and more specifically apple trees, tend to alter their growth patterns when light conditions are altered due to natural occurrences or by production methods, such as protective netting and tree training, we have to look at the role and characteristics of light. Different light waves and intensities thereof influence plant growth in different ways and it is mainly this external growth regulation that will be altered with the installation of netting.

Light has properties of both waves and particles. A wave is characterized by wavelengths measured by the distance between two successive wave crests (Taiz and Zeiger, 2002). The shorter these wavelengths are, the greater the energy that they carry. Light also consists of particles called photons, that contain different amounts of energy that we call quantum (plural *quanta*). Sunlight is thus made up of photons of different wavelengths and the energy that they carry is dependent on their frequencies (amount of wave crests that pass a point per unit time) (Taiz and Zeiger, 2002).

Of all the wavelengths, only a narrow range is visible to the human eye. We call this section of light the visible spectrum. It is within this spectrum of visible light, extending from 400 nm (violet) to 740 nm (red), between the high-energy waves of the UltraViolet (UV 280 – 400 nm) and the near infrared, (NIR 750 nm – 0.01 cm), that the plant finds most of its energy (Raven and Johnson, 1999).

Plants use photosynthetic pigments to absorb light and the energy-rich photons that they carry (Raven and Johnson, 1999). The most common pigments found in plants are chlorophyll *a* and chlorophyll *b*. These two pigments absorb predominantly violet-blue at 400 – 470 nm, and red light at 640 – 700 nm on either side of the visible spectrum, and reflect green light in the middle of the spectrum giving plants their green colour. Carotenoids also absorb light in the blue and green light ranges, and reflects orange and yellow light (Raven and Johnson, 1999).

Light is both the source of energy, and a major regulatory factor in plant life. All the physiological processes from the emergence of the seedling right up to fruit production are essentially dependent on light (Shahak et al., 2004). Quantity as well as quality of light plays a very important role in the functioning of the plant. Light energy that the plant harvests from the sun is the energy that the plant needs to support functions such as photosynthesis, respiration and transpiration that are essential for survival. With the installation of netting, we

alter or reduce the amount of direct sunlight that reaches the plant by reflection or absorption of light by the nets. Potential energy available for use by the plant is thus reduced, possibly upsetting the energy balance of the plant and influencing its growth pattern (Stampar et al., 2001).

Visible light intercepted by a tree plays an important role in the production of dry matter (Palmer, 1989). This, however, does not mean that the tree will produce a larger amount of marketable fruit when high light levels are available. Light also controls the partitioning of resources into the various sinks of the tree (Grappadelli, 2003). Alterations in the amount of available light could have an effect on the morphological and physiological traits of the vegetative component of the tree. This will lead to a shift from the normal in bud differentiation and leaf attributes as well as the ratio of spur vs. shoot leaf area (Grappadelli, 2003). The photosynthetic potential of these leaves and others that support fruit growth may also vary. Alterations in the amount of available light also influences fruit quality such as skin colour, acidity, total soluble solids (TSS) and post harvest disorders (Grappadelli, 2003).

A clear understanding of light and the reaction of the tree to alterations thereof must be established in order to understand the effects that netting could have on the orchard.

3. The regulatory role of light

Light influences certain responses in the plant and this is called photomorphogenesis. Light signals varying from far red to blue provide crucial information in many stages of plant development. Seed germination, proper development of photosynthetic machinery, architecture of the vegetative plant, the timing of flowering, tuberization, and the allocation of resources to root, stem, leaf, reproductive or storage structures are all potentially controlled by the perception of light signals by the plant (Smith, 2000). The most important pigments that promote photomorphogenesis in a plant are those that absorb blue and red light.

3.1 Red and far-red light: Its qualities and influence on the plant

Phytochrome is the pigment that absorbs red and far-red light most strongly and it is important to understand its method of working. Hendricks, Borthwick and colleagues proposed the hypothesis about phytochrome action over 50 year ago (Smith, 2000). It was suggested that the photoreceptors existed in two photoconvertible forms red absorbing phytochrome (Pr) and far-red absorbing phytochrome (Pfr). With the absorption of red photons, Pr turns from an inactive state to an active Pfr state. Pfr can then be converted back to Pr by far-red photons (Smith, 2000). The absorption spectra of the phytochromes peak at

about 665nm and 730nm. Because the absorption bands overlap, radiation below about 700nm activates photoconversion of both Pr and Pfr. In daylight a photoequilibrium of about 60% Pfr:P (P=total phytochrome) is thus established and in shaded plants the photoequilibrium can be as low as 10% Pfr:P (Smith, 2000).

The Pfr/Pr ratio is the basis for the shade avoidance syndrome that causes plants to grow away from shade (Smith, 2000) and is thus one of the factors that might cause trees covered with netting to increase their vegetative growth. The effect that the red/far-red ratio has on plants can be clearly seen in an experiment done by Van Hinsberg and Van Tienderen (1997) where plants (*Plantago lanceolata*) from a sun and shade population were grown in two environments differing in the ratio of red to far-red light. It was found that a high far-red/red ratio, simulating vegetation shade, promoted the formation of long upright leaves, increase in plant height and allocation towards shoot growth. The opposite effects were observed with a low far-red/red ratio.

During shading the levels of far-red/red increase and this ratio plays an important role in the formation of certain flavonoid compounds such as quercetin 3-glycoside and cyanidin 3-galactoside, a red anthosyanin pigment. In contrast, a decrease in far-red/red ratio resulted in a decrease in the levels of these two compounds in 'Jonagold' apple skin, resulting in poor colour development (Awad et al., 2001). There also appears to be a requirement for a far-red/red ratio of about 1 for significant quercetin 3-glycoside and cyanidin 3-galactoside formation (Awad et al., 2001), which is not the case in heavily shaded areas. By using electric lamps and fibreglass polyester sheets to alter light conditions, Eccher and Noe (1993) showed that different irradiance levels in the red and far-red regions of the spectrum have an effect on the shape and quality of 'Golden Delicious' apple fruit. They found that increased irradiance of wavelengths in the red and far-red regions caused an increase in the length to diameter ratio of fruit. Skin russeting was reduced, as well as the number of corked cells, but the number of seeds was higher in the fruit of control plants receiving less red/far red irradiance (Eccher and Noe, 1993).

3.2 Violet and blue light: Its qualities and influence on the plant

Violet and blue light (400-500 nm) is absorbed by both chlorophyll a and b, and also by phytochrome (Taiz and Zeiger, 2002). Blue light regulates a diverse range of plant responses that include phototropism, stem growth inhibition, leaf expansion, chloroplast development, stomatal opening, anthocyanin accumulation, enhancement of respiration and changes in expression of various genes (Khurana and Poff, 1999; Taiz and Zeiger, 2002). Responses such

as electrical events at the plasma membrane can be detected within seconds of irradiation by blue light (Taiz and Zeiger, 2002). These responses are elicited by different fluences of blue light and are regulated by the photoreceptors absorbing principally in the UV-A (320-390 nm) and violet-blue (390-500 nm) region of the electromagnetic spectrum. Molecular and physiological analysis of distinct genetic mutants has revealed that cryptochromes may be the predominant blue light photoreceptors in plants (Khurana and Poff, 1999). High fluence blue light responses, such as inhibition of hypocotyl elongation and stimulation of anthocyanin accumulation, as well as low fluence responses such as phototropism, are affected by both members of the cryptochrome (CRY) family, cryptochrome 1 (CRY1) and cryptochrome 2 (CRY2). Flower timing is also influenced by CRY2 (Khurana and Poff, 1999). With the installation of netting, an alteration in the amount of blue light could be expected and thus also in those growth characteristics of the tree influenced by blue light.

When artificial shade conditions are established as in the case of shade netting, alteration in the intensity of light could be expected. With these alterations we could expect the plant to react as discussed above. The plant does, however, experience uniform shading and as a whole and one side of the tree does not receive more shade than the other if orchard rows are planted in a north-south orientation.

Alteration in light could also have an effect on fruit growth and quality, as found in an experiment done by Eccher and Noe (1993). They reported that increased irradiance in the UV and blue regions of the spectrum caused an increase in the length to diameter ratio of 'Golden Delicious' fruit. Skin russeting was reduced, as well as the number of corked cells, but the number of seeds was higher in the fruit of control plants receiving less UV and blue irradiance.

3.3 Phototropism

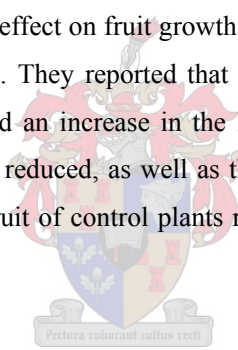Phototropism is the response that plants have causing them to grow towards light (Raven and Johnson, 1999). Responses like phototropism confer physiological advantages to the plant such as more efficient utilization of light energy, and protection against harmful processes such as photodestruction (Khurana and Poff, 1999).

In nature, plants sense the directional difference of light, its quality and intensity, which leads to directional growth, and eventually the development of curvature (Khurana and Poff, 1999). During low fluence and short irradiance, curvature development is small and is referred to as 'first positive' curvature. With increasing fluence of blue light up to a certain point, the curvature increases. Very high doses of blue photons, usually for prolonged periods,

result in the development of what is called 'second positive' curvature which can be of a much higher magnitude than the 'first positive' response (Khurana and Poff, 1999). It has also been shown that seedling hypocotyls/shoots of *Arabidopsis,* display positive phototropism and roots exhibit negative phototropism (grow away from light) in response to unilateral blue light of 450 nm (Ahmad et al., 1998).

Installation of shade netting could cause apple trees to grow more vigorously due to this characteristic of plants causing them to grow in the direction of most light. Being a sun plant, apple trees might show a very strong phototropism tendency and produce large amounts of vegetative growth in order to reach more adequate light levels. Due to uniform light scattering under protective netting, trees should grow uniformly under the netting.

3.4 Stomatal regulation

Stomata play a very important role in the photosynthetic process as well as in water relations and gas exchange of the plant (Khurana and Poff, 1999). In addition to photosynthesis that can lead to opening of guard cells, a non-photosynthetic photosensory system, which is sensitive to blue light, also regulates movement of the stomatal apparatus. Blue light is also involved in early morning opening of the guard cells and stomatal responses to sun flecks.

Stomatal opening is primarily driven by proton gradients across plasma membranes and the activation of the ion channels in the guard cells (Khurana and Poff, 1999). Assmann et al. (1985) and Shimazaki et al. (1992) showed that blue light activates the electrogenic ion pumping in guard cell protoplasts. A pulse of blue light results in a transient rise in stomatal conductance to water vapour, which peaks 20 min after the pulse. A red light pulse produces no increase in conductance. This demonstrates that the response stimulated by the blue light is independent of photosynthesis (Assmann et al., 1985). Stomatal functioning is also influenced by factors such as crop load, tree water status and requirements, internal CO_2 concentration and leaf-to-air vapour pressure difference (VPD) as determined by partial pressure of water vapour, temperature and wind (Pretorius and Wand, 2003; Wünsche and Ferguson, 2005). During the post harvest period, both stressful environmental conditions and altered tree carbohydrate demand could influence stomatal functioning and thus gas exchange and tree water requirements. It was found that stomatal conductance showed increasing sensitivity to increasing leaf temperature after harvest, resulting in a reduction in the optimum temperature for photosynthesis (Pretorius and Wand, 2003). Pre-harvest reductions in water use efficiency were measured with higher photosynthetic rates at higher leaf temperatures than the maintenance of high leaf water use efficiency post-harvest. The suggested reason for this is a

change from a carbohydrate-demanding strategy pre-harvest to a water-conserving strategy post-harvest when sink demand is reduced (Pretorius and Wand, 2003).

Leaf transpiration results from the diffusion of water vapour through the stomatal pore. Changes in stomatal resistance are important for the regulation of water loss by the plant and for controlling the rate of carbon dioxide uptake necessary for sustained CO_2 fixation during photosynthesis. Stomatal control thus couples leaf transpiration to leaf photosynthesis (Taiz and Zeiger, 2002). With the installation of shade netting we could expect stomatal conductance to increase in response to reduced atmospheric stress (VPD) and possibly due to an increase in leaf water availability (only if strong shading does not lead to light limitation of photosynthesis, then conductance would decrease), allowing the stomata to remain open for longer periods of the day, and thus positively influencing photosynthesis (Middleton and McWaters, 2002).

4. Effect of light on gas exchange

Visible light is the driving force of biomass production via its effect on the factors driven by gas exchange nl. photosynthesis, respiration, transpiration and water relations. Alterations in the quality and intensity of available light would have and effect on gas exchange of the plant.

4.1 Photosynthesis

The growth and functioning of any plant is dependent on energy derived from the sun (Taiz and Zeiger, 2002). The amount of sunlight that reaches the plant to enable photosynthesis is thus vitally important and by altering the amount of sunlight available, the plant could be expected to react and adapt to the change in light conditions in order to utilise the available light to its optimum. By covering apple trees with netting we could run the risk of reducing sunlight to levels where it might affect tree growth and yield negatively.

Photosynthesis is the system whereby plants capture energy from sunlight and use it to build food molecules rich in chemical energy (Raven and Johnson, 1999). The photosynthetic process is carried out in organelles called chloroplasts situated in the leaves and it takes place in three stages: (1) First energy is captured from sunlight. (2) This energy is then used to make adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH), which are energy-rich molecules that can be transported and used elsewhere in the plant. (3) ATP and NADPH are then used to power the synthesis of organic molecules from CO_2 in the air. This process is known as carbon fixation (Raven and Johnson, 1999).

Light has a primary influence on the photosynthetic activity of the plant and thereby its capability of producing large amounts of dry matter and quality fruit. The effect that shade has on a variety of agricultural crops has long been studied. Burnside and Böhning (1956) found that the leaves of shade grown plants were light saturated at a light intensity at least 1000 ft-c lower than those of sun plants. Light compensation points of the shade plants were also lowered by 0 to 100 ft-c from those of the sun plants. Henriot et al. (2004) found that well exposed leaves of the apple cultivar Arlet, positioned in the upper and exterior parts of canopies receiving 70-80% of the available photosynthetically active radiation, had a greater photosynthetic rate than leaves in the lower, intermediate positions or leaves of fruit trees artificially shaded with black Agryl covering. A logarithmic relationship between light and maximum photosynthetic rates was demonstrated.

The question, however, is whether the installation of shade netting, and the reduction in photosynthetic photon flux density (PPFD) under netting (Middleton and McWaters, 2002; Guerrero et al., 2002; Shahak et al., 2004) reduce the optimum photosynthetic potential of the leaf to the extent whereby vegetative and reproductive growth could be negatively affected. As will be discussed in greater detail later natural shading within the plant canopy has been found to result in anatomically distinct leaves with differing gas exchange characteristics to those leaves grown in full sunlight (Campbell and Marini, 1992).

Commercial shade netting has been shown to reduce sunlight or radiation levels (PAR) by 12-27% (Middleton and McWaters, 2002). Black netting reduced radiation by 33-37 % and white netting by 4-8 % respectively in an experiment done by Gardner and Fletcher (1990), and by 18-25% under black nets depending on the net type (Widmer, 2001). Stampar el al. (2001) showed that net photosynthesis rate was significantly higher in treatments where 'Elstar' apple trees were covered with black netting, than for unnetted treatments.

Ebert and Casierra (2000) showed that net photosynthesis rate of 'Golden Delicious' trees covered with black netting reducing radiation by 33% was lower in the morning and higher during the rest of the day compared with full sunlight trees.

Midday depression of photosynthesis is a phenomenon that commonly occurs in woody plant species. During this depression period, net photosynthesis decreases during the warmest period of the day. This is due largely to overheating and high evaporation at the time when radiation is at its strongest (Larcher, 1995). In a study done by Lio et al. (2004) to determine the reason for the occurrence of a midday depression in *Fagus crenata,* it was concluded that the midday depression in these trees was caused by the midday stomatal closure due to high air to leaf vapour pressure deficit (VPD). Pons and Welschen (2003) came

to the same conclusion in a study on the tropical rain forest tree *Eperua grandiflora*. In order to reduce water loss the stomata partially close, thereby increasing the CO_2 concentration inside the leaf and reducing the photochemical efficiency. Muraoka et al. (2000) concluded that the midday depression of assimilates in sun leaves of *Arisaema heterophyllum* was due to the increased rate of photorespiration caused by high temperature and stomatal closure, and that in shade leaves it was due to severe photoinhibition.

Reports have pointed out that with the installation of netting, wind speed within an orchard is reduced by 40-50% (Middleton and McWaters, 2002; Tanny and Cohen, 2003) and humidity can be increased by 10-15% (Middleton and McWaters, 2002). This reduces the amount of water lost by transpiration due to the fact that the vapour pressure deficit (VPD) between the air and the leaves (VPDleaf) is reduced. The stomata thus close much later in the day or not at all during daylight hours allowing photosynthesis to continue uninterrupted. This enables the plant to photosynthesise at a higher rate for longer periods of the day. The midday depression might also be caused by strong light causing photoinhibition, the inhibition of photosynthesis by excess light that damages photosystem Π (PS Π) (Larcher, 1995). With the reduction in light levels under the netting this inhibition could be reduced or eliminated thus enhancing photosynthesis.

Leaf nitrogen concentration (N) plays an important role in the photosynthetic ability of the plant, which increases as the leaf N content increases. It has been reported that Rubisco activation state decreases with increasing leaf N content of 'Fuji' apple, and this decreased activation state accounts for the curvilinear relationship between leaf N and CO_2 assimilation rate (Cheng and Fuchigami, 2000). In this study, a range of leaf N content (1.0 - 5.0 g m^{-2}) was achieved by fertilizing 'Fuji/M.26' apple trees for 45 days with different N concentrations. It was found that as leaf N increased, photosynthetic rate increased but photosynthetic N use efficiency declined with decreasing Rubisco activation state. Fallahi et al. (2001) found that for 'BC-2 Fuji' trees receiving 31g N/tree per year had lower leaf net photosynthesis than those receiving higher rates of N (99.8 g/tree). Netting could possibly influence the leaf N content thus affecting the photosynthetic ability of the leaf either positively or negatively.

4.2 Respiration

In order to form a clear understanding of the effect that netting might have on respiration we must distinguish between the different types of respiration and their functions.

The organic building blocks that plants depend on for survival are provided via photosynthesis. The energy stored in carbon compound, is released in a controlled manner for cellular use by aerobic respiration and its associated carbon metabolism (Taiz and Zeiger, 2002). Aerobic respiration, also referred to as dark respiration, takes place when oxygen gas (O_2) serves as the ultimate hydrogen, or electron acceptor, being reduced to water after a series of reactions whereby energy rich ATP and NADPH are produced. This form of respiration takes place in the mitochondria. During dark respiration, free energy is released and stored in ATP and NADPH, which can be readily utilized for the growth and maintenance of the plant (Taiz and Zeiger, 2002). Photorespiration takes place when CO_2 is released without the production of ATP or NADPH. Hence photorespiration undoes the working of photosynthesis (Raven and Johnson, 1999) and plants lose a considerable amount of photosynthate as CO_2 within a few seconds after being fixed. Under conditions of high light intensity and low intercellular CO_2, photorespiration is important to dissipate excess ATP and reducing power from the light reactions, thus preventing damage to the photosynthetic apparatus (Taiz and Zeiger, 2002; Guan et al., 2004). Increased photorespiration will lead to higher concentrations of carbon being released, as the plant will lose CO_2 and thus more energy.

Conditions causing high light stress are less severe in orchards covered by netting than in orchards that are in full sunlight. From studies done by Barden (1971), it is apparent that dark respiration rates are lower in shaded leaves and even more so in leaves grown in full sun and then subsequently shaded. Although photosynthetic potential of shaded leaves is lower than leaves that are not shaded, the reduced productivity is partially compensated for by lower respiration rates (Barden, 1977).

4.3 Transpiration

Transpiration (E) is the loss of water vapour through plant parts. Most E occurs through the stomata of the leaves and would thus also be influenced by the photosynthetic activity and the water status of the plant (Raven and Johnson, 1999). The rate of E is dependent on a combination of factors. Costes and Regard (2002) found that E values correlate to photosynthetic photon flux density (PPFD), air temperature and VPD. The driving force for

water loss is the difference in water vapour concentration that exists between the leaf and the air. The greater this difference, the more E will take place as regulated by the stomata.

High levels of light exposure on leaves lead to high energy loads and high E rates. This lowers shoot water potential in some species especially in perennials (Lakso et al., 1989). Apple leaves, however, show compensatory osmotic adjustment to maintain a relatively, constant turgor over the gradient of leaf exposure in the canopy (Lakso et al., 1989).

With the installation of shade netting, it has been shown that humidity could increase by up to 10-15% (Middleton and McWaters, 2002). This decreases the VPD and slows down transpiration. Cheng and Lue (1997) found that, in general, E increases with an increase of stomatal conductance and VPD. A thin layer or film of still air against the surface of the leaf called the boundary layer also influences E. This boundary layer is high in water vapour and thus reduces the VPD between the leaf and the atmosphere. The resistance to water vapour diffusion of the boundary layer is proportional to its thickness, which in turn is determined primarily by wind speed (Taiz and Zeiger, 2002). Netting reduces wind within an orchard by 40-50% (Middleton and McWaters, 2002; Tanny and Cohen, 2003) and the boundary layer is thus more protected and will reduce E more effectively. Because of the aerodynamically rough structure of apple orchards and the planting in rows, air mixes well in the canopy of orchards and couples the leaves with the atmosphere. Netting reduces this mix of air and forms a boundary layer over the whole orchard by reducing wind and increasing humidity.

During the warmest part of the day when E is at its highest, the plant closes its stomata in order to reduce water loss, resulting in the midday depression (Taiz and Zeiger, 2002). This, however, also reduces CO_2 uptake from the atmosphere and slows down photosynthesis. Plants cannot prevent outward diffusion of water without simultaneously excluding CO_2 from the leaf. This dilemma is overcome by the regulation of the stomatal apertures. During the night when photosynthesis is zero and there is no demand for CO_2, the stomatal apertures are kept at a minimum to prevent unnecessary loss of water. During times when soil water and radiation is freely available and photosynthesis activity is high, the demand for CO_2 inside the leaf is large. Stomatal pores will open wide during these periods, decreasing the resistance to CO_2 uptake. E is also high during these periods, but because water is available it is advantageous for the plant to trade water for the products of photosynthesis. On the other hand, when radiation is high but soil water is not freely available the plant will open the stomatal pores less, or keep them closed to avoid water loss through transpiration. By keeping the stomata closed during dry periods, the plant can avoid potentially lethal dehydration (Taiz and Zeiger, 2002). Middleton and McWaters (2002) showed that soil water in an orchard

covered by white netting tended to decline slower due to lower evapotranspiration, than in orchards that were not covered by netting.

It can thus be concluded that by installing shade netting evapotranspiration might be reduced and thus lessen the risk of dehydration, while enhancing the photosynthetic potential by reducing the intensity of the midday depression and keeping stomatal conductance high.

4.4 Leaf anatomy and characteristics of sun and shade leaves

Leaves are the energy factories of the plant using solar radiation to produce carbohydrates through a series of already mentioned mechanisms, in order to sustain the plant (Taiz and Zeiger, 2002). Because the leaf is dependent on both the amount of solar energy and CO_2 that is available, and in some cases photosynthesis is limited by the inadequate supply of light or CO_2, the leaf will try to optimize the uptake thereof and adapt to changes in its environment. Exposure to excess light, on the other hand, is also harmful to the leaf and multiple mechanisms exist against high light levels (Taiz and Zeiger, 2002).

Leaves absorb light in the photosynthetic active radiation spectrum (400-700nm) (Raven and Johnson, 1999). Chlorophyll absorbs very strongly in the blue and red spectrum and reflects light in the green spectrum, giving plants their characteristic green colour. The anatomy of the leaf is made up in such a way as to optimize light absorption. The surface of the leaf is covered entirely by a transparent epidermal layer protecting the leaf against the environment (Raven and Johnson, 1999). This layer could contain different types of glands and trichomes. The lower epidermis at the bottom of the leaf and occasionally the upper epidermis contain the stomata and their guard cells. Between the upper and the lower epidermis we find the mesophyll tissue. Close to the upper epidermis we find the palisade mesophyll, which consists out of chlorenchyma cells, which are parenchyma with chloroplasts. Between the palisade mesophyll and the lower epidermis there are spongy mesophyll cells. They are arranged loosely and have many air spaces throughout the tissue. These spaces along with the stomata assist in the function of gas exchange and the passage of water vapour from the leaves (Raven and Johnson, 1999).

Plants are capable of moving their chloroplasts inside the leaf to control the uptake of light. During low light conditions plants line the chloroplasts up perpendicularly to the incident light close to the cell surface. Positioning the chloroplasts in this way maximises light uptake. During periods of high light, the chloroplasts move away from the cell surface, thus avoiding excess light absorption (Taiz and Zeiger, 2002; Donald, 2001).

Leaves can be divided into two categories namely sun and shade leaves (Taiz and Zeiger, 2002). We can distinguish between the two by looking at some contrasting characteristics such as chlorophyll content. Shade leaves have more chlorophyll per reaction centre and they have a higher ratio of chlorophyll *b* to chlorophyll *a*. Shade leaves are also usually thinner than sun leaves. Higher concentrations of soluble protein, ribulose biphosphate carboxylase (rubisco) and components of the xanthophyll cycle (cycle in which excess heat is dissipated by the leaf) are found in sun leaves. We can expect leaves that grow in the sun to be thicker and have longer palisade cells, whereas shade leaves are wider and have less palisade cells (Taiz and Zeiger, 2002). A study done by Krause et al. (2004) on four tropical tree species showed that leaves of shade-grown seedlings are, within limits, capable of acclimating to full sunlight, including solar UV-B radiation. Conspicuous changes were also observed in the composition and content of photosynthetic pigments.

Further differences between sun and shade leaves can be found in the point where the amount of CO_2 uptake by photosynthesis balances the amount of CO_2 lost by mitochondrial respiration (Taiz and Zeiger, 2002). This point is known as the light compensation point and is lower in shade leaves than in sun leaves. This means that shade leaves have a lower respiration rate than sun leaves. The quantum yield, or the amount of photochemical products produced with the total amount off quanta absorbed, of sun and shade leaves do, however, show similar values despite their different growth environments. The level at which photosynthetic response to light starts to level off and reach saturation is lower in shade leaves than in sun leaves. At this point an increase in light will not increase photosynthesis and it is said to be CO_2 limited (Taiz and Zeiger, 2002). Muraoka et al. (2000) found that the CO_2 assimilation rate and leaf conductance of water vapour was lower in shade leaves than in sun leaves of *Arisaema heterophyllum*. They also found that the photochemical efficiency of PS Π and the electron transport rate was considerably lower in shade leaves than in sun leaves. The photorespiratory CO_2 efflux in the absence of atmospheric CO_2 was about 3-times higher in sun leaves than in shade leaves (Muraoka et al., 2000).

The effect of shading branches to 20% of available light from 40 days after full bloom until harvest time on leaf characteristics and seasonal fruit growth pattern of 5-year-old apple 'Braeburn/MM 111' were evaluated by Garriz et al. (2001) in Argentina. It was found that the reduction in sunlight yielded significant, contrasting anatomical features but did not affect stomatal density. In the shaded leaves the chlorophyll concentration was higher than in the exposed leaves. Shading reduced the biomass of spur and shoot leaves by 35 and 37%,

respectively. Shoots attained significantly greater individual leaves than spurs (Garriz et al., 2001).

5 Excess light

Although plants are dependent on light for gas exchange and the production of dry matter, light in excess of that which the plant can use could be damaging to the photosynthetic apparatus and functioning of the plant.

5.1 Light stress

In the case of too much light the plant has a range of protective mechanisms that enable it to withstand a certain degree of exposure to high light levels (Taiz and Zeiger, 2002). Non-photochemical quenching is one such process during which over one half of the light absorbed by PS Π chlorophyll in healthy, fully functional leaves can be redirected within the antenna ensemble of PS Π, which harmlessly discharges excess photon flux energy as heat (Taiz and Zeiger, 2002).

In a study done by Merzlyak and Chivkunova (2000), to investigate the role of anthocyanin in photoprotection of two apple cultivars, Antonovka and Zhigulevskoe during light stress periods, it was concluded that anthocyanin pigments act as a protection factor for chlorophyll against photodestruction. Because of the vacuolar localization of anthocyanins, they cannot be involved in free radical- and/or singlet oxygen-mediated reactions in chloroplasts and it is most likely that the photoprotective properties of anthocyanins are due to their light-screening effects (Merzlyak and Chivkunova, 2000). It was also found that anthocyanin accumulation, in the vacuoles of epidermal cells results in an increase of visible light absorption by 'Zhigulevskoe' apples. The quantity of light absorbed by the pigments participating in photosynthesis should thus be significantly reduced. Merzlyak and Chivkunova (2000) also found that anthocyanins exert a strong effect on light absorption by apples in the band 500-600 nm, which is exactly in the gap between the chlorophyll and carotenoid absorption bands. It was concluded that taking into account the high resistance of anthocyanin to irradiance, there are grounds to believe that the protective effects of anthocyanin pigments against both high-light-induced stress in, and damage to, plants are due to their functioning as an effective internal light trap for solar radiation in the green-orange region of the spectrum (Merzlyak and Chivkunova, 2000).

Photorespiration also plays an important protective role in the plant. Trials conducted on several water stressed grapevine cultivars concluded that photorespiration effectively

protects the photosynthetic apparatus from photo-damage under drought, assists in maintaining a relative high actual photochemical efficiency of PS Π, and helps towards rapid recovery of net photosynthetic rate after re-watering (Guan et al., 2004). Leaves and other tissues containing chlorophyll that are exposed to excess light levels have mechanisms to dissipate the surplus absorbed light, in order to prevent it from damaging the photosynthetic apparatus of the leaf. The most important mechanism in the dissipation of excess light is the xanthophyll cycle, capable of diverting up to 60% of the excitation energy to heat (Taiz and Zeiger, 2002)

High light conditions also influence fruit growth and quality. Wünsche et al. (2004b) studied the responses that take place at cellular level when fruit are exposed to high solar radiation and defence mechanisms used by the fruit. It was found that physiochemical properties of the fruit skin and homogeneity, thickness and composition of the epicuticular wax layer as well as the amount of hair on the skin surface, together with the concentration and quantity of skin pigments all contribute to the sensitivity of the apple fruit to sunburn differing between cultivars. Wünsche et al. (2004b) concluded that sunburn might be an expression of the mechanisms that plants use to tolerate oxidative stress caused by solar radiation. Free radicals form in plant tissue when exposed to high levels of UV-radiation, ozone and high temperatures. Once these highly reactive radicals are formed they can react with metabolites such as lipids and proteins that will lead to the loss of membrane integrity and eventually cell death. These free radicals are reduced by the interaction of antioxidants, heat-shock proteins and enzymes, which prevent vital molecular damage by protecting proteins from irreversible denaturation and breakdown. These mechanisms provide tolerance to excessive levels of skin temperatures and light and thus protect fruit from sunburn injury (Wünsche et al., 2004b).
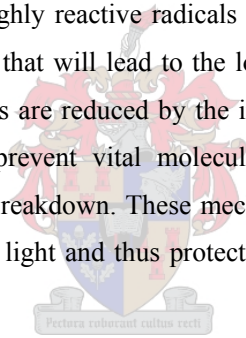
5.2 Photoinhibition

When the leaf is exposed to more light than what can be utilized or dissipated, photosynthesis is inhibited by the inactivation of PS Π, and quantum efficiency (the fraction of absorbed photons used in photochemistry) decreases. Bertamini et al. (2004) found that the efficiency of PS Π markedly declined under high irradiance especially in shade grown leaves of grape vine. The same was observed by Muraoka et al. (2000) in the leaves of *Arisaema heterophyllum* where it was found that the photochemical efficiency of PS Π and thus the electron transport rate was considerably lower in shade leaves than in sun leaves.

Two types of photoinhibition, namely dynamic photoinhibition and chronic photoinhibition occur, that are determined by the amount of light the plant is exposed to and the damage that is done (Taiz and Zeiger, 2002). Dynamic photoinhibition is observed in moderate cases of exposure to excess light. Here the photosynthetic rate stays unchanged but the quantum efficiency decreases. The decrease is caused by the diversion of absorbed light energy to heat dissipation. Quantum efficiency will return to its normal value when the photon flux decreases below the saturation point. Chronic photoinhibition occurs when the leaf is exposed to high levels of excess light damaging the photosynthetic system and lowering the quantum yield. These effects can be long lasting, persisting for weeks or months before being restored or the leaves replaced (Taiz and Zeiger, 2002). Dynamic photoinhibition normally appears at midday on warm days when the leaves are exposed to high light levels.

6. Chlorophyll Fluorescence

The measurement of chlorophyll fluorescence has been shown to be a useful technique in estimating the efficiency of the chlorophyll apparatus and has different groups of applications such as the measurement of chemical and physical stress as well as biosensing (Manuel et al., 2001). Chlorophyll fluorescence is also a valuable tool in determining the extent to which a plant is capable of adapting to unfavourable conditions (Frachebound and Leipner, 2003). For example, leaves pre-treated at moderately high temperatures (38ºC) are expected to maintain higher rates of photosynthesis, fluorescence (Fv/Fm), than control leaves upon exposure to heat stress (Frachebound and Leipner, 2003). As stated by Parchomchuk and Meheriuk (1996) and Schrader et al. (2003), apple fruit skin sustains a certain degree of injury when exposed to high temperatures and light, which is then classified as sunburn. Maximal fluorescence (Fm) decreases after exposure to high but not injurious temperatures (Manuel et al., 2001). More severe heat treatment causes an increase in the fluorescence value as measured immediately after illumination (Fo) and a decrease of Fm. This will cause inhibition of the activity of PS Π (Manuel et al., 2001). A decrease of the relation between variable fluorescence (Fv) and Fm, provides a good indicator of photoinhibition caused by light when plants undergo diverse types of environmental stresses, as drought, freezing, excessive illumination or severe heat stress (Manuel et al, 2001). Chlorophyll fluorescence has been evaluated as an indicator of low O_2 and high CO_2 stress in stored apples (DeEll et al., 1998). Studies have also been done to correlate fluorescence with maturation, ripening and senescence of apple (Song et al., 1997). Chlorophyll fluorescence is a reliable indicator of heat stress and freezing injury of apples (Song et al., 1997; Fan et al., 2005).

Exposure of fruit to excessive temperatures causes thermal death of epidermal and subepidermal cells resulting in browning of the apple skin (Schrader et al., 2003). By measuring the fluorescence of apple when exposed to different heat treatments, the heat tolerance of different apple cultivars or apples grown under different conditions can be determined (Song et al., 1997).

7. Heat stress of apple and the occurrence of sunburn

In many cases, sunburn is one of the largest motivating factors for the installation of shade netting over apple orchards. Sunburn of apples has been a problem in the production of fruit for many years and leads to enormous financial losses to fruit growers around the world (Bergh et al., 1980). Class 1 packout of cultivars such as Braeburn, Fuji, Royal Gala and Granny Smith can be reduced by 10 – 50% due to sunburn (Wünsche et al., 2001; Le Grange et al, 2004). Sunburn reducing technologies such as reflective sprays, overhead irrigation (evaporative cooling) or the installation of shade netting is much needed in the industry.

Sunburn has been defined as tissue damage caused by radiant heating of the fruit surface when directly exposed to sunlight (Parchomchuk and Meheriuk, 1996). Rabinowitch et al. (1974) concluded that the working of two external factor, light as well as heat, are the main causes of sunburn. Schrader et al. (2003) has identified two types of sunburn common on apple. The first type known as sunburn necrosis is caused by the thermal death of epidermal and subepidermal cells, when the peel reaches 52±1ºC. When this happens, a necrotic spot appears on the side of the fruit exposed to the sun. Sunburn browning, the second type of sunburn, is sub-lethal and results in a yellow, bronze, or brown spot on the sun-exposed side of the fruit. Schrader et al. (2003) also found that when fruit surface temperature (FST) exceeded about 45ºC, with the cultivar-dependent threshold temperature between 46 and 49ºC, for a period of 30-60 minutes, sunburn was most likely to occur. The threshold temperatures are for fruit that were previously fully exposed to sunlight and were therefore acclimated to heat and sunlight. According to Schrader et al. (2003), FST of 45ºC is attained at an air temperature of between 30 and 38 ºC. FST is also dependent on other external factors such as cloud cover, wind, relative air humidity and precipitation. Schrader et al. (2003) also observed that fruit on trees that are under water stress are more susceptible to sunburn than trees with a high water potential.

The cultivar and skin colour plays an important role in the amount of light that is absorbed by the fruit and thus the sensitivity of the apple to sunburn. Young apples absorb large amounts of light due to the high concentration of chlorophyll (Blanke, 1989). Blanke

(1989) reported that the red apple peels absorb more light below 620nm than green peels, while green peels absorb more light above 620nm than red and yellow peels. Yellow peels absorb the least light and so transmit more light to the core of the fruit. Blanke (1989) also found that the flesh of the apple cultivar Cox's Orange Pippin, received more light than that of cultivars such as Golden Delicious and Gloster. Compared with natural sunlight, the light absorbed by the peel was richer in blue-green light and poorer in red light making it more vulnerable to sunburn.

Sunburn is caused by a sudden increase in solar radiation and FST (Wünsche et al, 2004b) in fruit, which have not had the chance to acclimate, compared to fruit, which have been exposed for sometime. A sudden shift in the weather from cloudy and cool to sunny and hot conditions, especially after summer pruning or selective picking, can cause severe sunburn (Wünsche et al, 2004b). The acclimation of apple fruit to high sub-lethal temperatures plays an important role in inducing tolerance to sunburn damage, thus significantly reducing the rate of occurrence (Zhang et al., 2003). Heat treatments of 2, 4 and 6 hours at 45ºC increased the heat shock protein levels of 'Royal Gala' apples and thereby increased the resistance to sunburn when fruit were exposed to full sun, 3 days after treatment (Zhang et al., 2003). There is also a difference in the concentration of heat shock proteins of fully exposed and shade-grown fruit. This implies that the sensitivity of shade-grown fruit to sunburn can be expected to be higher than of fruit that have been exposed to high light levels (Zhang et al., 2003).

Fruit grown under protective netting could be more sensitive to sunburn because of the reduced acclimation to high light and temperature levels during development. This will, however only be problematic to the fruit grower if for some reason the netting is removed or damaged during the growing season, or the apples are exposed to high light and heat after harvest due to poor production practices.

7.1 Control methods against sunburn

In addition to the installation of shade netting there are other methods of reducing sunburn that have been researched and used in the field with some success.

Johnson et al. (1999) did experiments in Washington State, USA, on the effect of ascorbic acid sprays on incidence of apple sunburn. Weekly sprays of 1 or 3% ascorbic acid or an analogue, isoascorbic acid, were applied to the apple cultivars Fuji and Granny Smith. The results showed that only 3% ascorbic acid and isoascorbic acid sprays reduced sunburn in

'Fuji', but not in 'Granny Smith'. Positive results were also only found during the most susceptible time of the season (Johnson et al, 1999).

Treatments with vitamin E, Vapogard and Nufilm have been used in Chile to reduce sun damage but with little effect (Yuri et al., 2004).

Other techniques that have been shown to reduce sunburn of apples are overhead sprinkling or evaporative cooling systems and the application of kaolin based reflective particle film. With evaporative cooling water sprinklers are installed above the tree canopy. During the warmest period of the day or when the temperature exceeds a certain thresh old, water is pulsed for short periods over the tree canopy, cooling the fruit through evaporative cooling (Parchomchuk and Meheriuk, 1996). In a well-managed orchard where only a small portion of fruit may be susceptible to sunburn, the marginal cost benefits of evaporative cooling may be outweighed by its installation and running costs (Andrews, 1995). In areas where there is a shortage of water it is advisable to make use of other systems in order to preserve water.

Reflective kaolin particle film (Surround[®]WP, Engelhard Corporation, NJ, USA) has also been tested for use as a sunburn reducing mechanism. It is hypothesised that applications of Surround[®]WP reduce leaf and fruit surface temperature by increasing the amount of light reflected from the fruit surface (Wünsche et a., 2004a). Kaolin has been shown to have a positive effect on yield and fruit quality, by reducing sunburn, reducing stress to plants exposed to excessive high temperatures, improving net photosynthesis, and improving yield by reducing fruitlet drop due to extreme hot weather conditions (Erez and Glenn, 2004). Kaolin has also been shown to improve fruit colour by reducing surface temperature of exposed fruit and improving fruit size by enhancing cell division in the first stage of fruit development (Erez and Glenn, 2004). Even though kaolin does have a positive effect on fruit quality (Schupp et al., 2004), the removal of the particles from the fruit surface after harvest has proven to be problematic, and the installation of expensive equipment such as brushing and high-pressure sprayer methodology is needed (Erez and Glenn, 2004). In South Africa, kaolin has been shown to reduce sunburn on apple cultivars such as Royal Gala, Fuji and Granny Smith (Le Grange et al., 2004). Kaolin application of Surround[®]WP did not, however, reduce sunburn on 'Cripps' Pink' (Erez and Glenn, 2004).

A commercial whitening agent, Sunguard, similar to kaolin, has also been applied to apple trees in order to reduce sunburn incidence. Sunguard did not reduce the development of sunburn on fruit or reduce sunscald injury in fruit during storage (Sibbit et al., 1991).

The use of certain cultural practices, if followed correctly, could also aid in the reduction of sunburn on apples. It was suggested that changes in tree training and pruning to promote natural shading, and irrigation management to avoid tree stress (which predisposes fruits to heat injury) may reduce sunburn and sunscald (Sibbit, 1991). The use of dwarfing rootstocks, suitable planting systems, optimum row orientation and proper training and pruning systems as well as adequate irrigation can help increase fruit quality factors such as fruit size and colour (Wagenmakers and Callesen, 1995) and help reduce sunburn.

8. Protective netting

Protective netting is widely used and is gaining popularity for the protection of orchards against hail and sunburn damage. One hailstorm, or heat wave, could be enough to destroy a whole harvest and fruit producers are taking preventative measures by installing protective netting over orchards (Gardner and Fletcher, 1990; Widmer, 2001; Middleton and McWaters, 2002).

A wide range of netting is available differing in net density and colour. Studies have shown net colour and density to have an effect on fruit quality and tree growth, making the choice of netting critical. Net density is an important factor in the amount of solar radiation reaching the plant and thus plays an important role in fruit quality aspects such as red colour development, size, total soluble solids and starch conversion rate (Scott, 1989; Stampar et al., 2001; Shahak et al., 2004). The structure of the netting support system is also of importance and there are two main systems. The flat roof or flat net type and the hut-shaped or pitched roof system (Gardner and Fletcher, 1990). The flat roof type is the most economic to install and will protect against hail damage but will not go undamaged through a hailstorm and is thus more difficult to maintain. This installation method is mostly used for protection against sunburn in areas where hail is uncommon. A pitched roof structure that sheds hail has been the most popular installation type. In this system netting is pitched at an angle of about 45º with gaps at the bottom of the pitch allowing hail to fall to the ground (Gardner and Fletcher, 1990).

As the understanding of plants increase, shade net technology is also fast improving. New types of net are being developed that specifically modify and filter light in the ultraviolet (UV) and the visible or far-red spectral regions. These nets are also capable of enhancing the relative content of scattered-diffused light, and/or affect thermal components at the infrared region. The nets provide varying mixtures of natural, unmodified light, together with

spectrally modified, diffused light depending on the chromatic additives to the netting material, and the knitting design (Shahak et al., 2004).

8.1 Microclimate

As already discussed the installation of, netting changes the microclimate of the area under the netting. Relative humidity is increased, wind and light intensity reduced, and temperatures are altered. All these factors play an important role in the growth and development of the plant and will influence it accordingly.

8.2 Gas exchange

With the installation of shade netting over an orchard, we would expect changes in the physiology of the trees as they react to microclimatic changes in humidity, temperature, wind and available light, which are the major factors influenced by netting and which also influence gas exchange (Guerrero et al., 2002; Shahak et al., 2004). The ability of plants to adapt to altered light conditions is a fundamental response associated with specific changes in the morphology, physiology and biochemistry and the structure of the leaves and chloroplasts (Taiz and Zeiger, 2002).

The photosynthetic light-response curves of shade plants (Barden, 1977) typically have a lower light compensation point for net CO_2 assimilation, a lower maximal photosynthetic rate, and photosynthesis saturates at a substantially lower irradiance than for sun plants indicating that the photosynthetic properties of a leaf depend on its growing conditions (Taiz and Zeiger, 2002). Leaf transpiration results from the diffusion of water vapour through the stomatal pore. Changes in stomatal resistance are important for the regulation of water loss by the plant and for controlling the rate of CO_2 uptake necessary for sustained CO_2 fixation during photosynthesis. Stomatal control thus couples leaf transpiration to leaf photosynthesis (Taiz and Zeiger, 2002).

In a study done by Andersen (1991) on the leaf gas exchange of 11 different fruit crops supplied with nonlimiting soil moisture under varying levels of irradiance, it was found that in full sun light net CO_2 assimilation (A) and stomatal conductance to water vapour (gs) were highest for pecan (A = 16.4μmol m^{-2}s^{-1}, gs = 455 mmol m^{-2}s^{-1}). Peach, apple, grape, blackberry and fig had intermediate net CO_2 assimilation (A = 12.1 to 14.6 μmol m^{-2}s^{-1}, gs = 230 to 370 mmol m^{-2}s^{-1}) and Satsuma, persimmon, blueberry and kiwi was found to have low net CO_2 assimilation (A = 5.7 to 10.2 μmol m^{-2}s^{-1}, gs = < 220 mmol m^{-2}s^{-1}). After shading for 80 seconds at 100, 33 and 10% full sun, A declined rapidly, yet gs was not altered. It was also

found that transpiration rate (E) declined slightly, and water use efficiency (WUE) was often near zero at 10% sun (Andersen, 1991). Intercellular CO_2 concentration (Ci) was found to be 199 to 237 μmol mol^{-1} in full sun and rose to near ambient levels with increasing shade levels. A, gs, E, WUE and Ci returned to pre shade treatment levels within one minute for all species upon re-exposure to full sun. It was also found that interior canopy leaves of pecan, peach, apple, and grape exposed to prolonged periods of low irradiance manifested greater reductions in A, than gs or E, hence WUE was lower and Ci was higher than for sun-exposed leaves. In addition it was also found that pecan leaves shaded to 33% full sun for 54 min, manifested 50 and 25% reductions in A and gs, respectively (Andersen, 1991).

Jifon and Syvertsen (2001) found that for grapefruit and sweet orange, midday leaf temperature and VPD were reduced by shading resulting in increased gs and photosynthetic activity of shaded leaves compared to sunlit leaves. In a further study by Jifon and Syvertsen (2003) it was found that the physiological responses to 50% shading of grapefruit and orange leaves were similar. They found that mean daily maximum photosynthetic photon flux density under shade varied from 500 to 700 µmol m^{-2} s^{-1} and was sufficient to achieve maximum A in grapefruit and orange. Midday depressions of gs and A were observed in both sunlit and shaded leaves. Estimated stomatal limitation to A was generally less than 25% and did not differ between shaded and sunlit leaves (Jifon and Syvertsen, 2003).

It is thus important that the effect that shade netting might have on the gas exchange and water potential of apple trees in specific should be investigated in order to determine the sustainability of apple production under shade netting.

8.3 Vegetative growth

Orchard vigour can be defined as the intensity of vegetative growth, and is an important indicator for crop management in fruit tree cropping systems. The essence of plant life is lifelong growth. Growth zones in the buds and root tips of plants remain active for the production of new shoots, leaves and flowers throughout the entire life of a plant (Larcher, 1995).

The relationship that exists between vegetative and reproductive growth has been studied in depth over the years (Volz et al., 1993; Link, 2000). Lakso et al. (1989) found that within the range of natural light in the apple tree canopy, the growth rate of apple fruit during the first 5 weeks after bloom was correlated with the light exposure of spurs during that period. It was further stated that the effect of canopy shade on final fruit size occurred primarily in this first five-week period after bloom and that little additional effect could be

attributed to changes in light availability the rest of the season. Light affects the development and growth of plants in ways such as photostimulation of biosynthesis, phototropism and photoinduction (Larcher, 1995).

The effect that light has on growth is also found in shoot growth and development. Shoot growth on vigorous trees was found to be greater when covered by protective netting than in identically pruned comparable trees outside of netted orchards (Middleton and McWaters, 2002). Bepete and Lakso (1998), however, found hat early season shoot growth of 'Empire' apples was not significantly affected by shading although variability in fruit growth was found.

Vigorous growth of trees covered by netting can however be controlled by the use of dwarfing rootstocks and certain growth-retarding chemical sprays. Evans et al. (1997) reported that spray applications of prohexadione calcium provided excellent control of vegetative growth. Applications of daminozide and ethephon were also found to reduce shoot growth and increase flower bud initiation (Jones et al., 1989). It is generally agreed that fruit quality is affected by crop load and that the vegetative and reproductive growth of a tree are closely interlinked. Fruit and flower thinning is commercially practised to maximise crop value by optimizing marketable fruit sizes, yields, fruit colour, shape and quality, as well as to promote return bloom and tree growth and to maintain tree structure (Byers, 2003). Correct crop load control can be an important aid in altering vegetative growth (Wünsche and Ferguson, 2005).

8.4 Fruit set

In the production of fruit, sufficient flowering is essential but the flowers in themselves are not enough, they must set into fruit of good quality and size in order to be marketed (Dennis, 2003). The process whereby flowers set into fruit could also be affected by the installation of shade netting.

Shahak el al. (2004) found that netting of various colours increased fruit set in the apple cultivar Smoothee. The best results were observed under red and white netting. Middleton and McWaters (2002) consistently found a lower fruit set on trees that were covered by netting. In a trial done over a five-year period it was found that apple trees covered with netting developed approximately 19% less flower buds than uncovered trees (Leite et al., 2002). Middleton and McWaters (2002) found that 'Hi Early' and 'Red Delicious' trees under netting did not require chemical thinning, whereas adjacent uncovered trees received two sprays. In previous years the same pattern was observed where the trees

under the netting received two chemical thinning sprays and required minimal follow up hand thinning. Trees that were not covered by netting received three chemical thinning sprays and significant follow up hand thinning was required. The reason for the greater shedding of fruitlets on trees covered by netting could be due to direct competition between developing fruitlets and reduced bud strength as influenced by light levels (Middleton and McWaters, 2002). The competition between reproductive and vegetative growth is also a possible reason (Bebete and Lakso, 1998).

These results show that producers should pay particular attention to their thinning programs in order not to overthin the trees covered by netting. Flowers that are not pollinated will not set into fruit. Cross pollinators and the presence of bees must be adequate. The application of nitrogen is important for fruit set in most fruit orchards. Once sufficient leaf surface is available, urea, a source of nitrogen, can be sprayed onto the trees that will then be absorbed by the leaves, thus improving bud development. Ringing or girdling will reduce flower drop and increase final fruit set (Dennis, 2003). In a study done by Casierra and Ludders (2000) on the effect of leaf nitrogen content on vegetative and reproductive growth of 'Golden Delicious' apples, it was found that high levels of N increased the number of flowers per plant and shoot growth, but fruit set was reduced. Paclobutrazol application has also been shown to counteract the adverse effects of shading on the flowering of young vigorous 'Bramley's Seedling' (El-Hodairi and Canham, 1990).

In order to have a good fruit set the flowers must be well pollinated. Apple pollen is heavy and is not carried readily by the wind (Dennis, 2003). Apple pollen is primarily transferred from one tree to the other by insects, especially honey and bumble bees. Unfavourable environmental conditions during the flowering period such as rain or cold weather, during which bee activity is limited, could be detrimental to pollination. It is recommended that four to five strong bee colonies be placed per hectare during the flowering period (Dennis, 2003).

The installation of netting does influence the movement of bees under, or into the netted area, and care must be taken to ensure adequate bee penetration. It is very important to place the hives under the netted area. In some cases, especially if the nets are installed in such a way that they close the sides of the orchard, bees find it hard to enter the orchard (Middleton and McWaters, 2002). The hives must thus be distributed throughout the netted area. Bees must be introduced into the orchard at 3-5% bloom. Introduction before this could encourage bees to find nectar outside the netted area. Bees must also be able to fly freely between and over the rows to ensure an even distribution. It is thus advisable to leave a gap between the

treetops and the nets. The installation structure of the netting can also influence bee movement. Bee flight may be further inhibited if the structure is of pitched or hut design and the treetops grow into these peaks. A beneficial effect of hail netting is that the protected environment could encourage bee foraging across alleyways and between adjacent tree rows. The same hives should be used under the netted area every season because bees become acclimated to the netted environment and will perform better (Middleton and McWaters, 2002).

If persistent pollination problems occur, it might be advisable to remove nets, or sections of netting during the pollination period. This will allow bees to move freely over the trees and into the orchard (Middleton and McWaters, 2002).

8.5 Crop Thinning

A growing need to manage fruit production in order to optimise quality and produce fruit with specific quality attributes is being led by a trend of more consumer driven food markets. The most important determinants in achieving desired products are environmental and management factors during the growing season (Wünsche and Ferguson, 2005). Probably one of the most important and effective mechanisms of improving fruit quality is by thinning crop load to the optimum fruit bearing potential of the tree. Crop load is a key cultural component of final fruit quality, and thus of managing the risk associated with achieving commercial requirements for fruit size, consumer-based quality attributes, and freedom from disorders (Wünsche and Ferguson, 2005). Consistently lower fruit set has been recorded for apple trees under netting (Middleton and McWaters, 2002). This could offer a significant advantage in reducing thinning cost to producers but could also lead to fruit set problems if not managed adequately.

The photosynthetic performance and growth response of perennial fruit trees is greatly affected by the presence or absence of fruit. Effect of time and severity of fruit(let) thinning or crop load adjustment, and concomitant alterations of fruit to leaf ratios, have been extensively studied in a desire to achieve high orchard productivity without compromising potential fruit size and quality or return bloom (Wünsche and Ferguson, 2005). Optimised crop loads for a given cultivar and production system in a particular environment can give enhanced financial returns to growers.

Compared to other preharvest factors such as pollination, mineral nutrition, and light and temperature environment, variability in crop load may have the greatest impact on both fruit quality and tree physiology (Wünsche and Ferguson, 2005). Finding the optimum

thinning intensity is, however, difficult as pointed out by Link (2000). Adjusting crop load in order to produce fruit that meet the requirements of the market in specific aspects could, however, lead to the neglect of other fruit quality parameters. For example, fruit often will not yield sufficient fruit colour in certain cultivars, and when optimised for a perfect fruit colour, too many oversized fruit susceptible to physiological disorders tend to be recorded (Link, 2000). By increasing or reducing the fruit load of a tree and thereby altering the nutrient availability to the fruit and shoots we could expect fruit quality to be affected by crop load.

Previous investigations into the effect of crop load and thinning on fruit quality showed that the effects of thinning were primarily due to altering crop load (Link, 2000). An increase in fruit size is directly related to thinning intensity. Fruit size, colour, firmness and sugar as well as acid content were all found to be improved by increased thinning intensity (Link, 2000).

Gas exchange is also affected by crop load. Seasonal leaf photosynthesis is dependent on the developmental stage of the tree and on fruit load. Higher leaf photosynthetic efficiencies and transpiration rates in fruiting than in nonfruiting apple trees have been recorded in past studies (Wünsche and Ferguson, 2005). The effect of fruit on photosynthesis is, however, not consistent for all fruit crops, and only becomes significant at very low crop load or defruited trees.

Research on crop load has revealed a powerful interplay between fruit development and shoot growth and photosynthesis. The apple tree has a remarkable ability to acclimate to the differing demand of the fruit crop for carbohydrate. Special attention must be given to optimise crop load in order to best meet the requirements of the producer.

8.6 Fruit quality under protective netting

The light environment of an orchard influences fruit quality, including red pigmentation, soluble solids concentration, fruit size and mass as well as maturity development. Variations in photosynthetic photon flux density (PPFD) as measured at various canopy positions throughout the growing season, have been used to explain variations in fruit quality of 'Delicious' apples (Campbell and Marini, 1992). The uncertainty about effects of netting on fruit quality such as fruit colour, size, maturity development and the occurrence of diseases are concerns that have made producers reluctant to install netting over orchards (Gardner and Fletcher, 1990). A well-coloured fruit is a prerequisite for the export there of to foreign markets, and it is important for fruit producers to produce fruit which meet export requirements.

When fruit mature, the skin undergoes colour formation (Grappadelli, 2003). During this process, pigment synthesis (anthocyanins, carotenoids and flavonoids) must occur, along with chlorophyll degradation (Awad et al, 2001). Blush colouring of fruit is largely dependent on the amount of sunlight the fruit receives (Grappadelli, 2003). In the interior of fruit trees, where there is very little direct light, the levels of UV-A, blue, green and red light are lower and the far-red light as well as the far-red/red ratio is higher. This may suppress the synthesis of cyaniding-3-galactoside anthocyanin and quercetin-3-glycoside, which are both flavonoid compounds, and thus result in a decrease in fruit colour. With the scattering and decrease in light levels under netting a reduction in fruit colour could be expected, unless light conditions within the tree are improved. This can be done by using dwarfing rootstocks, suitable planting systems, optimum row orientation and proper training and pruning systems (Wagenmakers and Callesen, 1995). Gardner and Fletcher (1990) showed that when black nylon netting of ± 29% shade was installed over a 'Jonathan' apple orchard, fruit colouring was reduced by 10-16%. The effect that netting has on fruit colour seems to be cultivar and netting type dependent. Widmer (2001) observed that black netting had no significant effect on fruit colour for 'Jonagored' but reductions in fruit colour was however observed on 'Jonagold'. Time of harvest also plays a role. Widmer (2001) showed that colour development was delayed by 8 to 10 days. Stampar et al. (2001) did experiments on two cultivars, namely Elstar and Jonagold, where they looked at the effect that white and black shade netting had on fruit quality. It was found that 'Elstar' coloured the best under white netting and had the worst colour development in the uncovered control section. Stampar et al. (2001) also found that for 'Jonagold', colouration was negatively affected under black netting and positively affected under white netting. Guerrero et al. (2002) also found that colour development on 'Redchief Delicious' was better on fruit of trees covered by white netting than those of trees under the black netting. Best colour development was on uncovered fruit.

The effect that different colours of netting have on colour development was tested by Shahak el al. (2004). Blue, red, yellow, grey and pearl netting with a knitting density that yields 30% shade was installed, as well as a white and red/white net with a shading factor of 15-17% over 'Topred' trees. Colour development was significantly better under all the nets compared to control. The fruit covered by grey netting showed the best colouration followed by fruit covered with red netting (Leite et al., 2002). 'Royal Gala' and 'Fuji' showed a reduction in red colour with the installation of shade netting with a shade factor of 12, 18 or 30%. 'Royal Gala' had a 14.2% red colour reduction and 'Fuji' 7.2% (Leite et al., 2002).

Nitrogen levels also play an important role in fruit quality including fruit colour. It was found that for 'Fuji' red colour decreased as the rate of N application increased (Fallahi et al., 2001). Autumn application of N often results in lower leaf N, and thus better fruit colour (Fallahi et al; 2001).

It is very clear that colour development is dependent on the apple cultivar, training system and the colour netting that is installed over the orchard. Fruit also colour better in orchards where there is less water stress and agricultural practices such as rootstock, row orientation and thinning can play an important role in improving fruit colour.

Fruit size of apples is largely determined by the vigour of the tree, cultivar and crop load. Exposure to sunlight also plays an important role in the determination of final fruit size (Dennis, 2003). As found in various studies, netting can affect fruit size and this should be taken into consideration with the installation thereof. In a 'Jonathan' apple orchard covered with 20% shade netting the fruit size (mean diameter) was slightly reduced (Gardner and Fletcher, 1990). Widmer (2001), however, showed that black shade netting did not influence fruit size in most cultivars. The effect that different colour netting (blue, red, yellow, grey, pearl white and red/white) has on fruit size was researched by Shahak el al. (2004). It was found that in spite of heavier fruit load, fruit size was significantly larger under all nets, with diameters about 5 mm greater than the control at about 7 weeks prior to the expected harvest. The mean fruit size for 'Top Red' was especially larger under red nets, although the differences were not statistically significant. Early fruit growth rates have been shown to decrease by up to a quarter of the normal with the introduction of shade early in the season, and the shoot tip has priority over the fruit for assimilates under limiting light conditions (Bepete and Lakso, 1998).

In marketing fruit, especially on the export markets, date of harvest can play an important role in the selling price of the product. Fruit of a specific cultivar that arrives on the market before fruit of competing producers tend to reach much higher market prices. It is thus important whether or not the installation of netting will influence maturity development of different apple cultivars.

Fruit firmness and starch conversion rates are used as indicators of fruit maturity. It is well documented that starch levels in apple fruit decrease as fruit mature (Fan et al., 1995). Widmer (1997) found that 'Jonathan' apples grown under protective netting were firmer than uncovered apples. Gardner and Fletcher (1990) also found that apples harvested from under netted areas tended to be slightly firmer than from non-netted trees. No effect of netting on fruit firmness was, however, found by Scott (1989) or Wagenmakers and Tazelaar (1999). A

possible explanation for firmer fruit for certain cultivars could be delayed maturation as suggested by Widmer (1995) and Middleton and McWaters (2002). Fruit from netted areas are often harvested at the same time as fruit from uncovered sites. It would be better that cultivars tending towards slower starch conversion and loss of firmness under netting be harvested later than uncovered trees.

With the installation of shade netting the TSS and TA content of apple fruit may be affected due to alterations in CO_2 assimilation and water availability. Fruit size and the position of the fruit within the tree canopy can however confound any effect of protective netting on TSS and TA and make it difficult to attribute differences found in TSS and TA to netting. Reductions in TSS could however be due to a reduction in water stress under the netting as suggested by Middleton and McWaters (2002). Reductions in TSS could also be due to the delayed maturity as previously stated. Wagenmakers and Callesen (1995) found TSS to be lower in apples grown under shaded conditions. These results correspond with the findings of Middleton and McWaters (2002) showing TSS for 'Granny Smith' to be up to 1.5% lower under netting. Widmer (1997) found that 'Jonagold' and 'Jonagored' had higher acidity under netting. Results found by Stampar et al. (2001) showed TA to be significantly higher under white netting for 'Elstar' and no difference between netted and uncovered trees for 'Jonagold' was found.

8.7 Effect of netting on diseases and pests

Installation of shade netting could affect diseases found in apple orchards. Humid environments are known to be very conducive for the growth and development of pathogens. It is thus of concern how netting could influence the development and spread of diseasess within an apple orchard. Insect and other pests such as birds also cause large amount of damage to crops annually. These pests may be better controlled with netting.

Shahak et al. (2004) reported that an unexpected benefit of netting was the lack of Sooty mold, monitored under a range of net types compared to the control treatments where a substantial level of mold was found. Gardner and Fletcher (1990) found that there was no increase in the incidence of apple scab and mildew infections under netting. In a trial done in Brazil on the effect of netting with different shade factors, Leite et al. (2002) found that shading reduced the incidence of fruit with russeting, but that the incidence of *Colletotrichum sp.* was increased.

Middleton and McWaters (2002) also showed that with the installation of netting the incidence of russeting was reduced and apples had smoother skin. The effect of altered natural

daylight on the incidence of russeting on potted 'Golden Delicious' apple fruit were studied by Noé and Eccher (1996) and it was found that apples that were exposed to shading had decreased russeting compared to the fruit exposed to natural light conditions. A reduction or total elimination of bird damage on the fruit was also noted.

Shade netting thus reduces other crop damaging factors besides sunburn and hail. These 'bonus' benefits must be kept in mind when calculating the economic viability of the installation of shade netting.

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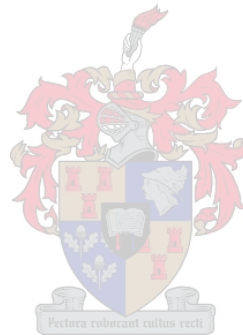
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CHAPTER 2 – The effect of black shade nets and crop load on fruit quality of four blushed apple cultivars.

ABSTRACT

Sunburn is a major cause of economic loss for apple producers in the Western Cape Province of South Africa as well as for other warm apple producing areas in the world. Trials were performed during the 2003/04 and 2004/05 growing seasons to evaluate the effects of black shade net (20%) on fruit quality of four blushed apple cultivars Braeburn, Fuji, Royal Gala and Cripps' Pink. Under both netted and non-netted treatments five different crop loads were established to test the interactive effects of nets and crop load on fruit quality. The study showed that cultivars reacted differently to the altered microclimate under the nets. Meaningful interaction between net and crop load treatments was only found for fruit mass of 'Royal Gala' and 'Fuji', with fruit mass declining more rapidly with increasing crop load under nets than in the open. Sunburn was significantly reduced in all the cultivars except 'Cripps' Pink'. Numbers of viable seeds were reduced under nets. No effect on ground colour was found except for 'Braeburn' that showed greener ground colour. Blush colour was reduced under the netting for 'Braeburn' and 'Fuji' but was unaffected for 'Royal Gala' and 'Cripps' Pink'. Fruit firmness, total soluble solids, titratable acidity and starch content were reduced under nets in most cases.

Keywords: Apple, crop load, fruit maturity, fruit quality, fruit thinning, *Malus domestica*, shade net, sunburn.

INTRODUCTION

Production of large volumes of high quality apples has become apple producers' main goal in order to become more competitive internationally. Due to ever increasing quality expectations and an increasingly unpredictable climate, apple growers have been experimenting with various new methods to mitigate climate stress and increase fruit quality. Packout percentages are often greatly reduced by natural elements such as hailstorms capable of eliminating whole harvests, and sunburn that can cause damage as high as 50% in warm areas. It is because of this economic risk that growers are looking into methods such as the installation of shade/hail nets over orchards (Scott, 1989; Middleton and McWaters, 2002). However, specific data for South African conditions on the effect of shade/hail nets is still in short supply, and apple
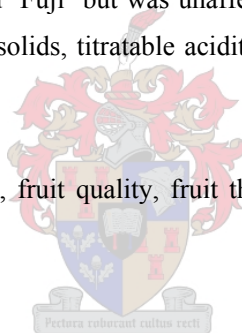
producers in the Western Cape region remain cautious about using protective netting for fear of negative effects on yield and quality, together with the high cost of installing shade netting.

Productivity of apple orchards varies greatly between different climates or years, and it is difficult to determine the critical factors over large ranges of climatic conditions (Lakso et al., 2001). With the installation of protective nets over an orchard, one would expect changes in the physiology of the trees as they react to further changes in climatic factors such as humidity, temperature and available light. For example, a reduction in available light may reduce fruit quality characteristics for certain apple cultivars, such as red pigmentation, total soluble solids (TSS) and titratable acidity (TA), fruit mass and size (Scott, 1989; Campbell and Marini, 1992; Widmer, 1995; Widmer, 1997; Wagenmakers and Tazelaar, 1999; Stampar et al., 2001; Middleton and McWaters, 2002). Not only could fruit quality be affected by altered light conditions but one could expect changes in tree productivity and growth, and flower bud initiation (Barden, 1977; Doud, 1980; Palmer, 1989).

During the last twenty years many reports have been published on the effects of shade nets on various aspects of apple production ranging from pollination and fruit set, to colour and fruit size (Scott, 1989; Middleton and McWaters, 2002; Guerrero et al., 2002; Shahak et al., 2004). Careful attention to achieving optimal crop load could be a mechanism to reduce some of the reported negative effects of nets on the balance between fruiting and vegetative growth. Fruit quality parameters such as colour, size, flesh firmness, TSS and TA have been shown to be improved by thinning trees to the optimum crop load (Volz et al., 1993; Daugaard and Grauslund, 1999; Link, 2000). It is, however, impossible to maximize all quality factors simultaneously in addition to achieving sufficient fruit volumes, and a reasonable balance must, therefore, be achieved.

The aim of this study was to investigate the interactive effects of shade net and varying crop load on apple fruit quality under Western Cape climatic conditions. The null hypothesis was that there would be reductions in sunburn under nets and no negative effects on other fruit quality characteristics.

MATERIALS AND METHODS

Plant material

The trial was established in a commercial orchard located on the Du Toit Group farm, Vastrap, situated in the Witzenberg Valley in the Western Cape Province (33°15'S 19°15'E, 901 m altitude), and was carried out during the 2003/04 and 2004/05 growing seasons. The apple (*Malus domestica* Borkh.) cultivars Royal Gala (RG), Fuji (FU), Braeburn (BR) and

Cripps' Pink (CP) were grafted on rootstock M793 and planted during 1996 in a slight north-east by south-westerly direction with 4m x 1m spacing for RG, FU and CP and 4m x 2m spacing for BR, and all were trained to a central leader. Standard commercial management practices for the region were followed. Micro-jet sprinklers were used for irrigation and scheduling was based on neutron moisture probe measurements taken in the netted and uncovered areas of each cultivar. During 2005 irrigation was reduced to 40% of the normal water requirement due to drought.

Treatments and experimental design

The four cultivars were planted in blocks on either side of a gravel road with RG and FU next to each other on one side of the road and BR and CP on the other side. Black shade/hail nets with a density of 20% were installed over the orchard in 2001 using a 45° pitched roof structure. Twelve rows of each cultivar were covered halfway down the rows with nets. The uncovered parts of the rows were used as control. These comprised the main treatments. Six rows of each cultivar, chosen from the inside of the netting outwards to avoid an edge effect, were chosen to use as blocks. There were 15 trees per replicate (except CP for which there were 6), and these were divided into five groups of three trees each for the thinning sub-treatments. Thinning sub-treatments were randomised within main treatments, and although main treatments were not randomised, environmental and cultural conditions were deemed to be highly comparable under the netted and non-netted areas. For this reason a split-plot ANOVA was used for statistical analyses.

During both seasons BR, RG and FU were thinned to 140%, 120% 100%, 80% and 60% optimum fruit bearing potential under each main treatment, and CP to 80% and 120%, as determined by the farm management. Optimum fruit bearing potential for the four cultivars was for 'Braeburn' 64.0 kg/tree, 'Fuji' 29.9 kg/tree, 'Royal Gala' 25.9 kg/tree and 'Cripps' Pink' 29.0kg/tree. Final thinning was done by hand after the specially adapted farm chemical thinning program (Table 1). The same trees were used for the thinning treatments during both seasons. During the 2003/2004 season hand thinning was done from 24 to 30 November 2003. An average number of fruit was calculated per tree to determine the number of fruit to be removed from each tree in order to achieve the required crop loads. During the 2004/2005 season hand thinning was done from 12 to 15 November 2004.

The chemical thinning program for the 2004/2005 (Table 1) season was more vigorous than the previous season and, on average, there were fewer fruit on the trees. Therefore, in the RG block only the 60, 80, 100 and 120% crop load treatments were hand thinned and the

140% treatment was left un-thinned. The CP block was only thinned for the 80% treatment and the 120% treatment was left un-thinned due to low crop loads. Actual yields as measured at harvest for both seasons are given in Figure 1-4.

Fruit sampling

The trees were individually harvested and yield/tree was recorded. During the 2003/04 season RG was harvested first over four picks (16 and 23 February, 2 and 9 March). FU was harvested second over two picks (1 and 7 April). BR was harvested next with just one pick on 14 April. CP was harvested last over two picks (22 and 29 April). A random fruit sample of 25 fruit was taken from each replication. Samples for laboratory analysis were drawn twice for RG (16 February and 2 March) and FU (both picks). Because BR was only picked once and the second pick for CP was too small, only one sample was taken for these two cultivars.

During the 2004/05 season the same sampling procedure was used. RG was harvested three times (2, 10 and 17 February), BR was harvested twice (21 and 30 March), and FU was harvested twice (23 and 31 March). CP was harvested on 14 and 26 April. Samples were randomly drawn twice from each cultivar for laboratory analysis.

Harvest quality determination

Fruit samples were kept in a cold room until analysed not later than one week after harvest. Before analysis the fruit were taken out of the cold room and allowed to reach room temperature. Sunburn damage was rated on a scale of zero to three, where Class 0 had no sunburn, Class 1 had light sunburn browning, Class 2 had darker sunburn browning, and Class 3 had necrotic sunburn as described by Schrader et al. (2001). In each class, the percentage of sample apples having sunburn are reported. Fruit mass was determined using an electronic scale. Ground colour was measured using a colour chart (Unifruco Research Services Ltd, Bellville, South Africa) with values 0.5-5.0 where 0.5=dark green and 5=yellow. Blush colour was determined by using the respective colour charts (Deciduous Fruit Board, Bellville, South Africa) for each cultivar: chart A42 (values 1-12 with 1=red) for 'Royal Gala', chart A44 for 'Braeburn' (chart values 1-8, with 1=red), chart A45 for 'Fuji' (chart values 1-12, with 1= red), and for 'Cripps' Pink' the Pink Lady® (Pink Lady Association) colour chart (values 1-12 with 12=red).

Fruit firmness was measured on opposite peeled cheeks of the fruit with a penetrometer (Southtrade fruit pressure tester, FT 327, Alphonsine, Italy), fitted with an 11mm diameter tip. During the second season fruit were cut in half and the number of viable

and unviable seeds counted. Slices were cut from each fruit and juiced together and a TSS (total soluble solids) reading taken with a handheld refractometer (Atago PR-100 9501, ATAGO CO. Ltd., Tokyo, Japan). The same juice was used for the titratable acidity (TA) determination which was done during the second season only, by titration with 0.1 M NaOH to a pH of 8.2 using the automated titrator (Tritino 719S and Sample Chamber 674, Metrolum Ltd., Herisau Switzerland). Results were expressed as percentage malic acid (g 100g^{-1} juice). The percentage starch breakdown of the apples was determined by placing one half of the fruit in an iodine solution and evaluating the starch breakdown using the starch conversion chart for pome fruit (Unifruco Research Services, Bellville, South Africa). The fruit were individually rated (present/absent) for damage by *Fusicladium pyrorum*.

Statistical analysis

The data was analysed as a split-plot ANOVA using the General Linear Models (GLM) procedure of SAS (SAS release 6.12P; SAS Institute, 1996, Cary, NC). Means comparisons were performed using Tukey's test at P≤0.05.

RESULTS

Very few interactions were found between the main treatments (trees covered by net and non-covered trees), and the sub-treatments (varying crop loads). Main effects of net treatments will be presented first, followed by main effects of the crop load treatments and significant interactions.

Effects of net treatment

Shade nets reduced the percentage sunburn damage during both seasons in FU and BR, during the first season only in RG first harvest, but not during either season in CP (Table 2). BR had a significantly higher percentage of fruit in Class 0 during 2004 and for the first harvest of 2005 under the net treatment. In 2004 there was a significant reduction in serious sunburn (Classes 2 and 3) while in 2005 most of the sunburn was lighter (Class 1) which was significantly reduced under nets. Similar trends were seen for FU. Class 0 was significantly higher for the net treatment during 2004 and the first harvest of 2005. RG only showed a significant reduction in sunburn under nets for the first harvest of 2004 due to reductions in more serious sunburn. Very little sunburn was recorded on RG during 2005. No significant differences in sunburn were observed for CP during either season. High levels of light browning in 2005 (first harvest) were not reduced under nets.

Of all the cultivars (Tables 3, 4, 5, 6) only FU showed significant effects of netting on fruit fresh mass, with increases in fruit mass under the net treatment for both harvests in 2004 (Table 6). Netting significantly increased the number of unviable seeds during 2005 for both harvests of RG (Table 3) and the first harvests of FU (Table 6) and BR (Table 5) but the incidence was low.

The data collected during both seasons on ground colour for BR (Table 5) showed a significantly lower chart value, thus greener colour, under the net treatment during both seasons. Blush colour for BR showed significantly higher chart values, thus reduced blush colour, during 2005 in the net treatment. Although ground colour was unaffected by netting for FU, red coloration was significantly less during both seasons at the second harvest (Table 6). RG showed significant differences in ground colour during 2004 for the second harvest where fruit from the non-net treatment had greener ground colour. The opposite was found at the first harvest during 2005. No significant differences were found in blush colour for RG. CP showed no significant differences over the two seasons in ground or blush colour (Table 4).

During both seasons, fruit firmness for FU was significantly reduced under nets (Table 6). Significant reductions were also found during 2004 for CP where fruit from the net treatment were firmer than fruit from non netted trees. The opposite was found during 2005 at first harvest (Table 4). BR and RG showed no changes in fruit firmness (Tables 3, 5).

TSS was lower in most cultivars during both seasons under the net treatment. In BR, TSS was significantly reduced during both seasons for every harvest (Table 5). FU showed significant reductions in TSS for both harvests in 2004 and for the first harvest in 2005 (Table 6). In RG, TSS was significantly reduced under net treatments during both harvests of 2005 (Table 3). No significant differences were found in TSS for CP (Table 4). Of all the cultivars only BR showed significant differences in TA which was lower under the net treatment, compared to the control (Table 5).

Significant difference in starch breakdown at the first harvest was found for BR (Table 5) and CP (Table 4) during 2004 with RG showing a similar trend. Fruit from the net treatments had a higher rate of starch breakdown than fruit from the non-netted treatments.

During 2004 a significant decrease in *Fusicladium pyrorum* damage was found for BR, FU, RG and CP under the net treatment compared to the controls (Tables 3, 4, 5, 6). Significant decreases were also found at first harvest for RG (Table 3) and CP (Table 4) during 2005.

Effects of crop load treatments

Fruit mass decreased with an increase in crop load for all the cultivars except CP (Fig. 1-4). Significant interaction between net and thinning treatments was found for RG during 2005 at the second harvest (Fig. 1d), indicating a faster decrease in fruit mass with increasing cropload under the net treatment compared to the non-netted treatments. A similar but non-significant trend was found for 'Fuji' (2005 first harvest, Fig. 2c, e). 'Braeburn' also showed a significant reduction in fruit mass with decreased crop load (2005 first harvest, Fig. 3b,e second harvest 2004, Fig. 3c, f).

The main effects of thinning treatments on other fruit quality parameters are shown in Tables 7, 8, 9 and 10. Total % sunburn class was only significantly affected by thinning treatments in FU (2004 second harvest, Table 8), with fruit on trees thinned to 140% (highest crop load) having more sunburn than those on trees thinned to 60% (lowest crop load). Fruit ground colour was significantly different between thinning treatment for BR, FU and CP. During 2004, BR fruit from the 120% and 140% crop load treatments had greener ground colouration than the 60% crop load (Table 7). During 2005, fruit from the 140% crop load treatments had greener ground colour than the 60% crop load. In FU (2004) the 100, 120 and 140% crop load treatments had greener ground colour than the 60% crop load (Table 8). CP fruit had greener ground colour under the 120% compared to the 80% treatment during 2004 (Table 10). Blush colour was only significantly affected in RG (Table 9) during 2005 (second harvest) with the 120% crop load treatment better coloured than the 60% crop load treatment.

Fruit firmness was significantly different between thinning treatments in all cultivars, but not all harvests. BR and CP (Tables 7, 10) had significant differences in fruit firmness during 2004 with the fruit from the 60% crop load for BR and the 80% crop load for CP having the highest fruit firmness. RG showed significant differences during 2004 and 2005 at the second harvest with fruit from the 100% crop load (2004) and from the 140% crop load (2005) being the firmest (Table 9). FU showed significant differences in fruit firmness only during 2005 at the first harvest, with the fruit from the 140% crop load being the firmest (Table 8).

TSS of BR was only significantly different in 2004 with fruit from the 60% crop load having the highest TSS (Table 7). RG had significantly different TSS values during 2005 at the second harvest with the highest TSS measured in the fruit of the 140% crop load (Table 9). TA, which was only measured for BR and FU during 2005, showed significant differences for the first harvest of BR and the second harvest of FU. In both cases TA was the highest in

the fruit from the 60% crop load. Starch breakdown was only significantly different for the second harvest during 2005 for RG, with the 60% crop load having the highest breakdown.

DISCUSSION

This study showed that netting has a significant effect on the lowering of sunburn. Sunburn is divided into two categories (Schrader et al., 2003): sunburn necrosis, caused by thermal death of epidermal and sub-epidermal cells when the peel reaches 52ºC or higher, and sunburn browning which is sub-lethal and results in a yellow, bronze or brown spot on the fruit skin surface when it reaches 46-49°C. It has been suggested that sunburn is caused by overheating of the fruit surface due to excessive levels of incoming solar radiation, in combination with high ambient air temperature (Wünsche et al., 2004). The installation of shade netting reduced fruit surface temperature by 4.0-5.3ºC on hot days (Chapter 4), thus reducing the incidence of fruit reaching damaging temperatures. Comparing air and fruit surface temperature with data presented in Chapter 4 with the sunburn results shows that netting did not reduce air temperature much, but fruit surface temperature and sunburn damage were reduced. This suggests that the reduction in sunburn under netting could be due to a reduction in direct sunlight, including ultraviolet, reaching the fruit. In our study, netting significantly increased the percentage of apples with no sunburn damage for 'Royal Gala', 'Fuji' and 'Braeburn'. Similar results have been reported by Middleton and McWaters (2002). No significant effect was found for 'Cripps' Pink'. There are a large number of factors that could influence sunburn incidence and give rise to the difference found in sunburn percentage between the two seasons. The occurrence of an early heat wave in the Witzenberg area gave rise to a higher sunburn incidence early in the first season.

It has been hypothesised that sunburn damage may be a response to varying factors such as high light/ultraviolet exposure and/or high fruit skin temperature. Key processes in the prevention of sunburn may include the synthesis of heat-shock proteins and ultraviolet-absorbing flavonoids, cuticular reflectance of light, epicuticular wax formation, and transpiration (Wünsche et al., 2001). Fruit, developing in shade during the early part of the season, which is exposed to sun later in the season due to tree growth, or bending of branches, tend to be more susceptible to sun damage than fruit exposed to the sun from the beginning of the season (Bergh et al., 1980). This would largely be due to the fact that fruit exposed to sun early in the growing season become better acclimated to high heat conditions than shade-grown fruit, and are thus more capable of withstanding sun damage.

'Fuji' was the only cultivar with significant differences in fruit mass, with fruit being significantly larger under the net treatment during 2004 at comparable crop loads. The increase in fruit mass under netting reported in the literature for some cultivars has been ascribed to a reduction in tree growth (vigour) and fewer fruit per tree (Wagenmakers and Tazelaar, 1999, Middleton and McWaters, 2002). Middleton and McWaters (2002) found that reduced fruit size and increased shoot growth occurred on more vigorous trees under netting compared to non-netted trees. However, in trees where the vigour of netted trees was controlled, the fruit size was increased. Early fruit growth rates have been shown to decrease by up to four times of the normal with the introduction of 60% or more shade early in the season, with shoot tip growth having priority over the fruit for assimilates (Bepete and Lakso, 1998). It is unlikely that reduced vigour in 'Fuji' under netting was responsible for increased fruit growth, rather, the vigour of 'Fuji' appeared to be greater under netting. Summer pruning mass was higher under netting (Table 1 in Chapter 3), but this growth stimulation was not reflected in trunk circumference growth (Table 2 in Chapter 3).

A higher crop load can also result in reduced individual fruit mass (Link, 2000). However, 'Smoothee' had an increase of about 5 mm in fruit size when covered by various netting types ranging from 15 to 30% shade, in spite of a heavier fruit load (Shahak et al., 2004). In these trials, net CO_2 assimilation rates (A) were higher under the nets. In 'Fuji', A was higher in trees under netting compared to trees in the open during January 2005 (Table 5 in Chapter 4). Soil water the increased fruit mass in 'Fuji' under comparable crop loads could also be due to higher soil water content measured during the 2004/05 season for FU (D. van Zyl, personal communication).

A well-coloured fruit is a prerequisite for the export of red or blushed cultivars to foreign markets. Blush colouring of fruit is dependent on the amount of sunlight the fruit receives and high light levels with adequate temperatures will result in good blush colouration of the fruit skin. Producing well coloured fruit without sunburn is, however, a challenge for apple growers. In this study it was found that fruit blush colour was reduced significantly but still remaining within export requirements, under the netted treatments for 'Braeburn' during 2005 at both harvests. Blush colour for 'Fuji' was significantly reduced to an unacceptable level for export under the net treatments at the second harvest during both seasons.

Past studies showed red colouration of 'Topred' (fully red) fruit to be significantly better under various coloured netting types ranging from 15 – 30% shade, than for fruit grown in full sunlight (Shahak et al., 2004). Fruit colouring of 'Jonathan' grown under 20% black netting was, on the other hand, less extensive than the control. The same cultivar grown under

white netting, which reduced photosynthetic photon flux density up to 8%, showed no difference in red colour compared to the control (Gardner and Fletcher, 1990). Middleton and McWaters, (2002) suggest that some of the poor colouring of netted fruit could be ascribed to excess vigour of trees, with excessive shoot growth shading fruit within the canopy. They found that where vigour was well controlled, the colour of 'Hi Early' apples under black netting was consistently better than the colour of fruit from uncovered trees. Shaded 'Fuji' from net covered trees also showed superior colour to apples from uncovered trees (Middleton and McWaters, 2002). Guerrero et al. (2002) found that a reduction of 37% in photosynthetic photon flux density caused by black netting had a reducing effect on final fruit colour. The colour of netting also seems to have an effect on the blush colouration of the fruit (Stampar et al., 2001). As seen in Chapters 6 of this thesis black netting causes greater reductions in PPFD than blue and grey netting. It was shown that white netting improved blush colour on 'Elstar' and 'Jonagold' and that black netting reduced blush in 'Jonagold' (Stampar et al., 2001). Scott (1989) also found that blush colour was reduced under black netting for 'Jonathan' apples.

The reduction in blush colour as found on 'Fuji' and 'Braeburn' could be ascribed to increased vegetative growth (see Chapter 3) and the reduction in direct sunlight reaching the fruit. The significant reduction in blush colour of these two cultivars during the second harvest could be due to the higher percentage of fruit harvested from within the canopy compared to the first harvest when fruit are preferentially picked on colour from the outside of the canopy.

Although quality parameters such as size and red colouration as well as fruit damage such as sunburn are important factors when considering fruit for export, maturity parameters such as firmness, ground colour, TSS, TA and starch content, are important when determining harvest dates or fruit development. In this study, fruit firmness as a response to netting was found to be inconsistent between cultivars. 'Braeburn' and 'Royal Gala' showed no trend in fruit firmness while 'Fuji' fruit were less firm under netting during both seasons. 'Cripps' Pink' fruit were significantly firmer under net treatment during the first harvest of 2004. During the first harvest of 2005, fruit from the net treatment were less firm. Past studies have shown that apples harvested from under netted areas tend to be slightly firmer (Gardner and Fletcher, 1990) than from non-netted trees. This was confirmed by Widmer (1997) who found 'Jonathan' apples grown under netting to be firmer than uncovered apples. Scott (1989) and Wagenmakers and Tazelaar (1999), however, found netting to have no effect on fruit firmness. A possible explanation for increased fruit firmness for certain cultivars could be delayed maturation, as suggested by Widmer (1995) and Middleton and McWaters (2002).

When harvesting fruit from netted areas, maturity levels should be noted to ensure harvesting at the optimum maturity stage.

Total soluble solids (TSS) were reduced under the net treatment for all the cultivars, confirming the results of Wagenmakers and Tazelaar (1999). Stampar et al. (2001) found the opposite trend, for 'Elstar', but also found lower TTS in covered trees for 'Jonagold'. These results also correspond with the findings of Middleton and McWaters (2002) and Scott (1989), showing TSS for 'Granny Smith' to be up to 1.5% lower under netting compared to the outside. The TSS of all the cultivars in this study over both seasons were, however, still above the minimum requirements for export. Berrit and Konishi (1997) found a positive curvilinear relationship between sunlight levels and TSS. Significant reductions in titratable acidity (TA) occurred for 'Braeburn' under the net treatment. Stampar et al. (2001) showed that TA was significantly higher under white netting for 'Elstar' and found no difference between netted and uncovered trees for 'Jonagold'. Widmer (1997) found that 'Jonagold' had higher acidity under netting, but Wagenmakers and Tazelaar (1999) reported that netting had no effect on the acidity of 'Elstar'. TSS is lower in immature fruit than in mature fruit and TA decreases with increasing maturity. Fruit maturity will thus influence TSS and TA at harvest as found by Widmer (1995) and Middleton and McWaters (2002).

It is well documented that starch levels in apple fruit decrease as fruit mature (Fan et al., 1995). Fruit starch content is used in combination with other maturity indices to determine maturity of fruit and time of harvest. In this study it was found that starch breakdown was significantly higher under nets during the first season for 'Braeburn' and the first harvest of 2004 in 'Cripps' Pink'. This agrees with the findings of Scott (1989) who also found starch levels to be lower for 'Jonagold' under netting. However, Widmer (1995) and Middleton and McWaters (2002) found that fruit under netting showed delayed maturation. Maturity development as affected by the installation of netting thus seems to be cultivar- and sitespecific.

Fusicladium pyrorum is a fruit skin disorder characterised by lesions consisting of dark brown or black spots, which become corky with age and sometimes support mould growth at the margins. Incidence of *F. pyrorum* damage was found to be significantly reduced in most cultivars under the net treatment. The characteristic lesions are usually most numerous around the calyx-end, and if infected during the early fruit growth period, the apple could become misshaped (Snowdon, 1990). 'Braeburn', 'Fuji', 'Royal Gala' and 'Cripps' Pink' all showed significant reductions in *F. pyrorum* damage during the first season under the net treatment. During the second season only 'Royal Gala' and 'Cripps' Pink' showed

significant reductions under the netted treatment. Possible explanations for this finding could be the reduction in air movement found under netted areas as noted by Middleton and McWaters (2002). *F. pyrorum* produces asexual spores on infected fruit, which are then dispersed by rain, irrigation splash and wind blown droplets. Chemical control, as done on the trees in this study, might also be more effective under netting with the spray being 'trapped' under the netting, ensuring better plant coverage.

Fruit thinning is probably the most important technique in apple production for improving the fruit quality parameters, size and colour in particular (Looney, 1993). Crop load is a key cultural component of final fruit quality, and thus of managing the risks associated with achieving commercial requirements for fruit size, consumer-based quality attributes, and freedom from disorders (Wünsche and Ferguson, 2005). Environmental factors important for setting a high potential yield are moderate ambient temperatures, high light energy input and a long growing season. Netting has a direct effect on light intensity and could influence potential crop load, making thinning an important factor in orchard management. Link (2000) pointed out that a major difficulty of thinning is to find the optimal thinning intensity. In adjusting crop load to produce fruit meeting market requirements, fruit often will not yield sufficient blush colour in certain cultivars, and when crop load is optimised for excellent fruit colour, too many oversized fruit susceptible to physiological disorders could be harvested (Link, 2000). Finding the optimum crop load is thus of great importance to the producer. If fruit demand for assimilates early in the season exceeds carbohydrate availability, the resulting supply limitation leads to "non recoverable" decreased fruit growth, resulting in fewer fruit cells and reduced final fruit size at harvest and/or increased fruit abscission (Wünsche and Ferguson, 2005). By increasing or reducing the fruit load of a tree and thereby altering the carbon availability to the fruit and shoots we could thus expect fruit quality to be affected. Trees covered with netting are less stressed, and have stronger growth which could enable the trees to possibly carry higher crop loads without forfeiting fruit quality.

The results of this study (Tables 7, 8, 9, 10) showed that for most of the fruit quality parameters there were very few significant differences between various crop loads. The effect of crop load on sunburn was only significant in 'Fuji' (Table 8), with the 140% crop load trees showing significantly more sunburn than the lower crop loads during the second harvest 2004. This could possibly be due to lower leaf to fruit ratios. Higher crop loads are associated with higher tree demand for water and a greater risk of water supply deficits to individual fruit, making them more susceptible to sunburn.

Fruit well supplied with carbohydrates attain good colour and in accordance with this thinning to lower crop loads should result in better coloured fruit (Wünsche and Ferguson, 2005). It was, however found that blush colour was only affected by crop load in 'Royal Gala', showing decreased colour with decreasing crop load. The trend was, however, weak and of no commercial importance. Firmness tended to increase in all the cultivars except 'Fuji' as the crop load decreased. Although TSS differed significantly between different crop loads in 'Braeburn' and 'Royal Gala', the trends were inconsistent. The same was found for TA and rate of starch breakdown. Fruit mass increased consistently with decreasing crop load as expected (Fig 1,2,3,4). This could be explained simply by the reduction in competition for assimilates between the fruit.

The results of this study show that netting has an effect on apple fruit quality. The severity of the effect does, however, differ between cultivars. Sunburn, which is one of the prominent reasons for the installation of protective netting in the Witzenberg area, was proven to be significantly reduced particularly in 'Fuji' and 'Braeburn' by the installation of netting. Netting could be a usable technology for 'Braeburn' and 'Fuji', but blush colour development could be problematic for 'Fuji', which shows vigorous growth and commercially important reductions in colour of fruit. Trees covered by netting do, however, seem capable of carrying high crop loads. Whether the reduction in sun-damaged fruit justifies the substantial installation cost of netting and loss of packout due to poorer blush remains debatable. Further studies into the economic viability of netting are suggested.

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Table 1: Chemical thinning program as used by Vastrap farm management on four blushed apple cultivars covered by 15% black shade netting during the 2003/04 and 2004/05 seasons. NAA = naphthaleneacetic acid; carbaryl = 1-naphthyl-*N*-methylcarbamate; ATS = ammonium thiosulphate. (As per 100l)

	2003/04		2004/05	
Trees covered by protective netting				
'Fuji'	17/10/2003	5ml NAA	14/10/2004	15ml NAA + 90 Carbaryl
	07/11/2003	90g Carbaryl	21/10/2004	15ml NAA + 90 Carbaryl
'Royal Gala'	20/10/2003	5ml NAA	21/10/2004	15ml NAA + 90 Carbaryl
	07/11/2003	90g Carbaryl		
'Cripps' Pink'	07/11/2003	90g Carbaryl	21/10/2004	15ml NAA + 90 Carbaryl
'Braeburn'	27/10/2003	90g Carbaryl	21/10/2004	90 Carbaryl
Uncovered trees.				
'Fuji'	17/10/2003	1% ATS	10/10/2004	1% ATS
	18/10/2003	15 ml NAA	11/10/2004	15ml NAA + 90g Carbaryl
	22/10/2003	15ml NAA + 90g Carbaryl	14/10/2004	15ml NAA + 90g Carbaryl
	03/11/2003	15ml NAA + 90g Carbaryl	21/10/2004	15ml NAA + 90g Carbaryl
		07/11/2003 + 90g Carbaryl		
		11/11/2003 + 90g Carbaryl		
'Royal Gala'		20/10/2003 + 11ml NAA	11/10/2004	15ml NAA
	27/10/2003	11ml NAA + 90g Carbaryl	21/10/2004	15ml NAA + 90g Carbaryl
	03/11/2003	15ml NAA + 90g Carbaryl		
	11/11/2003	90g Carbaryl		
'Cripps' Pink'	21/10/2003	5ml NAA	12/10/2004	Top half of tree 15ml NAA + 90g Carbaryl, Bottom half of tree, 11ml NAA + 90g Carbaryl
	29/10/2003	Top Half of tree, 11ml NAA + 90g Carbaryl, Bottom half of tree, 5ml NAA + 90g Carbaryl.		
	10/11/2003	90g Carbaryl	21/10/2004	15ml NAA + 90g Carbaryl
'Braeburn'	10/10/2003	5ml NAA	30/09/2004	Top half of tree 11ml NAA Bottom half of tree 5ml NAA
	27/10/2003	90g Carbaryl	12/10/2004	90g Carbaryl
			21/10/2004	90g Carbaryl

Table 2: Percentage sunburn damage during 2003/04 and 2004/05 (Class 0 = no sunburn, Class 1 = slight skin browning, Class 2 = severe skin browning, Class 3 = severe sunburn necrosis)

		Class 0	Class 1	Class 2	Class 3
'Royal Gala' 2004 harvest 1	Net	75.4	13.8	7.5	3.3
	No net	69.1	15.7	10.3	5.0
	P-value	0.0323	0.2539	0.0084	0.1586
'Royal Gala' 2004 harvest 2	Net	87.3	6.9	4.1	1.7
	No net	86.4	6.7	5.2	1.6
	P-value	0.7584	0.9302	0.4592	0.8593
'Royal Gala' 2005 harvest 1	Net	95.2	4.3	0.4	0.0
	No net	94.2	4.1	1.4	0.5
	P-value	0.3107	0.4119	0.1424	0.2865
'Royal Gala' 2005 harvest 2	Net	97.5	1.3	1.2	0.0
	No net	94.9	2.9	1.5	0.7
	P-value	0.1663	0.2474	0.7089	0.1895
'Fuji'2004 harvest 1	Net	89.9	10.0	0.1	0.0
	No net	70.9	24.5	2.9	2.0
	P-value	0.0416	0.0895	0.0090	0.0531
'Fuji' 2004 harvest 2	Net	99.3	0.5	0.1	0.0
	No net	93.5	2.4	1.6	2.5
	P-value	0.0096	0.0519	0.0121	0.0176
'Fuji' 2005 harvest 1	Net	58.1	29.7	9.5	2.9
	No net	41.3	32.7	18.8	6.5
	P-value	0.0056	0.4895	0.0793	0.0227
'Fuji' 2005 harvest 2	Net	84.9	13.1	1.3	0.5
	No net	73.0	19.5	4.9	2.6
	P-value	0.0606	0.1172	0.0937	0.0760
'Braeburn' 2004 harvest 1	Net	94.7	4.8	0.5	0.0
	No net	72.1	14.9	7.3	5.6
	P-value	0.0165	0.0891	0.0094	0.0067
'Braeburn' 2005 harvest 1	Net	59.1	38.8	1.6	0.5
	No net	46.9	48.0	4.0	1.1
	P-value	0.0122	0.0357	0.1256	0.1747
'Braeburn' 2005 harvest 2	Net	84.4	13.1	1.6	0.8
	No net	74.7	23.9	1.6	0.1
	P-value	0.0592	0.0144	1.0000	0.3165
'Cripps' Pink' 2004 harvest 1	Net	100.0	0.0	0.0	0.0
	No net	99.3	0.7	0.0	0.0
	P-value	0.1747	0.1747		
'Cripps' Pink' 2005 harvest 1	Net	67.2	30.0	1.3	0.7
	No net	69.6	27.3	2.3	0.3
	P-value	0.7550	0.8793	0.1688	0.6889
'Cripps' Pink' 2005 harvest 2	Net	92.3	6.7	1.0	0.0
	No net	92.0	4.3	2.0	0.7
	P-value	0.7412	0.2875	0.2031	0.3632

Table 3: 'Royal Gala' fruit quality parameters as affected by 20% black netting at the end of the 2003/04 and 2004/05 seasons.

	Mass (g)	Un-viable seed (%)	Ground colour (chart)	Blush colour (chart)	Firmness (KPa)	TSS (%)	Starch breakdown (%)	*F. pyrorum* (%)
2004 harvest 1								
Net	127.1		3.6	3.0	8.42	11.7		7.2
No net	122.9		3.6	2.5	8.34	11.7		28.9
P-value	0.1637		0.9090	0.0965	0.5282	1.0000		0.0006
P- Net*thin	0.1844		0.9730	0.0965	0.7905	0.6621		0.4995
2004 harvest 2								
Net	135.2		4.0	3.2	7.78	12.4	32.4	4.8
No net	133.3		3.8	3.5	7.79	12.0	23.7	34.1
P-value	0.5131		0.0212	0.3316	0.9334	0.1088	0.0609	0.0002
P- Net*thin	0.0596		0.5734	0.5702	0.5374	0.3994	0.4491	0.6304
2005 harvest 1								
Net	117.7	1.2	3.7	3.2	8.84	14.0	53.5	15.4
No net	121.1	0.7	3.8	3.2	9.05	14.7	50.7	12.5
P-value	0.0801	0.0095	0.0043	0.6573	0.2544	0.0228	0.3300	0.0461
P- Net*thin	0.2887	0.7455	0.6877	0.1498	0.6992	0.8521	0.3421	0.2506
2005 harvest 2								
Net	127.6	1.1	3.8	4.0	8.66	14.2	45.1	12.7
No net	132.4	0.4	3.7	3.7	9.05	14.8	30.8	18.0
P-value	0.2860	0.0024	0.0849	0.4551	0.1114	0.0015	0.1000	0.1952
P- Net*thin	0.0197	0.3791	0.2087	0.6634	0.0152	0.3555	0.4501	0.4245

Table 4: 'Cripps' Pink' fruit quality parameters as affected by 20% black netting at the end of the 2003/04 and 2004/05 seasons.

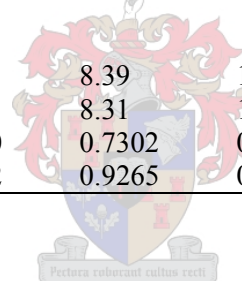|	Mass (g)	Un-viable seed (%)	Ground colour (chart)	Blush colour (chart)	Firmness (KPa)	TSS (%)	Starch breakdown (%)	*F. pyrorum* (%)
2004 harvest 1								
Net	151.7		3.9	4.1	8.05	13.2	61.2	0.7
No net	151.1		3.8	5.1	7.64	13.2	48.9	5.0
P-value	0.8446		0.1348	0.1974	0.0046	0.9681	0.0024	0.0104
P- Net*thin	0.7513		0.6856	0.7115	0.7099	0.7620	0.2400	0.3519
2005 harvest 1								
Net	156.6	0.2	3.2	10.8	8.46	15.6	43.4	7.7
No net	138.4	0.2	3.3	10.8	8.78	16.1	37.4	23.3
P-value	0.1095	0.2095	0.1256	0.9602	0.0102	0.0499	0.1945	0.0126
P- Net*thin	0.0516	0.7854	0.8467	0.4234	0.5113	0.1711	0.1752	0.8138
2005 harvest 2								
Net	163.5	0.0	3.9	10.0	8.39	14.1	59.5	2.7
No net	157.7	0.2	4.0	9.9	8.31	16.3	52.0	12.3
P-value	0.3561	0.2236	0.3246	0.8560	0.7302	0.1107	0.1403	0.1737
P- Net*thin	0.4743	0.9259	0.9580	0.8462	0.9265	0.4161	0.1457	0.8669

Table 5: 'Braeburn' fruit quality parameters as affected by 20% black netting at the end of the 2003/04 and 2004/05 seasons.

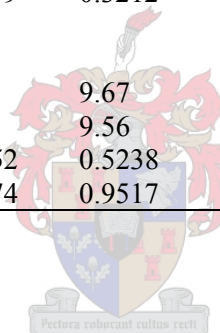|	Mass (g)	Un-viable seed (%)	Ground colour (chart)	Blush colour (chart)	Firmness (KPa)	TSS (%)	TA (%)	Starch breakdown (%)	*F .pyrorum* (%)
2004 harvest 1									
Net	146.9		3.7	1.5	7.85	13.1		56.4	1.6
No net	145.7		3.9	1.1	7.94	14.7		50.3	12.7
P-value	0.7570		0.0177	0.1436	0.2494	0.0001		0.0398	0.0077
P- Net*thin	0.3711		0.0157	0.6195	0.9982	0.0005		0.3366	0.7737
2004 harvest 2									
Net	142.0	0.7	2.7	1.6	10.02	13.5	0.515	19.1	1.7
No net	146.4	0.3	3.0	1.3	9.80	14.2	0.629	18.8	3.2
P-value	0.6089	0.0072	0.0031	0.0488	0.2984	0.0025	0.0012	0.9034	0.3992
P- Net*thin	0.5283	0.7042	0.5395	0.1739	0.3212	0.1894	0.7444	0.2558	0.7620
2005 harvest 2									
Net	136.3	1.0	2.4	2.1	9.67	13.2	0.554	22.8	0.5
No net	143.6	0.5	2.8	1.6	9.56	13.8	0.608	21.7	2.7
P-value	0.0720	0.0554	0.0008	0.0252	0.5238	0.0128	0.0030	0.6220	0.0723
P- Net*thin	0.7165	0.0339	0.3925	0.9474	0.9517	0.3238	0.7033	0.3339	0.7908

Table 6: 'Fuji' fruit quality parameters as affected by 20% black netting at the end of the 2003/04 and 2004/05 seasons.

	Mass (g)	Un-viable seed (%)	Ground colour (chart)	Blush colour (chart)	Firmness (KPa)	TSS (%)	TA (%)	Starch breakdown (%)	*F.pyrorum* (%)
2004 harvest 1									
Net	152.6		3.1	2.7	7.34	14.0			0.4
No net	134.8		3.1	2.8	7.59	15.6			16.8
P-value	0.0042		0.8010	0.7939	0.0584	0.0049			0.0181
P- Net*thin	0.2696		0.5166	0.3305	0.4705	0.7460			0.6631
2004 harvest 2									
Net	139.1		3.0	6.0	7.10	12.9			0.5
No net	113.8		3.0	4.4	7.49	15.3			15.3
P-value	0.0010		0.7950	0.0009	0.0012	< 0.0001			0.0027
P- Net*thin	0.0732		0.5093	0.2591	0.1470	0.3052			0.5800
2005 harvest 1									
Net	132.0	0.3	2.7	4.0	8.50	15.9	0.304	55.8	4.7
No net	149.2	0.1	3.0	3.5	8.95	17.4	0.322	50.8	3.6
P-value	0.0181	0.0182	0.0698	0.1631	0.0583	0.0030	0.1713	0.1032	0.6398
P- Net*thin	0.0516	0.3713	0.3566	0.9663	0.0023	0.1078	0.8589	0.9789	0.5032
2005 harvest 2									
Net	113.0	0.4	2.5	5.6	8.56	15.7	0.343	65.9	0.3
No net	115.3	0.3	2.8	4.7	8.86	17.0	0.329	61.5	2.6
P-value	0.4989	0.3660	0.1078	0.0129	0.0410	0.0855	0.2097	0.2010	0.1571
P- Net*thin	0.6877	0.2585	0.5982	0.9692	0.2653	0.8837	0.0167	0.0477	0.5814

Table 7: 'Braeburn' fruit quality parameters as affected by various treatments (crop load) at the end of the 2003/04 and 2004/05 seasons.100% thinning represents optimum crop load.

		60		80		Thinning % 100		120		140		P-value
Ground colour (Chart values)												
	2004	4.03	a	3.84	ab	3.80	ab	3.61	b	3.58	b	< 0.0001
	2005 Harvest 1	2.93	ab	2.91	abc	3.01	a	2.81	bc	2.72	c	0.0013
	2005 Harvest 2	2.74	a	2.60	ab	2.50	ab	2.62	ab	2.42	b	0.0148
Blush colour (Chart values)												
	2004	1.07		1.30		1.33		1.47		1.48		0.2915
	2005 Harvest 1	1.34		1.48		1.46		1.56		1.57		0.3040
	2005 Harvest 2	1.81		1.94		1.91		1.77		2.03		0.8317
Firmness (kg)												
	2004	8.24	a	7.84	ab	7.86	ab	7.80	ab	7.73	b	0.0298
	2005 Harvest 1	9.96		9.86		10.14		9.63		9.95		0.3238
	2005 Harvest 2	9.59		9.74		9.83		9.29		9.61		0.0921
TSS[z] (%)												
	2004	14.9	a	13.8	ab	13.8	ab	13.5	ab	13.6	b	< 0.0001
	2005 Harvest 1	13.7		13.9		14.1		13.8		13.7		0.2898
	2005 Harvest 2	13.4		13.5		13.6		13.5		13.5		0.9480
TA[y] (%)												
	2004											
	2005 Harvest 1	0.617	a	0.586	a	0.581	ab	0.558	ab	0.520	b	0.0021
	2005 Harvest 2	0.630		0.594		0.586		0.563		0.530	b	0.4140
Starch[x] (%)												
	2004	53.3		53.8		49.8		53.0		56.7		0.2354
	2005 Harvest 1	19.2		18.1		19.2		20.6		17.8		0.9484
	2005 Harvest 2	24.6		22.3		17.7		25.9		20.8		0.1701

[z]TSS = Total soluble solids
[y]TA = Titratable acidity
[x]Starch = Starch breakdown percentage

Table 8: 'Fuji' fruit quality parameters as affected by various treatments (crop load) at the end of the 2003/04 and 2004/05seasons.100% thinning represents optimum crop load.

		60		80		100		120		140		P-value
						Thinning %						
Average sunburn class	2004 Harvest 1	1.21		1.19		1.17		1.23		1.23		0.3081
	2004 Harvest 2	1.01	b	1.03	ab	1.03	ab	1.08	ab	1.17	a	0.0348
	2005 Harvest 1	1.56		1.77		1.75		1.71		1.90		0.1825
	2005 Harvest 2	1.14		1.21		1.34		1.33		1.34		0.1699
Ground colour	2004 Harvest 1	3.36	a	3.29	ab	2.97	b	2.94	b	2.92	b	0.0008
(Chart value)	2004 Harvest 2	3.26	a	3.10	ab	3.02	bc	2.90	bc	2.81	c	0.0089
	2005 Harvest 1	2.77		2.98		2.98		2.84		2.69		0.1445
	2005 Harvest 2	2.75		2.67		2.70		2.64		2.46		0.1384
Blush colour	2004 Harvest 1	2.56		2.88		3.03		2.65		2.72		0.1953
(Chart value)	2004 Harvest 2	5.70		4.88		5.45		5.17		4.82		0.2830
	2005 Harvest 1	3.58		3.78		3.99		3.60		3.75		0.9733
	2005 Harvest 2	5.46		5.33		5.15		5.00		4.92		0.1652
Firmness (kg)	2004 Harvest 1	7.40		7.34		7.60		7.36		7.62		0.0813
	2004 Harvest 2	7.27		7.33		7.20		7.34		7.35		0.8338
	2005 Harvest 1	8.20	b	8.74	a	8.91	a	8.75	a	9.02	a	0.0002
	2005 Harvest 2	8.42		8.76		8.65		8.73		8.98		0.0921
TSS[z] (%)	2003/04 Harvest 1	15.1		14.9		14.8		14.7		14.5		0.5226
	2003/04 Harvest 2	14.1		14.2		14.0		14.2		14.0		0.9148
	2004/05 Harvest 1	16.2		16.7		17.0		16.4		16.9		0.2735
	2004/05 Harvest 2	16.2		16.1		16.8		16.4		16.4		0.5930
TA[y] (%)	2004 Harvest 1											
	2004 Harvest 2											
	2005 Harvest 1	0.308		0.317		0.332		0.313		0.296		0.2419
	2005 Harvest 2	0.339	ab	0.343	ab	0.353	a	0.318	b	0.327	ab	0.0242
Starch[x] (%)	2004 Harvest 1											
	2004 Harvest 2											
	2005 Harvest 1	53.9		53.4		56.2		46.9		56.1		0.4662
	2005 Harvest 2	61.2		64.1		62.2		61.7		69.3		0.1428

[z]TSS = Total soluble solids

[y]TA = Titratable acidity

[x]Starch = Starch breakdown percentage

Table 9: 'Royal Gala' fruit quality parameters as affected by various treatments (crop load) at the end of the 2003/04 and 2004/05 seasons.100% thinning represents optimum crop load.

		60		80		Thinning % 100		120		140		P-value
Ground colour (Chart value)												
	2004 Harvest 1	3.65		3.63		3.64		3.60		3.60		0.4456
	2004 Harvest 2	3.98		3.79		3.94		3.90		3.87		0.2589
	2005 Harvest 1	3.66		3.82		3.83		3.79		3.79		0.0587
	2005 Harvest 2	3.73		3.74		3.81		3.72		3.77		0.3564
Blush colour (Chart value)												
	2004 Harvest 1	2.61		2.76		3.02		2.62		2.84		0.4456
	2004 Harvest 2	3.51		3.42		3.52		3.37		2.99		0.2662
	2005 Harvest 1	3.22		3.32		3.18		3.12		3.13		0.8649
	2005 Harvest 2	4.30	a	3.83	ab	3.83	ab	3.38	b	3.89	ab	0.0445
Firmness (kg)												
	2004 Harvest 1	8.56		8.28		8.47		8.42		8.17		0.1708
	2004 Harvest 2	8.13	a	7.81	ab	7.69	b	7.70	b	7.60	b	0.0009
	2005 Harvest 1	8.90		8.98		8.88		8.79		9.18		0.3206
	2005 Harvest 2	8.96	ab	8.79	ab	8.82	ab	8.52	b	9.19	a	0.0300
TSS^z (%)												
	2004 Harvest 1	11.9		11.6		11.9		11.8		11.6		0.6368
	2004 Harvest 2	12.3		12.2		12.1		12.2		12.3		0.8516
	2005 Harvest 1	14.1		14.6		14.5		14.3		14.4		0.4976
	2005 Harvest 2	14.5	ab	14.1	b	14.6	ab	14.5	ab	14.8	a	0.0233
Starch^x (%)												
	2004 Harvest 1											
	2004 Harvest 2											
	2005 Harvest 1	46.4		49.2		54.3		59.1		51.4		0.0665
	2005 Harvest 2	34.2		34.9		37.2		43.7		39.8		0.2525

^{z}TSS = Total soluble solids

^{x}Starch = Starch breakdown percentage

Table 10: 'Cripps Pink' fruit quality parameters as affected by various treatments (crop load) at the end of the 2003/04 and 2004/05 seasons.100% thinning represents optimum crop load.

		Thinning % 80		120		P-value
Ground colour (Chart value)						
	2004	3.89	a	3.72	b	0.0210
	2005 Harvest 1	3.20		3.27		0.5252
	2005 Harvest 2	3.84		4.00		0.0823
Blush colour (Chart value)						
	2004	5.05		4.11		0.2825
	2005 Harvest 1	10.94		10.70		0.3167
	2005 Harvest 2	10.39		9.55		0.1443
Firmness (kg)						
	2004	8.00	a	7.69	b	0.0347
	2005 Harvest 1	8.67		8.54		0.4472
	2005 Harvest 2	8.25		8.45		0.3694
TSS[z] (%)						
	2004	13.5		12.9		0.0723
	2005 Harvest 1	15.9		15.7		0.3090
	2005 Harvest 2	15.8		14.6		0.4096
Starch[x] (%)						
	2004	55.4		54.7		0.8575
	2005 Harvest 1	43.3		38.6		0.0494
	2005 Harvest 2	55.6		55.9		0.9100

[z]TSS = Total soluble solids
[x]Starch = Starch breakdown percentage
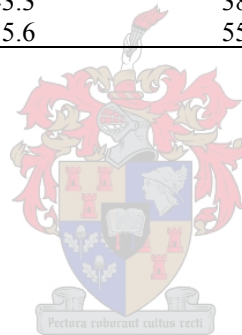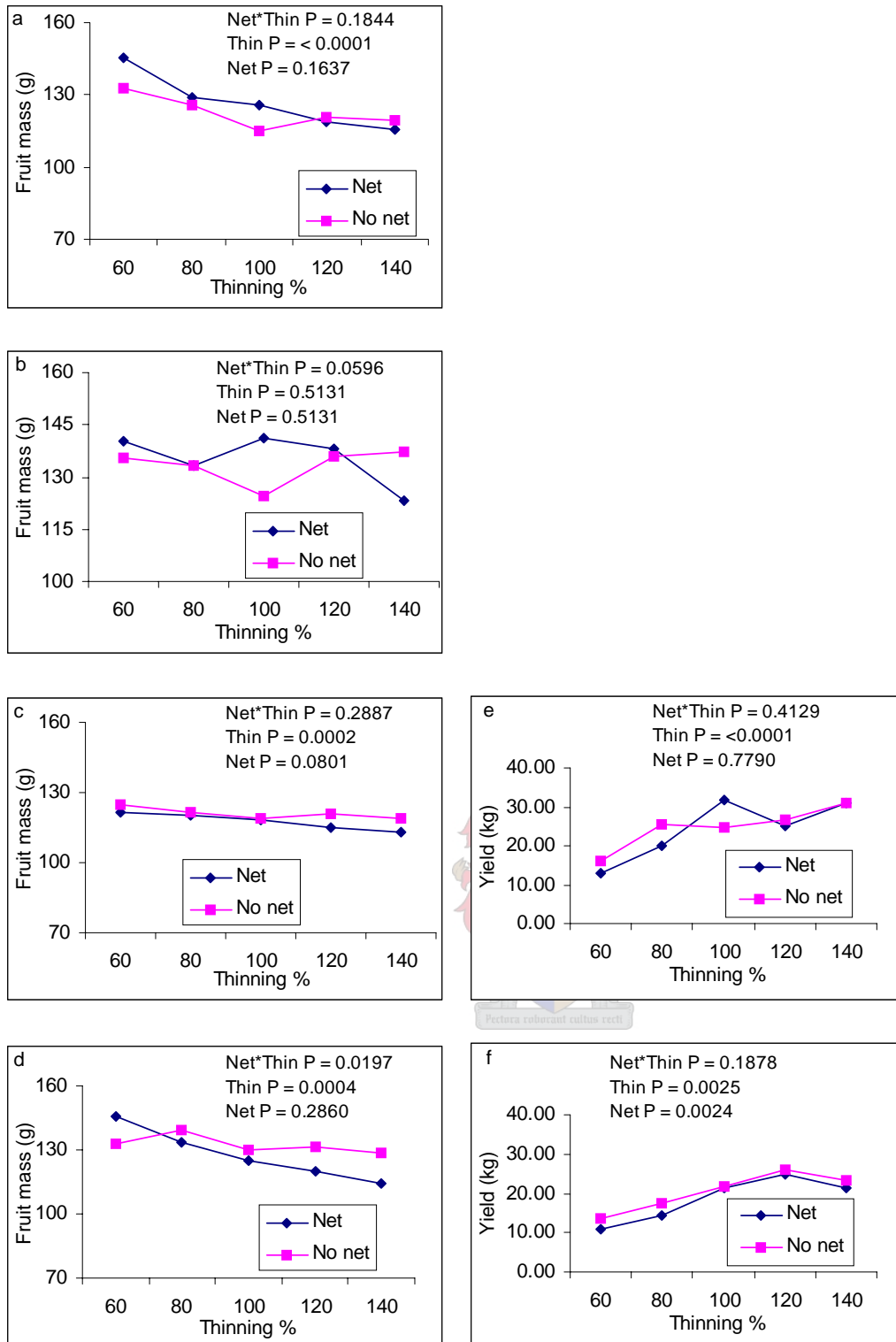
Figure 1: Interaction of fruit mass and crop load for 'Royal Gala' between thinning treatments and net or no net treatments and total crop load a: 2004 harvest 1, b: 2004 harvest 2, c: 2005 harvest 1, d: 2005 harvest 2, e: total yield 2004, f: total yield 2005.
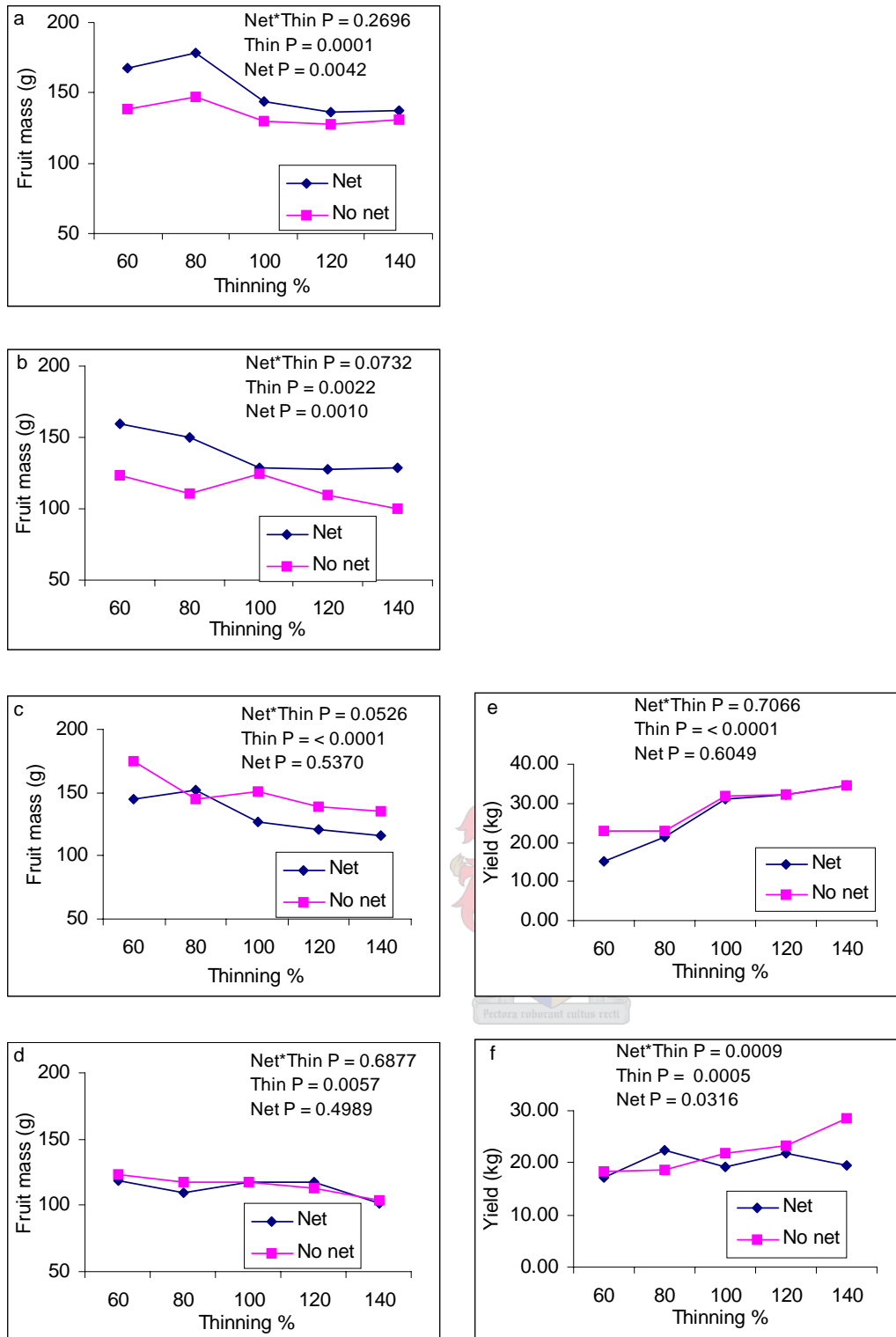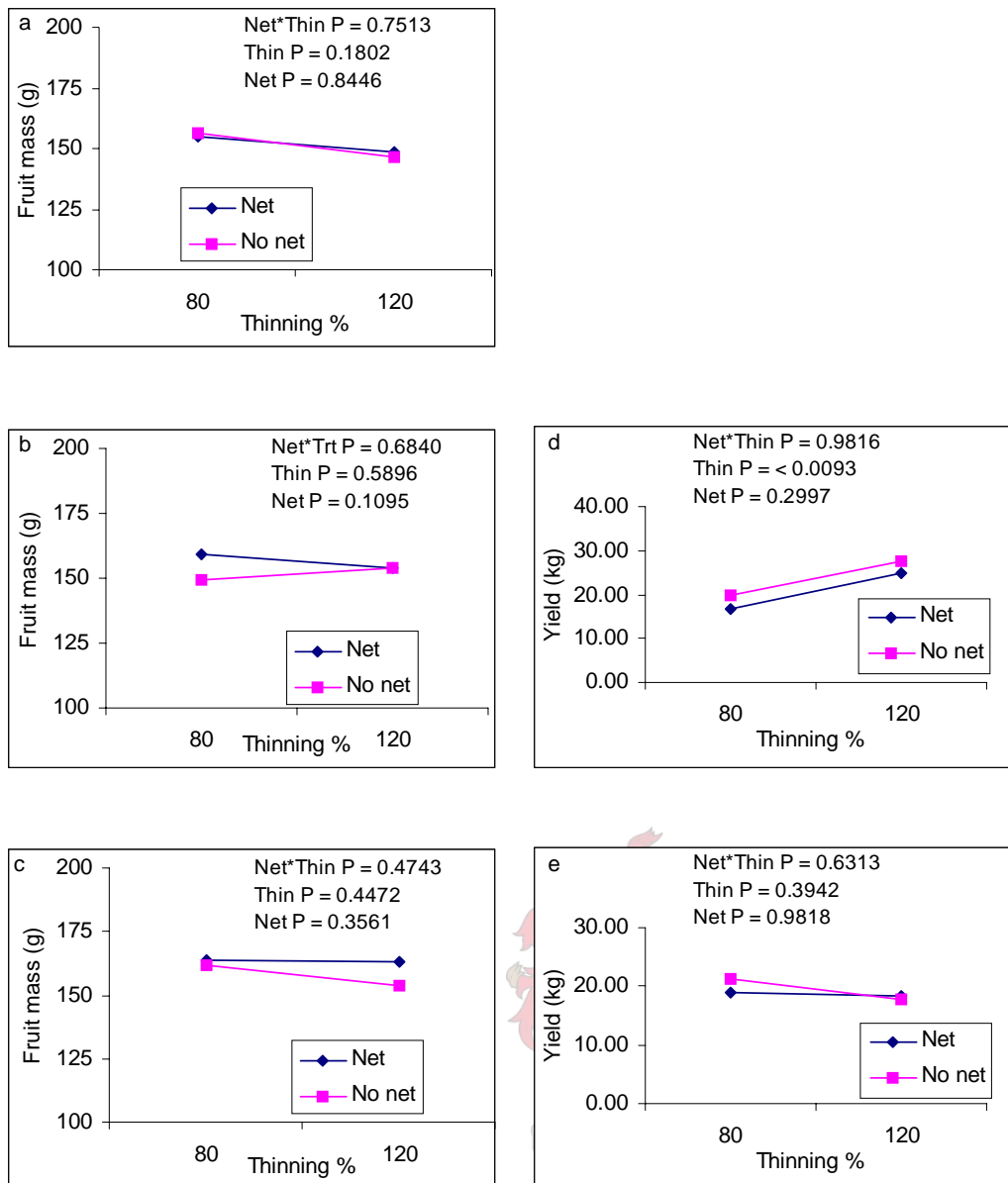
Figure 2: Interaction of fruit mass and crop load for 'Fuji' between thinning treatments and net or no net treatments and total crop load a: 2004 harvest 1, b: 2004 harvest 2, c: 2005 harvest 1, d: 2005 harvest 2, e: total yield 2004, f: total yield 2005.
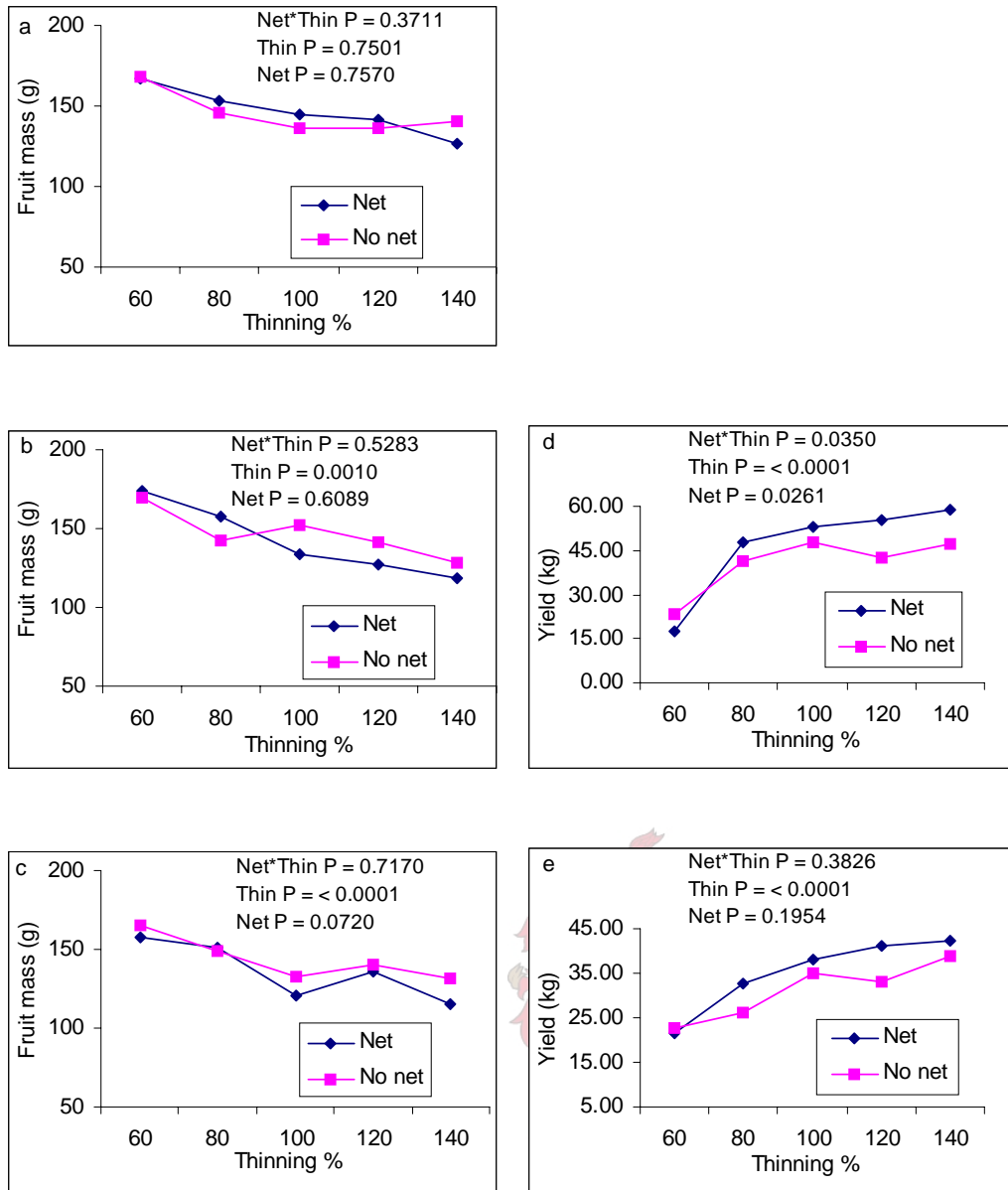
Figure 3: Interaction of fruit mass for 'Braeburn' between thinning treatments and net or no net treatments and total crop load a: 2004 harvest 1, b: 2005 harvest 1, c: 2004 harvest 2, d: total yield 2004,e: total crop load 2005.

Figure 4: Interaction of fruit mass for 'Cripps' Pink' between thinning treatments and net or no net treatments and total crop load. a: 2004 harvest 1, b: 2005 harvest 1, c: 2005 harvest 2, d: total yield 2004, e: total yield 2005.

CHAPTER 3 – Vegetative growth and reproductive potential of four blushed apple cultivars grown under shade netting.

ABSTRACT

The relationship between vegetative and reproductive growth is an important factor in the production of high volumes of quality apple fruit. During this study the influence of 20% black shade netting, in combination with five different crop loads, on vegetative growth and reproductive bud development of 'Braeburn', 'Royal Gala', 'Fuji' and 'Cripps' Pink' was determined. All cultivars showed a significant increase in summer pruning mass under netting, although in some cases this was statistically marginal (P<0.10). This increase was most likely due to the topping of the trees to prevent them from growing into the netting. 'Cripps' Pink' showed interaction for summer pruning mass between net and thinning treatments, with the 80% crop load treatments having higher pruning mass under the netting than the 120% crop load treatment. Only 'Braeburn' had higher percentage trunk growth under the netting. Reproductive bud development was better during 2004 under the netting for 'Braeburn', 'Cripps' Pink' and 'Royal Gala' and reduced during 2005 for 'Royal Gala' and 'Fuji'. During 2004, reproductive bud percentages for 'Braeburn' on short shoots and new spurs were significantly higher in low crop load treatments. 'Fuji' had significantly higher reproductive bud percentages on long shoots in low crop load trees, and in 'Cripps' Pink', reproductive bud percentages were significantly higher in low crop load trees on long shoots and old spurs. During 2005, significant differences were only found in 'Royal Gala', which had higher reproductive bud percentages on the low and target crop load trees.

Keywords: Flower bud development, crop load, *Malus domestica*, shade netting, reproductive growth, vegetative growth.
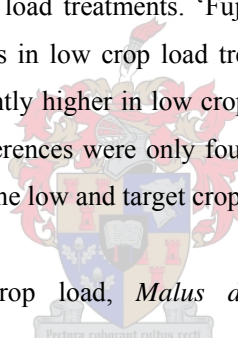
INTRODUCTION

The effect of light on growth is also found in shoot growth and development. Shoot growth on vigorous apple trees was found to be greater when covered by protective netting than on identically pruned comparable trees outside of the netted area (Middleton and McWaters, 2002). Bepete and Lakso (1998), however, found that early season shoot growth of 'Empire' apples was not significantly affected by 15, 40 and 60% shading, although variability in fruit growth was found. Sun plants such as apples in general tend to grow more vegetative when placed under reduced light conditions in order to increase the light absorbing area (Taiz and Zeiger, 2002). When covered by shade netting apple trees respond to the altered light

conditions by stimulating vegetative growth (Middleton and McWaters 2002). Shade netting causes an alteration in the ratio between red to far red light, stimulating increased vegetative growth (Salter et al., 2003).

Flower initiation refers to the change from vegetative to reproductive meristem growth and could also be affected by shade netting. Low light levels in the tree canopy can result in reduced flower-bud differentiation (Grappadelli, 2003). One reason for this could be that reduced localized photosynthetic activity, due to low light levels, may negatively affect floral differentiation due to reduced carbohydrate fluxes (Grappadelli, 2003). Flower initiation can also be inhibited by heavy cropping during the present or the previous season (Dennis, 2003). Flower initiation on the current season's shoots occurs after mid-summer and after extension growth has ceased, and continues into autumn (Forshey and Elfving, 1989). Heavy crop loads can delay, decrease or inhibit flower initiation, lowering the number of functional flowers the following spring (Wünsche and Ferguson, 2005). Fruit load must be adjusted as early as possible following bloom for thinning to be an effective measure for achieving adequate flower bud differentiation and regular cropping in apple trees (Wünsche and Ferguson, 2005). Vegetative growth and fruiting are antagonistic and flowering may be reduced in very vigorous trees or in trees that grow late in the season. Treatments that stimulate vegetative growth such as nitrogen fertilization, pruning, and irrigation may also reduce flowering (Forshey and Elfving, 1989). Due to the effect that crop load has on fruit quality and the link between reproductive and vegetative growth (Byers, 2003), fruit and flower thinning is commercially practised in order to maximize crop value by optimising marketable fruit sizes, yields, fruit colour, shape and quality, as well as to promote return bloom and tree growth and maintain tree structure (Byers, 2003).

The amount of light intercepted by the apple tree determines the amount of assimilates available for growth and production of flower buds and fruit (Grappadelli, 2003). With a reduction in available light and allocation of available assimilates into vegetative growth we could expect a decline in flower and fruit formation for trees covered by shade netting due to competition between sinks (shoots, fruit and buds), as pointed out by Wünsche et al. (2000). Bepete and Lakso (1998) also state that shoot growth has priority over fruit growth for allocation of carbohydrates in light-limited conditions early in the season. Wünsche et al. (2000) found that leaf area exposed to direct light as well as the percentage tree area intercepting light increased linearly as crop load decreased. Byers et al. (1990) found that shading trees for four days with 92% polypropylene shade material reduced fruit set by about 50%. Large crop loads also negatively affect return bloom by forcing trees into a rest year after large crops the previous year (Byers, 2003). The establishment of optimum thinning and

fruit bearing potential in order to avoid alternate bearing is especially important in the production of apples under protective shade netting.

The primary aim of this study was to determine if the installation of protective shade netting has a significant effect on the relationship between vegetative and reproductive growth of four blushed apple cultivars. The hypothesis was that there would be an increase in vegetative growth of trees under the shade netting, and reduced flower bud development. The secondary aim was to establish whether manipulating the crop load would alter these responses.

MATERIALS AND METHODS

Plant material

The trial was established in a commercial orchard located on the Du Toit Group farm, Vastrap, situated in the Witzenberg Valley in the Western Cape Province (33°15'S 19°15'E, 901 m altitude), and was carried out over the 2003/04 and 2004/05 growing seasons. The apple (*Malus domestica* Borkh.) cultivars Royal Gala (RG), Fuji (FU), Braeburn (BR) and Cripps' Pink (CP) grafted on M793 rootstock were planted during 1996 in a slight north-east by south-west direction with 4m x 1m spacing for RG, FU and CP and 4m x 2m spacing for BR (see Chapter 2). All trees were trained to a central leader. Standard commercial management practices for the region were followed. Micro-jet sprinklers were used for irrigation and scheduling was based on neutron moisture probe measurements. During 2005 irrigation was reduced to 40% of the normal water requirement due to drought.

Treatments and experimental design

The four cultivars were planted in blocks on either side of a gravel road with RG and FU next to each other on one side of the road, and BR and CP on the other side. Black shade/hail netting with a density of 20% was installed over the orchard in 2001 using a 45° pitched roof structure. Twelve rows of each cultivar were covered half way down the row with nets. The uncovered parts of the rows were used as control. These comprised the main treatments. Six rows of each cultivar, chosen from the inside of the netting outwards to avoid an edge effect, were chosen to use as blocks. There were 15 trees per replicate (except CP for which there were 6), and these were divided into five groups of three trees each for the thinning sub-treatments. Thinning to 60, 80, 100, 120 and 140% target crop load was performed as described in Chapter 2, where 100% represents the optimum fruit bearing potential as determined by the farm management. This was: 'Braeburn' 64.0 kg/tree, 'Fuji' 29.9 kg/tree,

'Royal Gala' 25.9 kg/tree and 'Cripps' Pink' 29.0 kg/tree. Actual yields for each treatment combination are shown in Chapter 2 (Figures 1-4).

Shoot growth estimations

In order to estimate the shoot fresh mass production of the trees during early- to mid-summer, the summer prunings of all cultivars were weighed on an individual tree basis on 16 February 2004. During 2005, no summer pruning was performed on any cultivar due to the high threat of sunburn as a result of the dry conditions that existed during the whole season. Winter prunings of BR and CP were weighed in 2004, but for various reasons data for the other two cultivars (2004) and for winter 2005 were not gathered, or the trees were not pruned. Only summer pruning results (2004) will thus be presented.

Trunk circumference measurements

At the beginning of the 2004/05 season, on 16 November 2004, the trunk circumferences of all the trees were measured at an estimated 10 cm above ground level using a soft 1.5 m nylon measuring tape. Measurements were repeated at the end of the 2004/05 season on 26 July 2005 in order to calculate the percentage stem growth that occurred during the season.

Bud analyses

Bud samples were taken during the dormant period on 4 August 2004 and 16 August 2005 from long shoots (LS, longer than 25 cm), short shoots (SS, shorter than 25 cm), old spurs (OS, spurs which have previously borne fruit) and new spurs (NS, spurs which had not yet borne fruit). Two buds from each bearing position were taken from each treatment replicate using six blocks during 2004 and four blocks during 2005. During 2005, budbreak had already taken place in 'Braeburn' and no samples were taken. Buds were taken to the laboratory where they were cut open and classified as vegetative or reproductive under a microscope using a 500x magnification.

Statistical analysis

Data was analysed using a split-plot ANOVA (P≤0.05) and the General Linear Model (GLM) procedure of SAS (SAS release 6.12P; SAS Institute, 1996, Cary, NC). Means comparisons for crop load main effects were performed using Tukey's test at P≤0.05.

RESULTS

During 2004, the amount of summer pruning that needed to be done was higher under the netting in all cultivars, significantly so (P≤0.05) in 'Fuji' and 'Cripps' Pink' (Table 1). In 'Cripps' Pink' there was significant interaction (P=0.0480) between net treatments and crop load treatments, with trees thinned to 80% crop load under nets showing greater pruning mass than trees from the other treatment combinations (Table 1). No crop load effects were seen for the other cultivars.

Absolute trunk circumferences measured at the beginning and end of the 2004/05 season did not show significant differences between net and control treatments for any of the cultivars (Table 2). There was no interaction between net treatments and crop load treatments. 'Braeburn' did, however, show significantly higher percentage trunk growth under the nets during 2004/05 (Table 2), and trunk growth was significantly higher in the 80% crop load trees (3.35%) compared to the 100 (1.76%) and 120% (2.05) crop load trees. No crop load effects on trunk growth were seen for the other cultivars.

There was no significant interaction between net and crop load treatments with respect to percentage reproductive buds. In 'Braeburn' during 2004, reproductive bud (R-bud) percentages were higher under nets on short shoots, new and old spurs (Table 3). In 'Cripps' Pink', R-bud percentages were also higher under nets on short and long shoot, and new spurs. No significant differences were found for 'Fuji' and 'Royal Gala' although a trend could be seen for higher R-bud percentages in 'Royal Gala' for long shoots and new spurs. During 2005 (Table 4), only 'Royal Gala' showed significant differences with a lower percentage R-buds on new spurs under nets. 'Fuji' showed a trend for lower R-bud percentages under netting on long shoots and old spurs.

Significant differences in R-bud percentages were found between crop load treatments during 2004 (Table 5). In 'Braeburn', R-bud percentages on short shoots were significantly higher on the 60% compared to the 100, 120 and 140% crop load trees. R-bud percentages on new spurs were higher on the 60 and 80% compared to the 100 and 120% thinned trees. On old spurs, R-bud percentages were higher on the 60, 80 and 120% compared to the 100% crop load trees. 'Fuji' had a significantly higher R-bud percentages on long shoots on the 80% compared to the 100, 120 and 140% crop load trees. In 'Cripps' Pink', R-bud percentages were significantly higher on 80% compared to 120% crop load trees on long shoots and old spurs. During 2005, significant differences were only found in 'Royal Gala', which had higher R-bud percentages (100% reproductive) on old spurs on the 60, 80 and 100% crop load trees compared to 120% crop load trees (Table 5).

DISCUSSION

The relationship between vegetative and reproductive growth of trees is a factor that can be manipulated by growers in order to optimize production with means such as shade netting and crop load.

In this study it was found that all cultivars had higher summer pruning mass from the trees under the net treatment during 2004. The reason for this could be because of increased vegetative growth, but was most likely because the trees under nets were topped to prevent them from growing into the netting, and this was not done on the uncovered trees. A significant interaction between net treatment and crop load treatment was seen for 'Cripps' Pink', with trees thinned to 80% crop load under netting showing greater pruning mass than trees from the other treatment combinations. Fruiting reduces growth and practices such as deblossoming or defruiting increase shoot growth (Wünsche and Ferguson, 2005). During early growth, trees with low crop load and in particular those with no crop partition larger amounts of photosynthate into alternative vegetative sinks. Reduced canopy development in fruiting trees is associated with competition between developing fruit and vegetative growth for available photosynthate (Wünsche and Ferguson, 2005). Due to altered pruning strategies between seasons and the need for topping trees under netting during some seasons to prevent growth into the netting, we suggest that measurements of the vegetative growth by means of pruning measurements be done over a longer period to acquire more accurate data. Orchard vigour can also be defined as the intensity of vegetative growth, and is an important factor used for crop management in fruit tree cropping systems. It is often measured by means of a single variable known as the trunk cross-section area or trunk circumference. In this study, trunk circumference growth only showed significant differences between net and control treatments for 'Braeburn'. It was, however, suggested by Nesme et al. (2005) that trunk circumference alone is not an adequate means of determining tree vigour, and two more morphological variables such as the number of water sprouts on the trunk and annual shoot growth at the distal part of the branches at the bottom of the tree should also be measured.

Sun plants such as apple trees, exhibit a phytochrome-controlled behaviour known as shade avoidance. The phytochrome perceives far-red light (wavelengths between 700 and 800nm) that is scattered by leaves of nearby vegetation (Salter et al; 2003) or in this case by the shade netting. This scattered far-red light then triggers a series of 'shade avoidance' responses, such as a rapid increase in elongation, by which the plant then attempts to outgrow the shaded area (Salter et al; 2003). The relationship that exists between vigour and fruiting is a very sensitive one and should be correctly managed to produce an optimum crop. Excessive

shoot growth not only reduces flowering, but may also compete directly with fruit set and thus reduce fruitfulness. The total shoot leaf area is closely related to total shoot growth and total spur leaf area is related to fruitfulness, and the two are inversely related (Forshey and Elfving, 1989). As discussed by Grappadelli and Lakso (2004), vegetative growth along with light microclimate, crop load and the type of leaves that support fruit growth all influence fruit development. Developing fruit act as a strong sink for carbohydrates and fruiting suppresses vegetative growth of other plant parts (Forshey and Elfving, 1989). Fruiting also reduces leaf size and increases dry matter production per unit of leaf area. Leaves provide the building material for fruit growth and fruit size at harvest increases with the leaf/fruit ratio. Fruit thinning thus improves fruit size by establishing a more favourable leaf/fruit ratio (Forshey and Elfving, 1989).

Jones et al. (1989) found that a reduction in vegetative growth was always closely correlated with increased flowering the following year. Shade netting tended to increase vegetative growth and one might thus expect the opposite to be true for flowering (Middleton and McWaters, 2002). The reason for a increase in flowering could also be higher availability of carbohydrates at the beginning of the following season. Reserve carbohydrates account for one to two quarters of the building materials for new growth until the flower buds begin to show colour (Forshey and Elfving, 1989). This study found that reproductive bud development during 2004 was significantly higher under the net treatment across all treatments on all bearing positions, suggesting that the netting did not negatively influence the initiation and development of reproductive bud growth. A possible reason for increased reproductive bud development could be the low crop loads of the previous season under the nets (data provided by farm management). This would have allowed sufficient carbohydrates for the formation and development of reproductive buds. The reason for the absence of effects during 2005 could thus be that equal crop loads were established during 2004 between net and no-net treatments. Plant hormones can also play a role in growth habits of the plant. Translocation of the hormone gibberellin, from apple seeds into the plant during years of high crop loads can inhibit the formation of flowers for the following season (Wünsche and Ferguson, 2005).

Flower induction on the current season's shoots occurs after mid-summer when extension growth has ceased (Forshey and Elfving, 1989). Induction may be delayed somewhat or reduced if the tree is bearing a heavy crop or if the tree is highly vigorous (Forshey and Elfving, 1989). Results from this study showed that light cropping trees tended to produce more reproductive buds than heavy cropping trees. The amount of available light would also play an important role in bud development. In a trial done over a five year period

it was found that apple trees covered with netting developed approximately 19% fewer flower buds than uncovered trees (Leite et al., 2002). Middleton and McWaters (2002) found that 'Hi Early Red Delicious' trees under netting did not need spray thinning due to the reduction in bud development, whereas adjacent uncovered trees received two sprays during the same season. In previous years, the same pattern was observed where the trees under the netting received two chemical thinning sprays and required minimal following up hand thinning. Trees that were not covered by netting received three chemical thinning sprays and significant follow up hand thinning was required (Middleton and McWaters, 2002). The reason for the greater shedding of fruitlets on trees covered by netting could be due to direct competition between developing fruitlets and reduced bud strength as influenced by light levels (Middleton and McWaters, 2002). Differences in the fruit set potential of apple cultivars have also been related to pollination, fertilization, ovule longevity, flower structure, temperature, solar radiation, genotype and competition between individual fruits and vegetative shoots (Byers et al., 1991). In an experiment done by Shahak el al. (2004), it was found that apple fruit set was not negatively affected by netting of various colours. Middleton and McWaters (2002) consistently found a lower fruit set on trees that were covered by black netting.

Cultural practices can be implemented in order to control vigour and maintain the best balance between vegetative and reproductive growth. The correct pruning methods and intensity play a vital role in controlling the relationship between vegetative and reproductive growth. Girdling can be an effective means of manipulating fruit set and development by concentrating assimilates to a specific region at a specific development stage. It could also be an effective tool in maintaining a good relationship between vegetative and reproductive development. Evans et al. (1997) reported that spray applications of prohexadione-calcium provided excellent control of vegetative growth. In apple trees grafted on vigorous rootstocks, sprays such as prohexadione-calcium and paclobutrazol could be used to control tree vigour (El-Hodairi and Canham, 1990; Evans et al., 1997; Pretorius, 2006) and aid in apple production under shade netting. Thinning strategies should be adapted to best suit the altered growth of the tree due to netting.

The results of this study thus suggest that trees covered by protective netting do have adequate cropping capacity if the relationship between vegetative and reproductive development is controlled. Care should be taken to achieving correct crop loads to maintain sufficient bud development for the following season.

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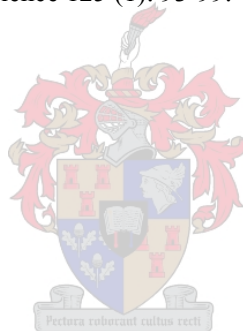
Table 1. Summer prunings fresh mass (kg) during 2003/04 as influenced by netting/no netting treatments and crop load treatments.

Cultivar	Net treatment	Crop load treatment (% thin)	Mass (kg)
'Royal Gala'	Net	60	1.94
		80	1.45
		100	2.17
		120	2.31
		140	2.52
	No net	60	1.43
		80	1.64
		100	1.77
		120	1.59
		140	1.80
	P-value nets		0.0713
	P-value thin		0.2016
	P-value net*thin		0.4580
'Braeburn'	Net	60	1.66
		80	1.59
		100	1.87
		120	1.65
		140	1.57
	No net	60	0.53
		80	1.16
		100	0.71
		120	1.36
		140	0.94
	P-value nets		0.0517
	P-value thin		0.5600
	P-value net*thin		0.2803
'Fuji'	Net	60	2.36
		80	2.89
		100	2.33
		120	3.05
		140	2.15
	No net	60	1.13
		80	1.25
		100	1.47
		120	1.22
		140	1.31
	P-value nets		<0.0001
	P-value thin		0.1586
	P-value net*thin		0.0518
'Cripps' Pink'	Net	80	3.18
	Net	120	1.99
	No net	80	1.39
	No net	120	1.50
	P-value nets		0.0273
	P-value thin		0.0908
	P-value net*thin		0.0480

Table 2: Trunk circumferences at the beginning and end of the 2004/05 growing season for netting and no netting treatments.

|	Start season trunk circumference (cm)	End season trunk circumference (cm)	Seasonal trunk growth (%)
'Braeburn'			
Net	27.2	28.1	3.1
No net	27.4	27.9	1.8
P-net	0.8965	0.6037	0.0030
P-thinning	0.5635	0.6346	0.0176
P-interaction	0.3176	0.2772	0.3891
'Fuji'			
Net	28.4	29.5	3.7
No net	27.6	28.8	4.3
P-net	0.6794	0.2486	0.6716
P-thinning	0.2545	0.3052	0.4996
P-interaction	0.5979	0.1082	0.6689
'Cripps' Pink'			
Net	28.6	30.3	5.2
No net	30.6	31.9	3.9
P-net	0.6765	0.7608	0.9536
P-thinning	0.7576	0.1151	0.1995
P-interaction	0.9531	0.1151	0.0667
'Royal Gala'			
Net	27.7	28.5	3.5
No net	29.1	30.0	3.8
P-net	0.8356	0.9531	0.6112
P-thinning	0.0590	0.0718	0.5738
P-interaction	0.8082	0.3534	0.7237
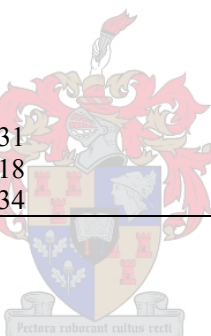
Table 3: Reproductive bud percentages during August 2004 on short shoots (SS, <25 cm), long shoots (LS, >25 cm), new spurs (NS, which have not previously borne fruit), and old spurs (OS, which have previously borne fruit), as affected by 20% black shade netting

	SS	LS	NS	OS
'Braeburn'				
Net	60.0	33.9	61.7	82.2
No net	27.8	21.1	35.5	61.1
P-net	0.0004	0.1728	0.0022	0.0069
P-thinning	0.0040	0.1135	0.0038	0.0069
P-net*thinning	0.3808	0.2404	0.1198	0.4487
'Fuji'				
Net	78.9	53.3	78.9	81.1
No net	81.7	39.1	84.4	85.0
P-net	0.6947	0.2750	0.3877	0.2724
P-thinning	0.2326	0.0194	0.8129	0.8821
P-net*thinning	0.6941	0.5030	0.2385	0.9649
'Cripps' Pink'				
Net	91.7	91.7	100.0	88.9
No net	73.6	75.0	83.3	72.2
P-net	0.0062	0.0066	0.0249	0.1191
P-thinning	0.0978	0.0017	0.5151	0.0157
P-net*thinning	0.3344	0.1891	0.5151	0.0157
'Royal Gala'				
Net	93.9	53.3	98.9	96.1
No net	93.3	34.4	90.0	97.8
P-net	0.6087	0.0730	0.0575	0.4563
P-thinning	0.9106	0.1767	0.5571	0.3471
P-net*thinning	0.1742	0.2744	0.4722	0.3880
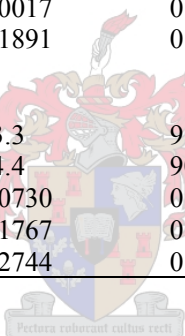
Table 4: Reproductive bud percentages during August 2005 on short shoots (SS, <25 cm), long shoots (LS, >25 cm), new spurs (NS, which have not previously borne fruit), and old spurs (OS, which have previously borne fruit), as affected by 20% black shade netting

	SS	LS	NS	OS
'Fuji'				
Net	65.0	39.2	75.8	91.0
No net	78.3	71.7	98.9	96.7
P-net	0.2781	0.0598	0.1163	0.0663
P-thinning	0.8843	0.9362	0.5426	0.9223
P-net*thinning	0.8734	0.9278	0.9519	
'Cripps' Pink'				
Net	91.7	93.7	97.9	
No net	85.4	85.4	91.7	
P-net	0.5710	0.2530	0.4446	
P-thinning	0.7961	1.000	0.3835	
P-net*thinning	0.7961	0.5097	0.7682	
'Royal Gala'				
Net	80.0	51.7	82.5	95.8
No net	90.0	63.3	97.5	95.8
P-net	0.3873	0.1550	0.0182	1.0000
P-thinning	0.9639	0.6396	0.1168	0.0229
P-net*thinning	0.9385	0.2485	0.3727	0.9791
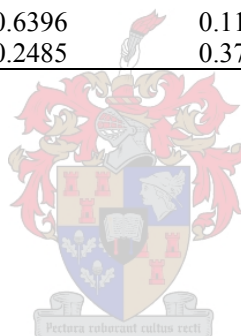
Table 5: Reproductive bud percentages during August 2004 and 2005 on short shoots (SS, <25 cm), long shoots (LS, >25 cm), new spurs (NS, which have not previously borne fruit), and old spurs (OS, which have previously borne fruit), as affected by crop load treatments where 100% crop load refers to the commercial target

Crop load treatment	SS		LS		NS		OS	
2004								
'Braeburn'								
60%	68.1	a	33.3	a	59.7	a	80.6	a
80%	47.2	ab	31.9	a	61.1	a	80.5	a
100%	31.0	b	36.1	a	36.1	b	50.0	b
120%	43.1	b	22.2	a	36.1	b	76.4	a
140%	29.2	b	13.9	a	50.0	ab	70.8	ab
P-value	0.0040		0.1135		0.0038		0.0069	
'Fuji'								
60%	73.6	a	55.6	ab	77.8	ab	87.5	a
80%	76.4	a	62.5	a	87.5	a	82.0	a
100%	77.8	a	38.9	b	81.9	b	83.3	a
120%	86.1	a	38.9	B	80.6	b	84.7	a
140%	87.5	a	37.5	b	80.6	b	77.8	a
P-value	0.2326		0.0194		0.8129		0.8821	
'Royal Gala'								
60%	90.3	a	45.8	a	98.6	a	98.6	a
80%	94.4	a	59.7	a	95.8	a	100	a
100%	94.4	a	33.3	a	94.4	a	91.7	a
120%	93.1	a	43.1	a	94.4	a	97.2	a
140%	95.8	a	37.5	a	88.9	a	97.2	a
P-value	0.9106		0.1767		0.5571	a	0.3771	a
'Cripps' Pink'								
80%	88.9	a	91.7	a	94.4	a	90.3	a
120%	76.4	a	75.0	b	88.9	a	70.8	b
P-value	0.9780		0.0017		0.5151		0.0157	
2005								
'Royal Gala'								
60%	83.3	a	52.1	a	97.9	a	100	a
80%	87.5	a	68.8	a	85.4	a	100	a
100%	87.5	a	56.3	a	95.8	a	100	a
120%	85.4	a	58.3	a	87.5	a	81.2	b
140%	81.3	a	52.1	a	83.3	a	97.9	ab
P-value	0.9463		0.3759		0.1513		0.0212	

CHAPTER 4 – Effect of shade netting on microclimate, gas exchange and water potential of four blushed apple cultivars.

ABSTRACT

The influence of 20% black shade netting on the photosynthetic photon flux density (PPFD), leaf and fruit surface temperature, gas exchange rates and leaf water potential was measured over a two-year period in the Koue Bokkeveld area, Western Cape, South Africa, on the four blushed apple cultivars Royal Gala, Fuji, Braeburn and Cripps' Pink. Significant reductions in PPFD of 22%, 29% and 31% were found on three different measurement dates. Leaves under the netting were cooler by $1.7 – 3.9°C$ on a milder day (11 January 2005) and by $4.3 – 6.2°C$ on a hot day (28 February 2005) than control leaves. Fruit surface temperature under the netting was cooler by $0.7 - 2.9°C$ on milder days, and by $4.0 - 5.3°C$ on a hot day (28 February 2005) than control fruit. Significantly lower leaf to air vapour pressure deficit (VPD_{leaf}) was measured under netting during March 2004 and January 2005 compared to the control. Significant increases in net CO_2 assimilation rate (A) were found during March 2004 for 'Royal Gala' and during January 2005 for all four cultivars. Stomatal conductance and transpiration rate were generally higher under the netting than the control. Light- and CO_2- saturated net CO_2 assimilation rate (A_{sat}) and leaf nitrogen concentration showed no significant difference between treatments, indicating that netting does not negatively influence the photosynthetic capacity on a leaf area basis. Water potential was generally improved under the netting during periods of soil water deficiency.

Keywords: Gas exchange, leaf nitrogen, light levels, *Malus domestica*, photosynthetic photon flux, shade netting, temperature, water potential.

INTRODUCTION

Due to ever increasing quality expectations and an ever less predictable climate, apple growers have been looking for various new methods to increase their packout percentages. Hailstorms and sunburn have caused growers to experiment with the installation of protective netting over orchards (Scott, 1989; Middleton and McWaters, 2002). Apple orchard productivity varies greatly between different climates or between years, and it is difficult to determine the critical factors over such a range of climatic conditions (Lakso et al; 2001). With the installation of protective netting over an orchard, we would expect changes in the physiology of the trees as they react to microclimatic changes in humidity, temperature and available light, which are the major factors influenced by netting (Guerrero et al., 2002; Shahak et al., 2004).

Apple producers in the Western Cape region of South Africa are cautious about using protective netting due to the uncertainty of the effects thereof on tree physiology and fruit quality, and the high installation costs of netting. The ability of plants to adapt to altered light conditions is a fundamental response associated with specific changes in the morphology, physiology and biochemistry and the structure of the leaves and chloroplasts (Taiz and Zeiger, 2002).

Leaves on shaded plants typically have a lower light compensation point for net CO_2 assimilation rate (A), a lower maximal A (A_{max}), and A saturates at a lower irradiance than leaves on sun plants (Barden, 1977), indicating that the photosynthetic properties of a leaf depend on its growing conditions (Taiz and Zeiger, 2002). These studies were, however, carried out under strong shading (>60%). The question now is whether the installation of shade netting for purposes of sunburn control would negatively affect the photosynthetic capabilities of the apple leaf. Potential changes in stomatal conductance are important for the regulation of transpirational water loss and rate of carbon dioxide uptake necessary for sustained CO_2 fixation during photosynthesis. Stomatal control thus couples leaf transpiration to leaf photosynthesis (Taiz and Zeiger, 2002). With the installation of shade netting we could expect stomatal conductance and thus A to increase in response to lower levels of atmospheric stress (leaf to air vapour pressure deficit, VPD_{leaf}) and possibly due to an increase in leaf water availability, as found by Jifon and Syvertsen (2003). This would be the case only under light to moderate shading (reducing only excess irradiance) which would not lead to a light limitation of photosynthesis. Under stronger shading, the light limitation would override this effect, and A and thus stomatal conductance would decrease (Middleton and McWaters, 2002).

Leaf nutrient concentration and especially nitrogen concentration [N] reflects the factors influencing nutrient availability from the soil, year-to-year variation in climate, crop load and photosynthetic capacity (Neilsen and Neilsen, 2003). The enzyme rubisco, which plays a central role in CO_2 assimilation, has also been found to be influenced by leaf [N]. Total rubisco concentration is positively correlated with leaf [N] (Cheng and Fuchigami, 2000).

The effect of shade netting on the microclimate, gas exchange and water potential of apple trees should be investigated in order to determine the sustainability of apple production under shade netting. The objectives of this study were thus to evaluate the effects of 20% black shade netting on net CO_2 assimilation rate, stomatal conductance, transpiration rate, leaf nitrogen concentration and leaf water potential of four blushed apple cultivars, ie, Braeburn, Fuji, Cripps' Pink and Royal Gala. The hypothesis was that the installation of 20% protective netting over apple trees would not significantly reduce the photosynthetic capacity of the leaves, and would in fact allow stomatal conductance to remain higher than in full sunlight.

MATERIALS AND METHODS

Plant material

The trial was established in a commercial orchard located on the Du Toit Group farm, Vastrap, situated in the Witzenberg Valley in the Western Cape Province (33°15'S 19°15'E, 901 m altitude), and was carried out over the 2003/04 and 2004/05 growing seasons. The apple (*Malus domestica* Borkh.) cultivars Royal Gala (RG), Fuji (FU), Braeburn (BR) and Cripps' Pink (CP) on M793 rootstock were planted during 1996 in a slight northeast by southwesterly direction with 4m x 1m spacing for RG, FU and CP and 4m x 2m spacing for BR. All were trained to a central leader. Standard commercial management practices for the region were followed. Micro-jet sprinklers were used for irrigation, and scheduling was based on neutron moisture probe measurements, where individual probes were placed in the unshaded parts of each cultivar block so that all trees of each cultivar received similar amounts of water based on full sun conditions. Due to drought in the 2004/05 season water availability was low and irrigation had to be reduced to 40% of the normal requirement. Soil moisture measurements using neutron probes in both shaded and unshaded parts of each cultivar block (RG, FU and CP) were obtained from the farm management for the 2004/05 season.

Treatments and experimental design

Black shade netting with a density of 20% was installed in 2001 (Addendum A, Figs 1,2). The four cultivars were situated in blocks on either side of an orchard road with RG and FU next to each other on the one side of the road and BR and CP on the other side. Twelve rows of each cultivar were covered for half the row with netting. Netting was installed using the 45° pitched roof system with about one meter between the top of the trees and the netting. During both seasons the netting was pulled back early in May to avoid damage caused by winter rainstorms and snowfalls. The netting was replaced during bloom in 2003 and shortly after bloom in 2004. The uncovered parts of the rows were used as controls. Six rows of each cultivar were chosen as experimental blocks from the inside of the netted area outwards, to avoid an edge effect. Thinning sub-treatments were established as described in Chapter 2. For gas exchange and leaf water potential measurements presented in this article, only trees thinned to commercial crop load (BR 64.02 kg/tree, FU 23.93 kg/tree, RG 25.9 kg/tree, CP 29.04 kg/tree) were used. Harvest dates were RG, 16, 23 February, 2, 9 March 2004, FU, 1, 7 April, BR, 14 April, CP, 22, 29 April 2004 and during 2005, RG, 2, 10, 17 February, FU, 23, 31 March, BR, 21, 31 March, CP, 14, 26 April.

Microclimatic measurements

During both seasons the photosynthetic photon flux density (PPFD) was measured under the netting, and outside the netting using a light meter (LI-250 with LI-190SA quantum sensor, Li-Cor, Lincoln, Nebraska, USA). During the 2003/04 season, PPFD was measured on 3 March 2004 from 11:00 until 15:00, at 10 min intervals between the measurements. Measurements were repeated on 11 March 2004 from 10:00 until 16:00, at 45 min intervals. During the 2004/05 season, measurements were taken on 1 March 2005, from 10:00 until 16:00 at 30 min intervals.

Fruit surface temperature measurements were taken during both seasons on all the cultivars using an infrared thermometer (Raynger MX 4, Raytek Corp., Berlin, Germany). During 2003/04, measurements were taken on 12 January 2004 and 11 March 2004. The sun side of fully exposed fruit was measured. Measurements of replicates alternated between shade net and control treatments, in order to keep differences in ambient temperature and light as low as possible. Samples were taken block by block using 30 fruit for 'Braeburn', 'Royal Gala' and 'Fuji' and 12 fruit from 'Cripps Pink' per replicate (n = 6). On 15 December 2004 and 28 February 2005 fruit surface temperature of 10 fruit per replicate (n = 6) was measured.

Leaf surface temperature was measured only during the 2004/05 season using the infrared thermometer. The adaxial surfaces of 10 fully exposed leaves per replicate (n = 6) were measured. Measurements were done on 11 January and 28 February 2005.

Gas exchange measurements

During both seasons gas exchange measurements were taken with an infrared gas analyser (LI-6400 Photosynthesis System, Li-Cor, Lincoln, Nebraska, USA).

On 20 January 2004, photosynthetic light response curves were measured using irradiances of 2000, 1500, 1000, 600, 400, 300, 200, 100, 50 and 0 μmol m^{-2} s^{-1} PPFD provided by an internal red/blue LED light source (LI-6400-02B Li-Cor, Lincoln, Nebraska USA). Cuvette CO_2 concentration was controlled at 380 μmol mol^{-1} using the LI-6400 CO_2 injection system and compressed CO_2-cylinders. Leaf temperature under ambient conditions was 24-29°C. Response curves of net CO_2 assimilation rate (A) against PPFD were fitted individually using nonlinear regression (Statistica 5.5, StatsOft Inc., Tulsa, OK, USA) and the monomolecular function y=a(1-e^{b-cx}) given by Causston and Dale (1990). In this function the coefficient "a" represents the light-saturated rate of net CO_2 assimilation (A_{max}) "ace^b" represents the apparent quantum efficiency (AQE, the slope of the curve at x=0) "b/c" represents the light compensation point (LCP). Values for dark respiration (R_d) were taken as net CO_2 exchange rate at 0 μmol m^{-2} s^{-1} PPFD.

Measurements were taken on one extension shoot leaf per tree, for each replicate and treatment for FU and CP using three blocks.

Spot measurements of A, stomatal conductance (g_s) and transpiration rate (E) under ambient atmospheric conditions with sunlight levels above 1000 µmol mol^{-1} PPFD, were taken on 16 March 2004 from 9:30-16:30. One mature leaf on one tree from each of five replicates was measured for both treatments for all four cultivars. This was repeated six times through the day. Diurnal data were pooled for each replicate for the statistical analysis since treatment effects were not variable diurnally. Harvest dates for the 2003/04 season were, RG 16, 23 February and 2, 9 March, FU 1,7 April, BR 14 April and CP 14,26 April 2004.

During the 2004/05 season, spot measurements under ambient atmospheric conditions with sunlight levels above 1000 µmol mol^{-1} PPFD were taken on 14 January (FU), 17 January (BR) and 18 January 2005 (CP and RG) in the same manner described above. Harvest dates for the 2004/05 season were, RG, 2,10,17 February, BR, 21, 30 March, FU, 23,31 March, CP, 14,26 March 2005.

Spot measurements under ambient atmospheric conditions and 1500 µmol mol^{-1} PPFD (internal light source) were taken during the midday period (12:00-14:00) on 27 April (FU), 28 April (BR) and 29 April 2005 (CP and RG). Two cycles, one leaf for each of the five replicates was measured for each cultivar. On the same dates, two replicate photosynthetic measurements under controlled cuvette conditions were made on one leaf per replicate, over five replicates. A_{max}, g_{smax} and E_{max} were measured by setting the cuvette CO_2 concentration to 380 µmol mol^{-1} and the light to saturated levels of 1500 µmol m^{-2} s^{-1} PPFD. A_{sat} (light- and CO_2-saturated A) was measured by increasing the CO_2 concentration to a saturated level of 1000 µmol mol^{-1}, and R_d was measured at 380 µmol mol^{-1} CO_2 and darkness (0 µmol m^{-2} s^{-1} PPFD). Average leaf temperatures were ca. 27°C.

Leaf water potential

Leaf water potential was measured during the 2004/05 season on all cultivars before and after harvest, using a Scholander pressure chamber (PMS Instrument Co., Corvallis, USA). Two sun-exposed leaves per tree over five blocks were cut an estimated 20 cm from the tip of long shoots and measured immediately. Before harvest, measurements were done on 10 and 25 January 2005 for FU and BR, respectively. Measurements for RG and CP were done on 4 February 2005. After harvest, measurements were taken on 11 March for RG and on 29 April 2005 for FU and BR. Due to bad weather conditions after harvest, measurements could not be taken for CP.

Leaf nitrogen concentration

Leaf samples were picked at the beginning of the 2003/04 and 2004/05 seasons as well as after harvest. Six leaves per replicate were taken from long shoots approximately 15 cm from the tip for

both treatments and all cultivars. Leaf samples were dried in an oven at 50°C, milled and analysed for nitrogen concentration in a commercial laboratory (Bemlab (PTY) Ltd, Somerset West, South Africa).

Statistical analysis

The data was analysed using one-way ANOVA ($P \leq 0.05$) and the General Linear Models (GLM) procedure of SAS (SAS release 6.12P; SAS Institute, 1996, Cary, NC). Although the two treatments were not randomised, environmental and control conditions were deemed to be highly comparable under the netted and non-netted areas (see Chapter 2).

RESULTS

Significant reductions in PPFD of 22%, 29% and 31%, as measured on three different measurement dates, were found under the netted area compared with the control (Table 1). Leaf and fruit surface temperatures were lower during both seasons under the net treatment compared to the control for all the cultivars (Table 2). The fruit surface temperature difference between net and control treatments ranged from 0.7°C to 2.9°C on milder days depending on cultivar and 4.0 to 5.3°C on a hot day (28 February 2005). The measurements taken on 12 January 2004 and 11 March 2004 were lower than the measurements taken on the other dates due to cloudy conditions. Leaves showed a temperature difference of 1.7 to 3.9°C on a milder day (11 January 2005) and 4.3 to 6.2°C on a hot day (28 February 2005), depending on cultivar.

The photosynthetic light response parameters measured on 20 January 2004 showed no significant differences between net and control treatments (Table 3). For the photosynthetic measurements taken under ambient conditions on 16 March 2004 (Table 4), A and E were significantly higher under nets than in the control treatment in 'Royal Gala'. On the same date, g_s was significantly higher under nets in 'Braeburn', 'Cripps' Pink' and 'Royal Gala' with a similar trend in 'Fuji' (Table 4). A was significantly higher under nets than in the control treatment in all the cultivars when measured under ambient conditions during January 2005 (Table 5). g_s was significantly higher under nets in 'Fuji', 'Braeburn' and 'Cripps' Pink'. VPD_{leaf} and T_{air} measurements taken on 16 March 2004 (Table 4) and during January 2005 (Table 5) were significantly lower in the net treatment than in the control treatment with the exception of T_{air} in 'Braeburn' and 'Cripps' Pink' (16 March 2004) and T_{air} in 'Braeburn' (January 2005). No significant differences between treatments were found for any parameter during April 2005 (Table 6).

During the gas exchange measurements in April 2005, A_{max}, $g_{s\ max}$ and E_{max} were significantly higher under the net treatment only in 'Fuji' (Table 7). There were no differences between treatments in A_{sat}.

Before harvest, midday leaf water potential (Table 8) was significantly higher under the net treatment on days with a higher soil water deficit and lower leaf water potential ('Braeburn' 25 January 2005, 'Cripps' Pink' 4 February 2005). After harvest, reduced irrigation resulted in lower leaf water potentials in all blocks, and significantly higher water potentials were again found in the block with the highest water deficit ('Royal Gala' 11 March 2005).

Leaf nitrogen concentration [N] was significantly higher at the beginning of the season compared to the end of the season (Table 9). Significantly lower leaf [N] was found under the net treatment during 2004 for 'Cripps' Pink' (Table 9).

Soil moisture availability during 2004/05 did not differ between net and control treatments in RG and CP, but was higher under netting in FU (D. van Zyl, personal communication).

DISCUSSION

The growth and functioning of any plant is dependent on energy derived from the sun (Taiz and Zeiger, 2002). The amount of sunlight that reaches the plant to enable photosynthesis is thus vitally important and by altering the amount of sunlight available to the plant we could expect the plant to react and adapt to the change, in order to utilize the available light to the optimum. By covering apple trees with netting, we run the risk of reducing sunlight to levels which may affect tree growth and yield negatively.

The installation of shade netting affects the amount of photosynthetic photon flux density (PPFD) that reaches the leaf surface. A significant reduction in PPFD of 20 – 30% was found under the black netting. These results confirm the findings of Widmer (1995, 1997), Middleton and McWaters (2002), Guerrero et al. (2002) and Shahak et al. (2004) for netting over apple orchards. In both seasons these measurements were taken during March, and we suggest that in further studies, measurements should be taken throughout the season to determine the amount of light available during the fruit set and growth periods, as well as during the post harvest period. From the light response curve of apple leaves (Grappadelli, 2003; Pretorius, 2006), we would, however, not expect that a reduction of 20 – 30% (400-600 μmol m^{-2} s^{-1}) in PPFD of a maximum of ca. 2000 μmol m^{-2} s^{-1} in mid-summer (Pretorius, 2006) would negatively influence the gas exchange of the tree. During periods of low light levels caution would have to be taken (Widmer, 1997).

Leaf surface temperature was reduced by up to 4.3°C and fruit surface temperature up to 5°C, concurring with the results of Gardner and Fletcher (1990), Ebert and Casierra (2000), and Middleton and McWaters (2002). Air temperatures (Tables 4, 5 and 6) were only slightly lower

under the netting compared to the control, suggesting that the reduction in leaf and fruit surface temperatures was primarily due to a reduction in direct sunlight reaching the fruit and leaf surfaces rather than a reduction in air temperature. The measurements taken on ambient air temperature and leaf temperature during the photosynthesis measurements (Tables 4, 5, 6) concur with those shown in Table 2, since they were consistently lower under the netted treatments. Although the differences for air temperature were significant in most cases, the actual difference was often not more than 1°C. Leaf temperature as measured on 16 March 2004 and during January and February 2005 showed larger differences between treatments of up to 3°C.

The driving force behind water loss in the plant is the difference in water vapour pressure between the leaf tissues and the atmosphere, the vapour pressure deficit (VPD_{leaf}) (Taiz and Zeiger, 2002). Under netting, VPD_{leaf} tends to be reduced due to the increased humidity of up to 15% (Middleton and McWaters, 2002) and the lower air and leaf temperature. The undisturbed layer of air next to the leaf surface (leaf boundary layer) through which water vapour must diffuse to reach the turbulent air of the atmosphere can thus be thicker for leaves under netting. This is due to a reduction in air movement of up to 50% (Middleton and McWaters, 2002). At high temperatures leaves also tend to have a higher water vapour diffusion potential than at lower temperatures due to the fact that molecules in a warm leaf are more excited than in cooler leaves, resulting in higher mobility of these molecules.

In this study it was found that netting reduced VPD_{leaf} for reasons mentioned above, and increased stomatal conductance (g_s), but did not significantly affect transpiration rate (E) in most cases. The loss of water through E is a direct consequence of the opening of the stomatal pores in sunlight to allow photosynthesis, together with the diffusive driving force of VPD_{leaf} (Costes et al.. 2002). Under netting, significant increases in g_s were counteracted by the reductions in VPD_{leaf}, thus explaining the lack of effect on E. The greatest short term control over water relations in the leaf is exerted by the stomata reacting in response to VPD_{leaf}. Under conditions of decreased VPD_{leaf} the stomata can remain open for longer periods and photosynthesis can be enhanced due to higher diffusion rates of CO_2 into the leaf.

High stomatal conductances and transpiration rates lower the leaf water potential (Lakso et al., 1989), particularly when water supply from the roots does not keep pace with losses, owing to hydraulic resistances (Lambers et al., 1998). Under these conditions stomatal conductances may be decreased and this is generally seen around midday in many woody species. In the net trial, significant differences in midday leaf water potential were found before and after harvest, being higher in leaves under netting than outside when soils were drier. This suggests a higher soil moisture content in response to lower evaporation rates in a low-energy light environment under the netting (Shahak et al., 2004). A greater water supply from the roots to the leaves would also allow

g_s to remain high, and reinforce the positive VPD_{leaf} effects on g_s. However, soil moisture content measured during the dry 2004/05 season showed no marked differences in soil water between net and non-netted treatments, except for FU where the soil water content under the netting was higher than the non-netted area. Therefore, the stomatal responses were likely dominated by VPD_{leaf} effects.

The influence that shade netting has on dark respiration rates (R_d) and photosynthetic capacity (A_{sat}) is important for the net production and partitioning of carbohydrates. Barden (1977) showed R_d to be lower in shade grown leaves and that it tends to decline in leaves grown in full sun and then subsequently shaded. This study showed no significant differences in R_d or A_{sat} suggesting that the reduced PPFD due to netting does not influence the photosynthetic capacity of the leaves at saturated conditions at least in the outer sun-exposed leaves.

Results for net CO_2 assimilation rate (A) showed that, on 16 March 2004, only 'Royal Gala' showed significant differences with trees covered by netting having higher photosynthetic rates and higher stomatal conductances. This is most likely due to the fact that the fruit were already harvested. The trees under the netting were able to maintain higher photosynthesis rates compared to exposed trees which had begun to downregulate photosynthesis capacity post-harvest. The measurements taken during January 2005 show significant differences in net CO_2 assimilation rate, with all the cultivars having higher photosynthetic rates under netting than in the open. These results correspond to those found by Stampar et al. (2001) who showed net photosynthesis for 'Elstar' covered by black shade netting to be significantly higher than for uncovered trees.

Measurements taken in April 2005 showed no significant differences in net CO_2 assimilation rate. This could be due to the lower air and leaf temperatures and no effect of netting on T_{air}, T_{leaf} and VPD_{leaf}. Photosynthetic CO_2-response (A/c_i) measurements taken during April 2005 however showed only FU to have a significant higher A_{max} as well as a higher gs_{max} and E_{max} under the netting. This could possibly be ascribed to the higher soil moisture content measured under the netting, allowing the stomata to stay open resulting in better gas exchange. It is thus clear that netting did not negatively influence net CO_2 assimilation on any of the cultivars on any date. In fact, where significant results were found the netting increased CO_2 assimilation. These results also concur with the findings of Ebert and Casierra (2000) that net CO_2 assimilation rate was lower under netting in the morning under low light conditions, but higher for the rest of the day. In contrast, Stampar et al. (2001) reported lower net photosynthesis rates in orchards covered with black netting compared to uncovered orchards probably due to high net densities and stated low light conditions (values not given).

Leaf analysis is a valuable method of assessing the nutritional status of plants. During the 2003/04 season, significantly lower leaf [N] was found in netted compared to the non netted

treatments in 'Cripps' Pink'. During both seasons, leaf [N] was significantly lower at the end of the season compared to the beginning. Leaf [N] was, however, always above the optimum level of 2.1% (Toldam- Anderson and Hansen, 1995). This reduction in leaf [N] during the season is expected due to the utilization of the element as regulated by sink demand (Aichner and Stimpfl, 2002; Klein, 2002).

N plays a role in the activation and concentration of rubisco. Total rubisco activity increases linearly with increasing leaf [N] throughout the leaf [N] range (Cheng and Fuchigami, 2000). As a result, rubisco activation state decreases with increasing leaf [N] (Cheng and Fuchigami, 2000). DeJong (1982) found a linear relationship between leaf [N] and CO_2 assimilation rate in peach trees. This linear response was accompanied by linear increases of mesophyll and leaf conductance to water vapour. Intercellular CO_2 concentrations at ambient external CO_2 concentrations generally decrease with increasing leaf N content, due to this higher CO_2 assimilation rate (DeJong, 1982). Although this was found in studies done on peach, it was suggested that other species such as apples would respond in the same way. During this study neither [N] nor A_{sat} showed a decrease during the season in which both were measured (2005) under the net treatment. No long-term downregulation of the photosynthetic capacity of apple leaves covered by shade netting was thus found.

In conclusion, with the installation of shade netting a significant reduction in PPFD was found. However, the results showed that this reduction was not detrimental to the photosynthetic capacity of the leaves. It was found that net CO_2 assimilation rates of leaves grown under shade netting were often higher than that of leaves from uncovered trees. This might not be the case in areas and periods of low light and net density will have to be taken into consideration under such conditions.

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Table 1: Photosynthetic photon flux density (PPFD µmol m^{-2} s^{-1}) measured under 20% black protective netting.

	03-Mar-2004	11-Mar-2004	01-Mar-2005
Net	897	1314	1248
No net	1297	1677	1769
% Reduction	31	22	29
P-value	<0.0001	<0.0001	<0.0001
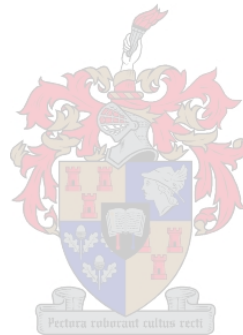
Table 2: Leaf and fruit surface temperature (°C) under 20% black protective netting.

	Fruit 12-Jan-04	Fruit 11-Mar-04	Fruit 15-Dec-04	Leaf 11-Jan-05	Leaf 28-Feb-05	Fruit 28-Feb-05
'Royal Gala'						
Net	20.5		28.8	30.0	40.8	
No net	21.8		30.8	33.9	44.9	
P-value	0.0057		0.1240	0.0007	0.0144	
'Braeburn'						
Net	27.2	20.9	29.0	30.6	32.6	41.6
No net	28.3	23.0	31.9	32.3	38.8	45.6
P-value	0.0004	0.0113	0.0151	0.0097	0.0554	0.0019
'Fuji'						
Net	22.4	24.9	28.9	28.4	31.2	37.8
No net	23.1	25.6	29.9	30.2	36.2	42.8
P-value	0.2664	0.0125	0.0190	0.0630	0.0020	0.0001
'Cripps' Pink'						
Net	22.1	19.6	28.9	32.8	37.6	40.2
No net	23.4	21.8	31.5	36.7	41.9	45.5
P-value	0.0276	0.0670	0.0032	0.0007	0.1190	0.0033
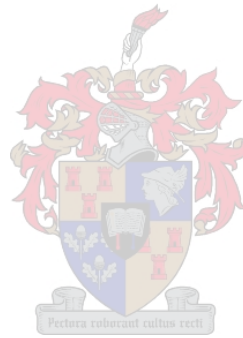
Table 3: Photosynthetic light response parameters under 20% black protective netting on 20 January 2004. Abbreviations: dark respiration rate (R_d), apparent quantum efficiency (AQE), light saturated net CO_2 assimilation rate (A_{max}) and light compensation point (LCP).

	R_d ($\mu mol\ m^{-2}\ s^{-1}$)	AQE ($\mu mol\ CO_2\ \mu mol^{-1}\ quanta$)	A_{max} ($\mu mol\ m^{-2}\ s^{-1}$)	LCP ($\mu mol\ m^{-2}\ s^{-1}\ PPFD$)
'Fuji'				
Net	1.07	0.062	19.0	18.2
No net	1.06	0.058	18.1	17.1
P-value	0.9580	0.4400	0.1070	0.8252
'Cripps' Pink'				
Net	1.29	0.072	21.6	17.7
No net	1.19	0.069	21.3	16.9
P-value	0.6740	0.6320	0.3410	0.7260
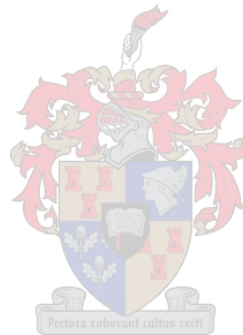
Table 4: Photosynthetic measurements taken under ambient conditions on 16 March 2004 under 20% black protective netting. Abbreviations: net CO_2 assimilation rate (A), stomatal conductance (g_s), transpiration rate (E), air temperature (T_{air}), leaf temperature (T_{leaf}) and leaf-to-air vapour pressure deficit (VPD_{leaf}). Harvest dates were RG, 16, 23 February, 2, 9 March, FU 1, 7 April, BR, 14 April, CP, 22, 29 April 2004.

	A ($\mu mol\ m^{-2}\ s^{-1}$)	g_s ($mol\ m^{-2}\ s^{-1}$)	E ($mol\ m^{-2}\ s^{-1}$)	T_{air} (°C)	T_{leaf} (°C)	VPD_{leaf} (kPa)
'Royal Gala'						
Net	10.4	0.232	4.53	27.1	28.8	2.10
No net	5.2	0.094	2.84	28.1	31.9	3.05
P-value	0.0011	0.0004	0.0006	0.0002	0.0001	<0.0001
'Braeburn'						
Net	12.0	0.347	6.11	28.4	28.7	1.79
No net	10.7	0.247	5.70	28.5	30.7	2.30
P-value	0.0657	0.0035	0.0791	0.6670	0.0017	0.0015
'Fuji'						
Net	14.1	0.294	4.8	25.2	26.3	1.70
No net	13.4	0.234	4.69	26.2	28.4	2.07
P-value	0.5953	0.0761	0.6955	0.0006	0.0042	0.0027
'Cripps' Pink'						
Net	12.9	0.387	6.43	28.4	28.6	1.71
No net	12.1	0.332	6.53	28.5	30.0	2.03
P-value	0.5012	0.0126	0.5865	0.0593	0.0016	0.0044
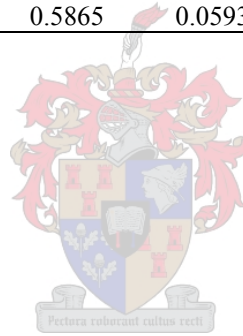
Table 5: Photosynthetic measurements taken under ambient conditions during January 2005 under 20% black protective netting. Abbreviations: net CO_2 assimilation rate (A), stomatal conductance (g_s), transpiration rate (E), air temperature (T_{air}), leaf temperature (T_{leaf}), leaf-to-air vapour pressure deficit (VPD_{leaf}).

	A ($\mu mol\ m^{-2}\ s^{-1}$)	g_s ($mol\ m^{-2}\ s^{-1}$)	E ($mol\ m^{-2}\ s^{-1}$)	T_{air} (°C)	T_{leaf} (°C)	VPD_{Leaf} (kPa)
'Royal Gala' (18 Jan)						
Net	7.1	0.214	7.69	37.2	37.6	3.63
No net	4.2	0.136	5.60	37.3	38.8	4.33
P-value	0.0390	0.1090	0.1350	0.0490	0.0310	0.0610
'Braeburn' (17 Jan)						
Net	13.6	0.331	8.49	40.6	34.0	2.59
No net	9.6	0.218	6.95	40.7	35.2	3.10
P-value	0.0190	0.0276	0.0651	0.2580	0.0023	0.0122
'Fuji' (14 Jan)						
Net	14.4	0.369	6.66	30.7	31.3	1.95
No net	13.0	0.318	6.40	30.9	31.9	2.09
P-value	0.0136	0.0149	0.2660	0.0025	0.0027	0.0330
'Cripps' Pink' (18 Jan)						
Net	10.1	0.231	7.51	35.4	35.9	3.22
No net	5.9	0.137	5.66	35.7	37.5	3.98
P-value	0.0350	0.0480	0.0890	0.0033	0.0041	0.0190

Table 6: Photosynthetic measurements taken under ambient conditions during April 2005 under 20% black protective netting. Abbreviations: net CO_2 assimilation rate (A), stomatal conductance (g_s), transpiration rate (E), air temperature (T_{air}), leaf temperature (T_{leaf}) and leaf-to-air vapour pressure deficit (VPD_{leaf}).

	A $(\mu mol\ m^{-2}\ s^{-1})$	g_s $(mol\ m^{-2}\ s^{-1})$	E $(mol\ m^{-2}\ s^{-1})$	T_{air} (°C)	T_{leaf} (°C)	VPD_{leaf} (kPa)
'Royal Gala' (29 Apr)						
Net	5.2	0.0611	1.82	29.5	29.1	2.86
No net	6.8	0.0949	2.68	29.6	29.2	2.74
P-value	0.3686	0.3945	0.3781	0.1576	0.7662	0.3651
'Braeburn' (28 Apr)						
Net	10.1	0.142	3.36	27.8	27.6	2.24
No net	9.7	0.146	3.36	27.7	27.5	2.21
P-value	0.7493	0.9031	0.9917	0.1123	0.2125	0.7698
'Fuji' (27 Apr)						
Net	11.3	0.208	3.83	26.7	26.4	1.89
No net	9.1	0.129	2.80	26.6	26.6	2.04
P-value	0.0887	0.1425	0.1160	0.3910	0.2263	0.1400
'Cripps' Pink' (29 Apr)						
Net	9.3	0.162	4.03	28.7	28.6	2.40
No net	8.7	0.137	3.52	28.8	28.8	2.47
P-value	0.3528	0.4771	0.4593	0.0044	0.3105	0.5231
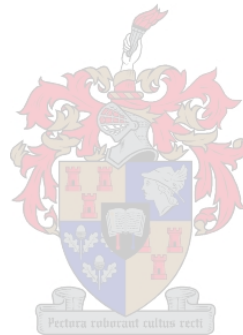
Table 7: Photosynthetic CO_2-reponse (A/c_i) measurements taken during April 2005 under 20% black protective netting. Abbreviations: light saturated net CO_2 assimilation rate at ambient CO_2 concentration (A_{max}), maximum stomatal conductance (gs_{max}), maximum transpiration rate (E_{max}) and light- and CO_2-saturated net CO_2 assimilation rate (A_{sat}).

	A_{max} ($\mu mol\ m^{-2}\ s^{-1}$)	gs_{max} ($mol\ m^{-2}\ s^{-1}$)	E_{max} ($mol\ m^{-2}\ s^{-1}$)	A_{sat} ($\mu mol\ m^{-2}\ s^{-1}$)
'Royal Gala' (29 Apr)				
Net	7.1	0.083	2.42	20.7
No net	8.8	0.087	2.68	21.4
P-value	0.3490	0.8640	0.6840	0.8868
'Braeburn' (28 Apr)				
Net	11.0	0.159	3.26	21.6
No net	10.7	0.167	3.50	19.3
P-value	0.7605	0.7591	0.5671	0.1847
'Fuji' (27 Apr)				
Net	12.7	0.204	4.09	22.2
No net	10.4	0.150	3.26	23.2
P-value	0.0180	0.0009	0.0012	0.7742
'Cripps' Pink' (29 Apr)				
Net	12.1	0.197	4.18	26.7
No net	11.0	0.189	4.30	25.9
P-value	0.3950	0.6742	0.6813	0.5944
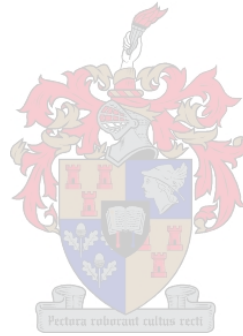
Table 8: Midday leaf water potential (MPa) measured during 2005 under 20% black protective netting

	Before harvest	After harvest
'Royal Gala'	(4 Feb 05)	(11 Mar 05)
Net	-0.20	-2.70
No net	-0.20	-3.30
P-value	0.5016	0.0107
'Braeburn'	(25 Jan 05)	(29 Apr 05)
Net	-1.20	-1.80
No net	-2.04	-1.83
P-value	0.0312	0.6912
'Fuji'	(10 Jan 05)	(29 Apr 05)
Net	-0.18	-1.64
No net	-0.20	-1.79
P-value	0.0693	0.1574
'Cripps' Pink'	(4 Feb 05)	
Net	-2.20	
No net	-2.38	
P-value	0.0182	
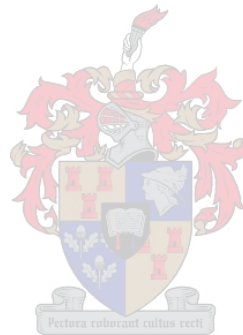
Table 9: Leaf nitrogen concentration (mg g^{-1}) at the beginning and the end of the 2003/04 and 2004/05 seasons for netted and non netted treatments and between beginning and end season measurements (no interaction was found for treatment*date)

Treatment	2004	2005	Date	2004	2005
'Royal Gala'					
Net	2.21	2.22	Beginning of season	2.31	2.38
No net	2.25	2.10	End Season	2.15	1.94
P-value	0.5894	0.1983	P-value	0.0748	0.0017
'Braeburn'					
Net	2.60	2.48	Beginning of season	2.87	2.71
No net	2.61	2.37	End Season	2.34	2.15
P-value	0.8774	0.4006	P-value	0.0004	0.0023
'Fuji'					
Net	2.52	2.39	Beginning of season	2.80	2.58
No net	2.56	2.50	End Season	2.29	2.30
P-value	0.7100	0.3433	P-value	0.0016	0.0377
'Cripps' Pink'					
Net	2.17	2.33	Beginning of season	2.37	2.75
No net	2.37	2.47	End Season	2.16	2.05
P-value	0.0195	0.7612	P-value	0.0156	< 0.0001
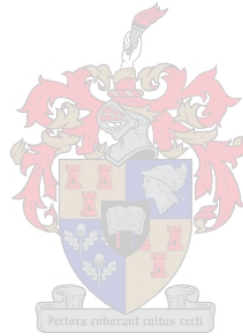
CHAPTER 5 – Heat stress resistance of blushed apple fruit grown under black shade netting, as determined by chlorophyll fluorescence (Fv/Fm).

ABSTRACT

Detached fruit from four blushed apple cultivars grown under black 20% shade netting or in the open were exposed to five different oven temperatures ranging from 35°C to 55°C (fruit surface temperature of 31 – 53ºC) and for different lengths of time (two, four, six or eight hours). Injury to the photosynthetic apparatus was measured by means of maximum quantum yield of fluorescence (Fv/Fm) immediately after removal from ovens and after a 12h recovery period. Only 'Fuji' showed significant interaction between shade net/control treatments and time of exposure, with netted apples showing lower Fv/Fm values after two hours than control apples, but not for longer durations. 'Fuji', 'Royal Gala' and 'Cripps' Pink' showed significant interaction between shade net/control treatments and temperature treatments for measurements of Fv/Fm immediately following exposure as well as following a 12h recovery period, with netted fruit having lower Fv/Fm values at 45°C in all cases. All fruit exposed to 35 or 40°C showed no signs of a decrease in Fv/Fm. Fruit exposed to 45°C showed reductions in Fv/Fm after two or four hours exposure, with further decreases thereafter. 'Fuji' showed the most resistance at 45ºC with higher Fv/Fm values than the other cultivars, particularly after the recovery period. Fv/Fm for 'Fuji' was zero after four hours of exposure to 50ºC, and for the other cultivars after six hours. Exposure to 55ºC resulted in all the cultivars having zero Fv/Fm values after four hours. 'Braeburn' could withstand temperatures of 50ºC up to two hours. 'Royal Gala' and 'Fuji' showed intermediate tolerance to high temperatures and 'Cripps' Pink' was found to have very low heat tolerance.

Keywords: Apple, chlorophyll fluorescence, heat stress, *Malus domestica*, photosynthetic injury, shade netting, temperature**.**
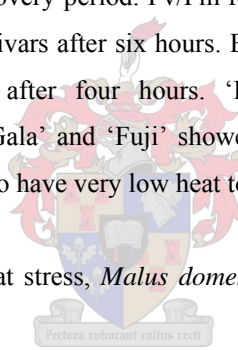
INTRODUCTION

The measurement of chlorophyll fluorescence has been shown to be a useful technique in estimating the efficiency of the chlorophyll apparatus in applications such as the measurement of chemical stress (inhibitors, fertilisers, gases), physical stress (light and temperature), and biosensing (productivity, resistance to stress) (Manuel et al., 2001). Chlorophyll fluorescence and gas exchange measurements provide the experimental interface between the plant response to the environment and the biochemical mechanisms that determine this response (McDermit et al., 2000). Maximal fluorescence (Fm) decreases after exposure to high but not injurious temperatures. More severe heat treatment causes an increase in the fluorescence value as measured immediately after illumination

(Fo) and a decrease of Fm. This will cause inhibition of the activity of photosystem two (PS Π) (Manuel et al., 2001). A decrease of the ratio between variable fluorescence (Fv, Fm-Fo) and Fm (Fv/Fm) represents the maximum quantum yield of fluorescence and is a good indicator of the damage caused when plants undergo diverse types of environmental stresses (Manuel et al., 2001).

Chlorophyll fluorescence has been evaluated as a rapid indicator of low O_2 and high CO_2 stress in apples stored over different time durations and different temperatures (DeEll et al., 1998). The study showed that chlorophyll fluorescence techniques can detect low O_2 or high CO_2 stress in apple prior to the development of associated disorders, and thus has potential as a rapid and non-destructive method to screen for atmospheric stress tolerance in apples. Studies have also been done to correlate fluorescence as a non destructive method, with destructive determinations of maturation, ripening and senescence of apple (Song et al., 1997). Chlorophyll fluorescence has been investigated as a signal of freezing and heat injury in apple fruit (Song et al., 2001). Fruit were kept at 0ºC and at 46ºC for different time periods, after which they were transferred to 20ºC and evaluated after one, two, four, and seven days. The extent of heat and freezing stress was found to correlate with chlorophyll fluorescence (Song et al., 2001). Fan et al. (2005) also showed chlorophyll fluorescence to be effective as a means for determining heat stress of apple fruit, when exposed to temperatures of 46ºC for different time periods, followed by cold storage.

Previous studies have shown that apple trees grown under reduced light levels have lower photosynthetic rates than those grown in full sun conditions (Barden, 1977). Ebert and Casierra (2000) showed net CO_2 assimilation rate to be higher for most of the day under protective netting. In contrast, Stampar et al. (2001) reported net photosynthesis in treatments covered with black netting to be lower than uncovered treatments. The influence that protective netting might have on the photosynthetic capacity of apple trees may be cultivar specific. The photosynthetic system can also be damaged by exposure to high light and temperature, which would cause the reaction centre of photosystem two to be inactivated, or damaged (Taiz and Zeiger, 2002). When this occurs, dynamic (temporary decrease of the photosystem) or in severe cases chronic photoinhibition (long lasting damage of the photosystem) could occur (Taiz and Zeiger, 2002). Leaves that grow in full sunlight contain a substantially larger pool of xanthophylls assisting in the dissipation of excess light energy, compared to shade leaves. Sun leaves also have a higher ability to dissipate heat by the emission of long wave radiation, by sensible and evaporative heat loss (Ort, 2001). It is thus clear that leaves and probably fruit of sun and shade grown trees differ in their acclimation to high light and heat.

This study was done to evaluate the extent of heat stress injury that different combinations of high temperature and duration of exposure might have on blushed apples developed under 20% shade netting. Initial injury levels (reductions in Fv/Fm) and the ability of the photosynthetic

apparatus to recover were measured to determine possible differences in heat acclimation between net and control treatments. The hypothesis was that fruit from the uncovered control trees would be more resistant to and recover better from heat stress than fruit from under the netting.

MATERIALS AND METHODS

Heat stress injury tests were done on blushed apple cultivars on 28 January 2004 on 'Royal Gala' (RG) and 'Cripps' Pink' (CP), and on 5 February 2004 on 'Braeburn' (BR) and 'Fuji' (FU). The trial was laid out as described in Chapter 2 using net and non-netted treatments. 60 Sun-exposed apples per net or control treatment were randomly picked for each cultivar, of which 12 apples were placed in the dark in each of five ovens set to different temperatures of 35, 40, 45, 50 or 55°C. The fruit were kept in the ovens for two, four, six or eight hours. After every time period, three fruit per net/control treatment were removed from each oven and allowed to recover at room temperature under weak light for 12 hours. Dark-adapted maximum quantum yield of fluorescence (Fv/Fm) was used to determine heat injury of the apples, using a fluorimeter (FMS2, Hansatech Instruments, King's Lynn, UK). Initial Fv/Fm of all the fruit was measured at room temperature before placement in the ovens. After the fruit were removed from the ovens, Fv/Fm was immediately measured, as well as fruit surface temperature using an infrared thermometer (Raynger MX 4, Raytek Corporation., Berlin, Germany). Fv/Fm and fruit surface temperatures were again measured after a recovery period.

Statistical analysis

60 Sun-exposed apples per net or control treatment were randomly picked for each cultivar, of which 12 apples were placed in each of five ovens set to 35, 40, 45, 50 or 55°C. The fruit were kept in the ovens for two, four, six or eight hours. The experimental design was completely randomised, and the data was analysed using a three-way ANOVA, with net treatment (trt), temperature (temp) and duration of heat stress (time) as factors, and the General Linear Models (GLM) procedure of SAS (Enterprise Guide VI, realese1.3; SAS Institute, 1996, Cary, NC, USA). Significance was set at $P \leq 0.05$.

RESULTS

Initial Fv/Fm before the start of heat treatments was measured to ensure that all the fruit used were of good quality (data not shown). The mean fruit surface temperature measured on the fruit over all experiments was 31-32°C, 36°C, 43-44°C, 44-47°C and 50-53°C at oven air temperatures of 35, 40 45, 50 and 55°C, respectively.

Significant Three-way interactions (Time*Trt*Temp) were only found on 'Fuji' (Table 7, 8) with fruit taken from the netted area having slightly lower Fv/Fm values when exposed to 45°C after 6-8 hours than fruit from the non netted area. Two-way interactions were, however, significant for all the cultivars and will be discussed in detail.

In 'Braeburn' there was no significant interaction between field treatments and time of exposure immediately after removal from the ovens (Fig 1a). The interaction for recovery after heat exposure between Treatment and time (Trt*Time) also showed no significant results (Fig 1d). There was however significant interaction between temperature and time (Temp*Time) for Fv/Fm measured immediately after heat treatment and following recovery (Fig 1b, e, Tables 1, 2). Fv/Fm of fruit exposed to 35 and 40°C remained high, while fruit exposed to 45°C showed a marked decrease in Fv/Fm after four hours (Fig 1b). Fv/Fm of fruit exposed to 50ºC was still high after two hours of exposure but then dropped significantly after 4 hours and reached zero after six hours of heat exposure. Fv/Fm of fruit exposed to 55°C reached zero after 4 hours of exposure. Following the 12 hour recovery period (Fig 1e), fruit exposed to 35 and 40°C was not negatively affected by the heat exposure and the Fv/Fm values remained the same as before treated. The fruit exposed to 45°C showed a significant recovery in Fv/Fm over all the exposure times but did not fully recover after six and eight hour treatments. A further reduction in Fv/Fm to zero was measured for the fruit exposed to 50 and 55°C for 4 hours. No significant interaction was found between field treatment and temperature (Fig 1c,f).

In 'Royal Gala' there was no significant interaction between field treatments and time of exposure immediately after removal from the ovens (Fig 2a, Table 3). The interaction for recovery after heat exposure between Treatment and time (Trt*Time) showed significant results with the netted fruit having better recovery after two and four hours of exposure and non-netted fruit recovering better after six and eight hours (Fig 2d). Significant interaction was found between temperature and time (Temp*Time) both before and after the recovery period (Fig 2b, e, Tables 3, 4). Exposure to 35° and 40°C had no influence on Fv/Fm immediately following treatments and after recovery. Fruit exposed to 45°C showed a rapid reduction in Fv/Fm after 2 hours exposure reaching a minimum after six to eight hours of exposure (Fig 2b). Fruit exposed to 45°C for 2-4 hours recovered almost fully. Fruit exposed for six hours and longer, however, remained at a Fv/Fm of about 0.4. Exposure of fruit to 50 and 55°C resulted in very low Fv/Fm values, reaching zero after six hours for the 50°C treatment and after four hours for the 55°C treatment (Fig 2b) with little recovery after 12 hours (Fig 2e). Significant interaction between Trt*Temp (Fig 2c, f, Tables 3, 4) was due to fruit from the non-netted treatment having higher Fv/Fm values than fruit from the netted treatment after exposure to 45ºC, when measured both before and after recovery.

No significant interaction between field treatment and time of exposure was found for 'Cripps' Pink' (Fig 3a, d, Tables 5, 6). 'Cripps' Pink' did, however, show significant 2-way interactions between temperature and time (Temp*Time) (Fig 3b, e, Tables 5, 6). Exposure of apples to 35°C and 40°C had no influence on Fv/Fm. Exposure to 45°C resulted in a rapid reduction of Fv/Fm as exposure time increased reaching a value of 0.2 after 8 hours (Fig 3b), and the fruit did not recover well (Fig 3d) Fruit exposed to 50°C and 55°C had Fv/Fm values of close to 0.2 after two hours, with the fruit exposed to 50°C reaching zero after six hours, and fruit exposed to 55°C reaching zero after four hours. There was no recovery of the fruit exposed to 50°C and 55°C. Significant interaction between field treatment and temperature was due to a significantly stronger decrease in Fv/Fm at 45ºC and Fv/Fm in netted compared to non-netted fruit (Fig 3c), with the non-netted fruit recovering to above an Fv/Fm at 0.7 and the fruit from the netted treatment recovering poorly (Fig 3f).

In 'Fuji' significant interaction was found between field treatment and time (Trt*Time) after removal from the ovens (Fig 4a) but not after recovery (Fig 4b, Tables 7, 8). Fruit from the non-netted area had higher Fv/Fm values after two hours of exposure than fruit from the netted treatment (Fig 4a). Interaction between time and temperature (Fig 4b, e, Tables 7, 8) showed that, as for the other cultivars, temperatures of 35°C and 40°C had no effect on Fv/Fm values. A linear reduction in Fv/Fm over time was found for fruit exposed to 45°C (Fig 4b). Fruit exposed for two hours recovered fully and fruit exposed for four hours recovered almost fully (Fig 4e). Recovery of the fruit exposed for six and eight hours was also good reaching Fv/Fm values of above 0.7 after six hours and close to 0.6 after eight hours of exposure. Fruit exposed to 50°C and 55°C had Fv/Fm values of close to zero after 4 hours of exposure (Fig 4b). Slight recovery occurred for fruit exposed for two hours (Fig 4e). Fruit exposed for longer times did not recover. Interaction between field treatments and temperature (Fig 4c, f, Tables 7, 8) was due to a smaller reduction in Fv/Fm at 45°C in fruit from the non-netted compared to the netted treatment. Non netted fruit exposed to 45°C showed a very high recovery capability, with fruit from the netted treatment recovering less well (Fig 4f). Recovery of the non-netted fruit also remained higher than that of the netted fruit after exposure to 50°C.

DISCUSSION

Compared to leaves the acclimation of fruit to its environment is unique in two aspects. First, fruit shades itself as it develops. Secondly, fruit has much lower capacity for photosynthesis than leaves (Ma and Cheng, 2003). It is therefore expected that there is more excess absorbed PPFD and greater need to dissipate the excess excitation energy for sun exposed sides of fruit. Ma and Cheng (2003) found that the sun exposed peel of apple fruit compared to the shaded side had a larger xanthophyll

cycle pool size and a higher conversion state and higher activities of the enzymes in the ascorbate glutathione cycle. A larger size and a higher reduction state of the ascorbate pool and the glutathione pool were also measured. This would indicate that both the xanthophyll cycle and the ascorbate-glutathione pathways are acclimated to the prevailing light exposure within the tree canopy to meet the respective need for dissipating excess PPFD (Ma and Cheng, 2003). In the sun exposed peel of the exterior fruit, the xanthophyll cycle operates at its full capacity in order to dissipate excess excitation energy (Ma and Cheng, 2003).

Exposure of fruit to excessive temperatures causes thermal death of epidermal and sub-epidermal cells resulting in browning of the apple skin defined as necrosis (Schrader et al., 2001). The severity of fruit injury due to high temperatures as found in this study, may be related to the physiochemical properties of the fruit skin, such as thickness and composition of the epicuticular wax layer and the concentration and quantity of skin pigments of the fruit skin (Wünsche et al., 2004). Schrader et al. (2003) reported that sunburn damage of the type he termed "browning" occurred when fruit surface temperature was between 46°C and 49°C, depending on the cultivar, and that the threshold for necrosis was about 52°C. The results of this study confirmed these findings. It was found that the Fv/Fm values of the fruit for all the cultivars and from both treatments, declined when the fruit was exposed to 45°C air temperature for longer durations when the fruit surface temperature was 43-44°C, pointing to the inhibition of photosystem two (PS Π). Song et al. (2001) found that apples exposed to 46°C fruit surface temperature for 12 hours showed a decrease in Fv/Fm of more than 50%. No change in Fv/Fm was, however, found after eight hours of exposure to 45°C.

Measurements taken directly after heat exposure and after the recovery period showed that fruit from the netted treatment were more sensitive at a temperature of 45ºC and had lower Fv/Fm values than fruit from the control treatment. The reason for this could be that fruit exposed to heat and high light conditions during growth, are better acclimated to these conditions by having protective mechanisms such as better developed heat shock proteins, thicker wax layers and more pigments (Ma and Cheng, 2003) that provide protection against heat. Wünsche et al. (2004) stated that sunburn damage more readily occurs when there is a rapid shift in weather from cloudy and cool, to sunny and hot conditions, not giving fruit time to acclimate.

As could be seen in this study fruit exposed to temperatures above 50°C showed total loss of PS Π function and Fv/Fm values were close to zero. 'Fuji' showed the most recovery 12 hours after exposure, suggesting that this cultivar is more tolerant than the others. 'Fuji' from outsie the netting showed less decrease in Fv/Fm than fruit from under the netting during exposure at 45°C (Fig 4c, f). However, damage occured earlier after two-hour treatments in shaded compared to non-shaded fruit (Fig 4a,d). It must however be kept in mind that during oven treatments no additional moisture was

added to the ovens and dehydration of fruit during heat treatments could have added to the stress conditions. It is thus clear that each cultivar has a different tolerance to heat stress conditions. Similar studies done by Song et al. (2001) also found cultivars to differ in their tolerance to heat stress. Fruit taken from non-netted areas thus have more adequate coping capabilities at higher temperatures than fruit grown under protective netting. Fruit covered by protective netting could thus be severely damaged if the netting is removed or damaged during the fruiting season. Care should be taken to ensure that nets are well maintained and fastened.

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Table 1: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Braeburn' apple, for netted and control fruit (Trt) at different oven temperatures (Temp) for Fv/Fm after heat treatment.

	Degrees of freedom	F-value	Pr>F
Model	39	68.29	<.0001
Time	3	152.07	<.0001
Trt	1	1.79	0.1842
Temp	4	440.67	<.0001
Time*Trt	3	1.17	0.3248
Time*Temp	12	34.86	<.0001
Trt*Temp	4	0.08	0.9878
Time*Trt*Temp	12	1.71	0.0808

Table 2: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Braeburn' apple, for netted and control fruit (Trt) at different oven temperatures (Temp) for Fv/Fm after heat treatment and twelve hour recovery time.

	Degrees of freedom	F-value	Pr>F
Model	39	49.15	<.0001
Time	3	82.82	<.0001
Trt	1	0.03	0.8600
Temp	4	340.30	<.0001
Time*Trt	3	0.37	0.7754
Time*Temp	12	25.26	<.0001
Trt*Temp	4	0.10	0.9806
Time*Trt*Temp	12	0.21	0.9979

Table 3: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Royal Gala' apple, for netted and control fruit (Trt) at different oven temperature (Temp) for Fv/Fm after heat treatment.

	Degrees of freedom	F-value	Pr>F
Model	39	29.82	<.0001
Time	3	20.43	<.0001
Trt	1	0.89	0.3483
Temp	4	251.88	<.0001
Time*Trt	3	0.69	0.5638
Time*Temp	12	5.54	<.0001
Trt*Temp	4	4.46	0.0027
Time*Trt*Temp	12	0.59	0.8420

Table 4: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Royal Gala' apple, for netted and control fruit (Trt) at different oven temperature (Temp) for Fv/Fm after heat treatment and twelve hour recovery time.

	Degrees of freedom	F-value	Pr>F
Model	39	22.32	<.0001
Time	3	16.68	<.0001
Trt	1	0.01	0.9055
Temp	4	178.53	<.0001
Time*Trt	3	2.73	0.0490
Time*Temp	12	4.54	<.0001
Trt*Temp	4	6.41	0.0002
Time*Trt*Temp	12	1.49	0.1456

Table 5: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Cripps' Pink' apple, for netted and control fruit (Trt) at different oven temperature (Temp) for Fv/Fm after heat treatment.

	Degrees of freedom	F-value	Pr>F
Model	39	75.21	<.0001
Time	3	30.09	<.0001
Trt	1	1.58	0.2122
Temp	4	675.21	<.0001
Time*Trt	3	1.81	0.1526
Time*Temp	12	8.67	<.0001
Trt*Temp	4	4.16	0.0041
Time*Trt*Temp	12	1.21	0.2899

Table 6: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Cripps' Pink' apple, for netted and control fruit (Trt) at different oven temperature (Temp) for Fv/Fm after heat treatment and twelve hour recovery time.

	Degrees of freedom	F-value	Pr>F
Model	39	49.53	<.0001
Time	3	5.27	0.0023
Trt	1	8.92	0.0037
Temp	4	455.31	<.0001
Time*Trt	3	1.38	0.2562
Time*Temp	12	3.36	0.0005
Trt*Temp	4	8.46	<.0001
Time*Trt*Temp	12	0.60	0.8320

Table 7: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Fuji' apple, for netted and control fruit (Trt) at different oven temperatures (Temp) for Fv/Fm after heat treatment.

	Degrees of freedom	F-value	Pr>F
Model	39	102.88	<.0001
Time	3	36.17	<.0001
Trt	1	11.73	0.0010
Temp	4	928.37	<.0001
Time*Trt	3	4.58	0.0052
Time*Temp	12	9.63	<.0001
Trt*Temp	4	5.35	0.0007
Time*Trt*Temp	12	2.33	0.0130

Table 8: Abbreviated ANOVA table for analysis of the effect of duration of exposure (Time) of 'Fuji' apple, for netted and control fruit (Trt) at different oven temperature (Temp) for Fv/Fm after heat treatment and twelve hour recovery time.

	Degrees of freedom	F-value	Pr>F
Model	39	44.86	<.0001
Time	3	27.22	<.0001
Trt	1	13.66	0.0004
Temp	4	377.09	<.0001
Time*Trt	3	2.11	0.1051
Time*Temp	12	7.01	<.0001
Trt*Temp	4	3.98	0.0054
Time*Trt*Temp	12	3.29	0.0007
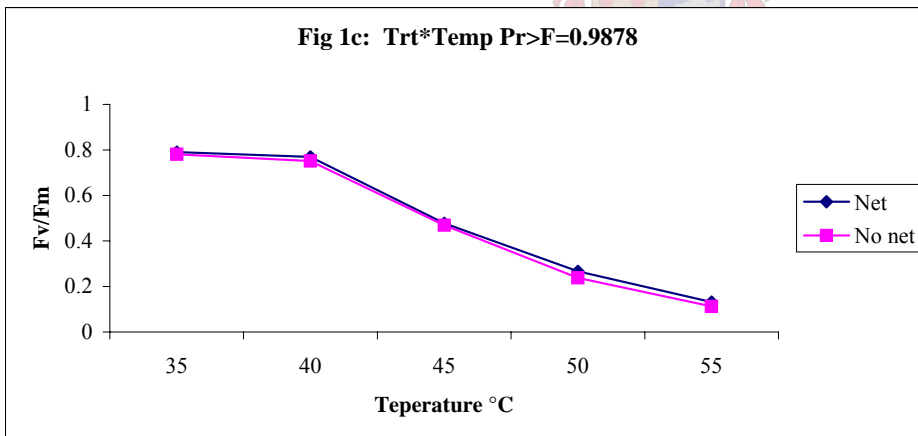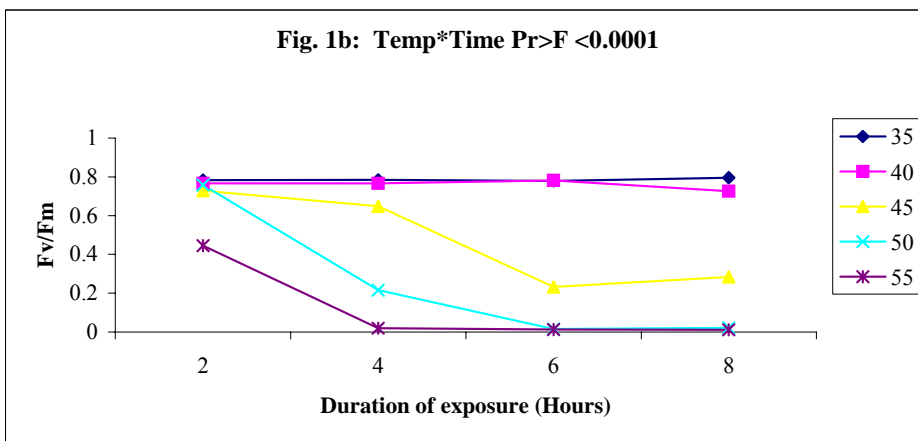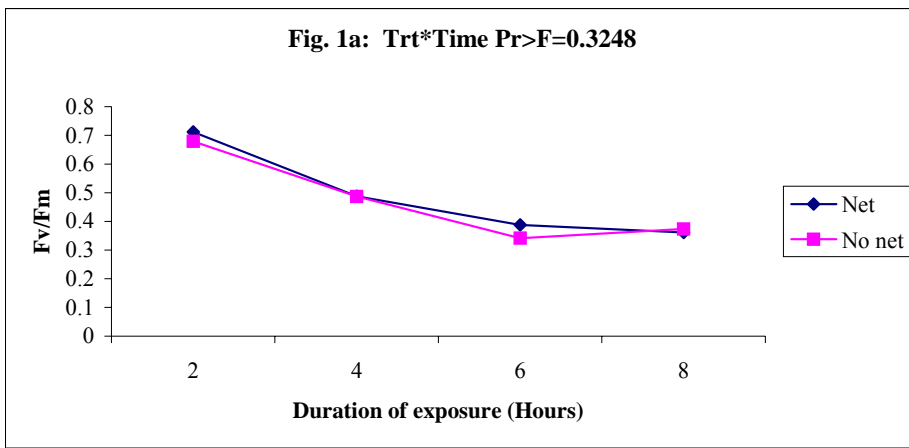
Figure 1abc. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Braeburn' apples immediately following heat treatment .
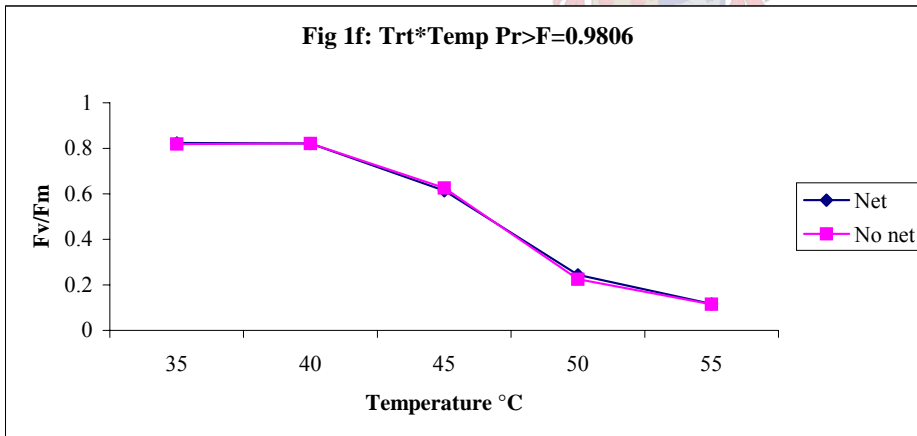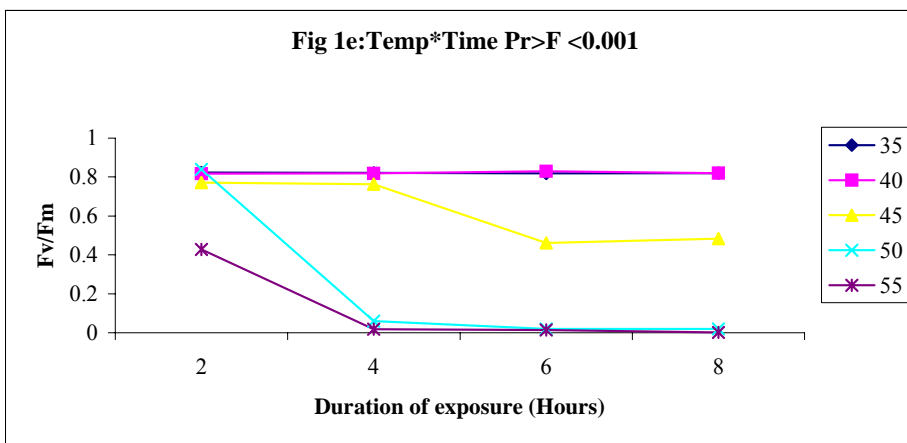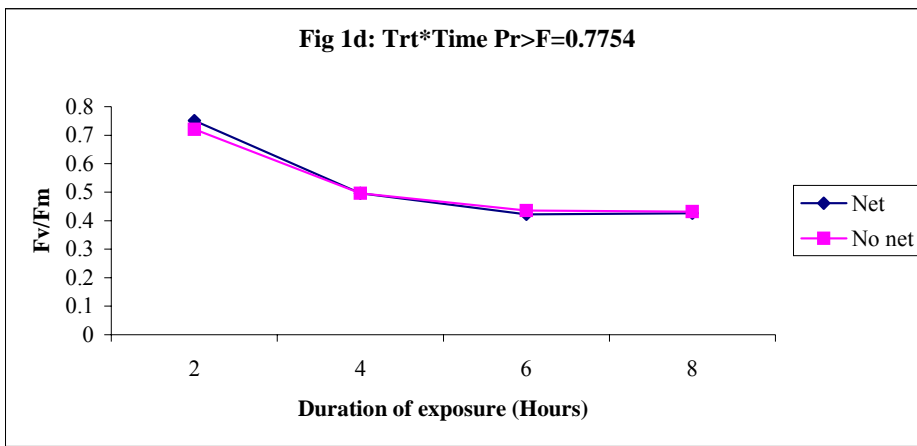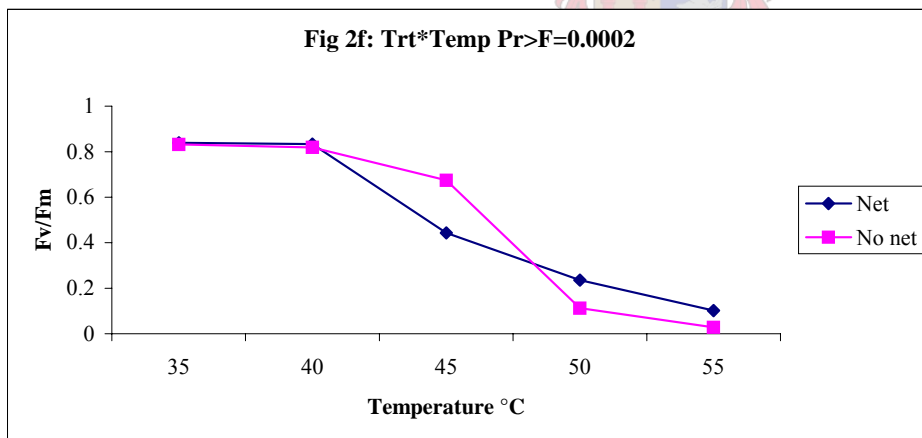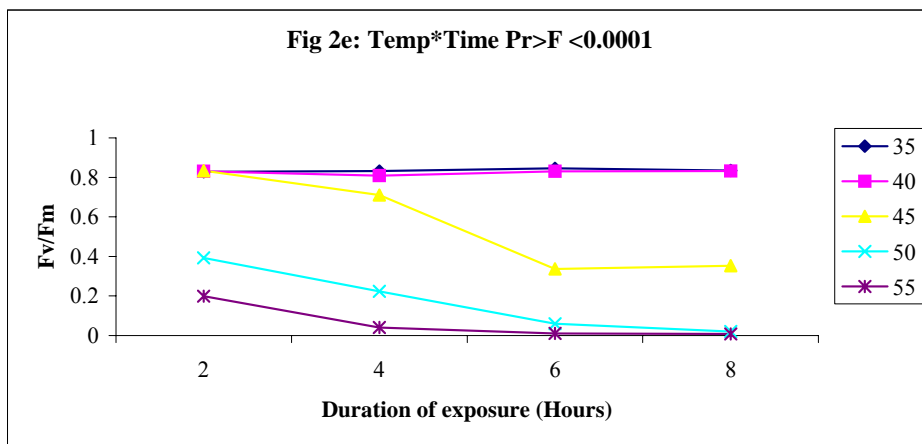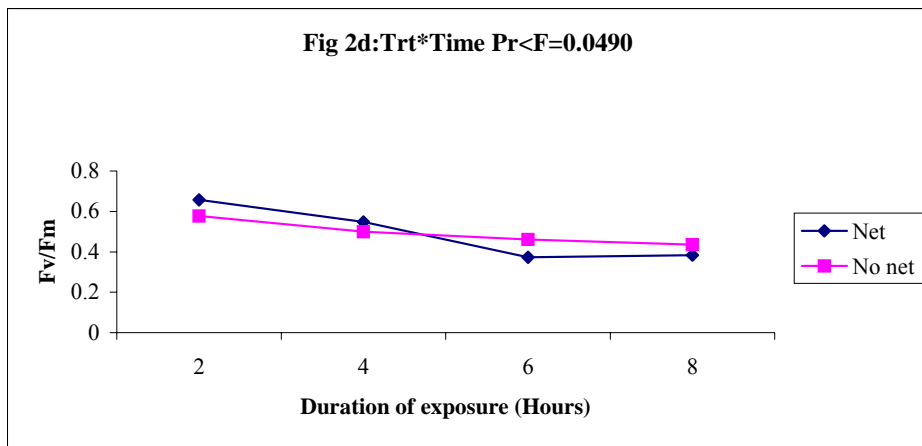
Figure 1def. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Braeburn' apples immediately following heat treatment and recovery
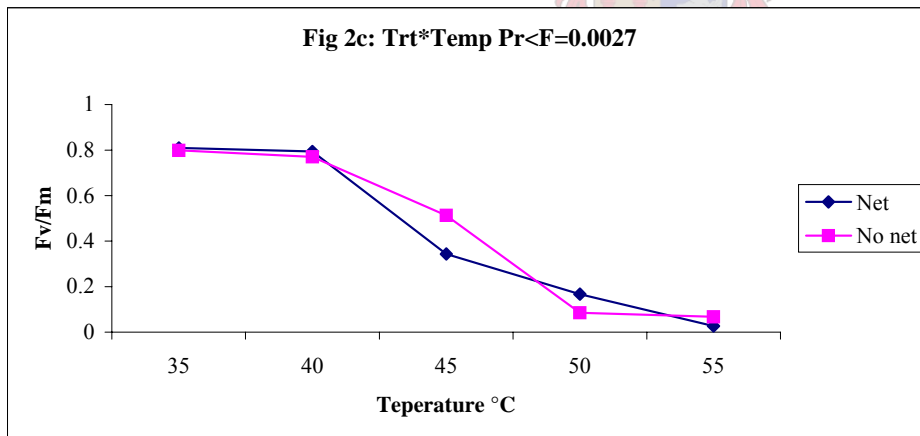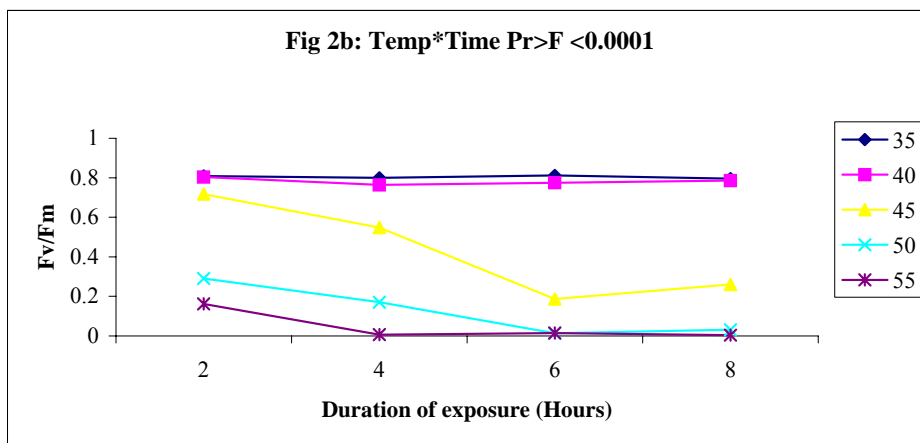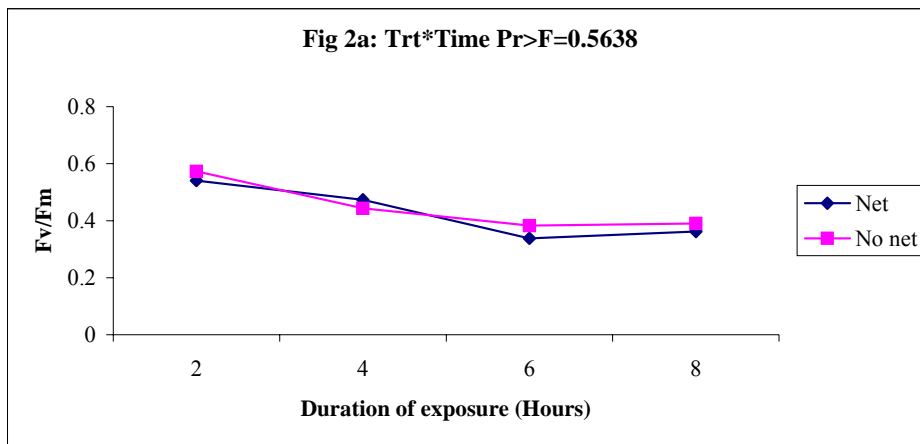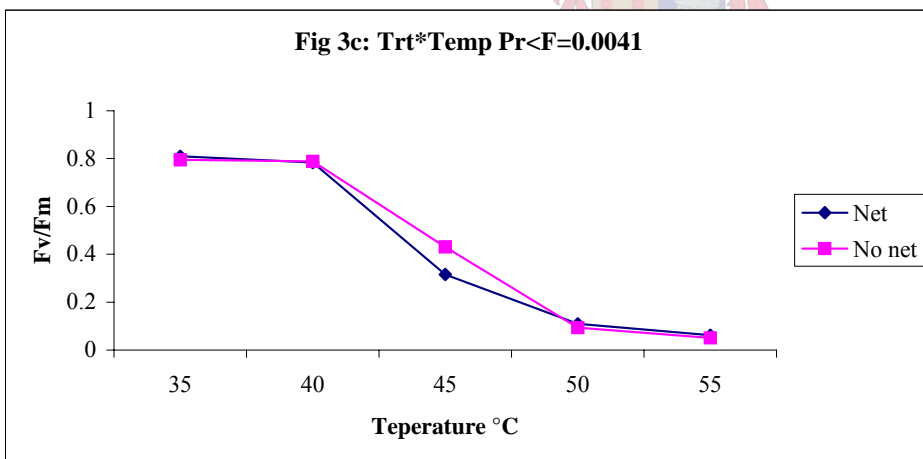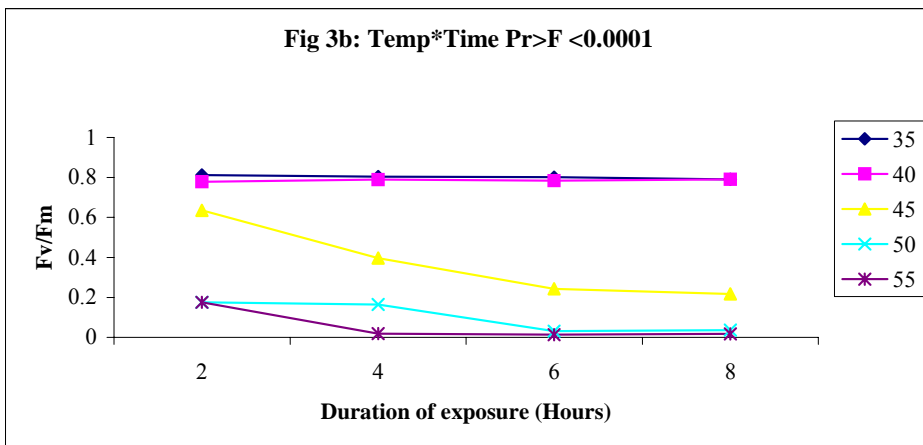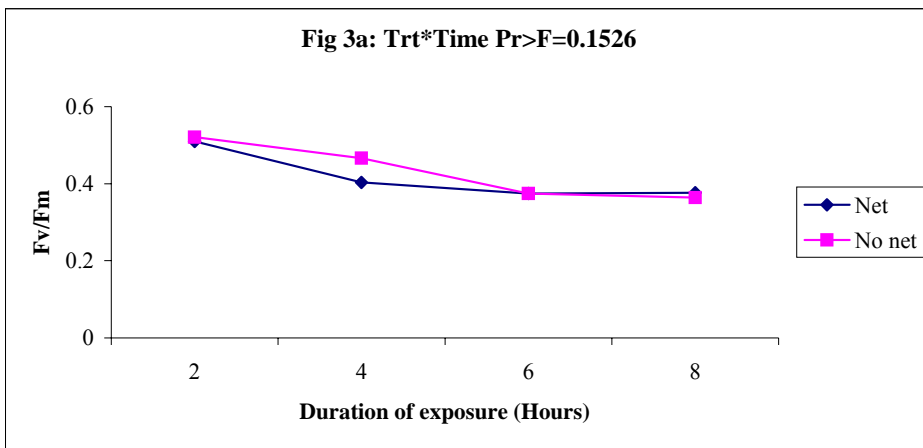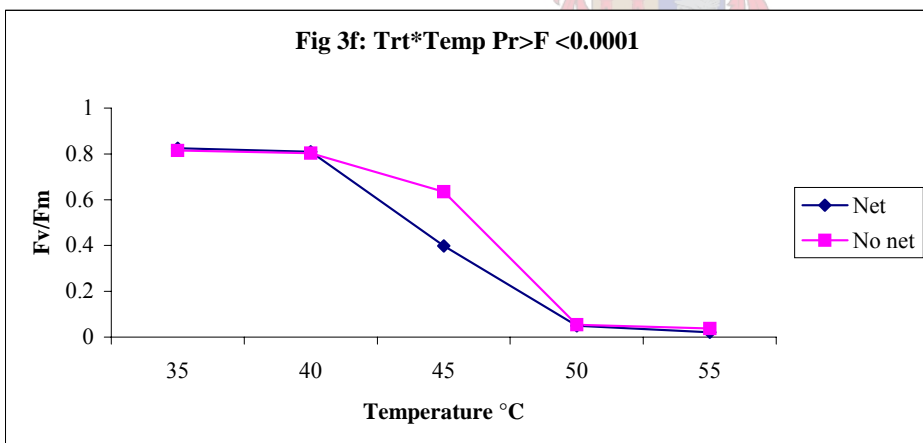
Figure 2abc. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Royal Gala' apples immediately following heat treatment

Figure 2def. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Royal Gala' apples immediately following heat treatment and recovery
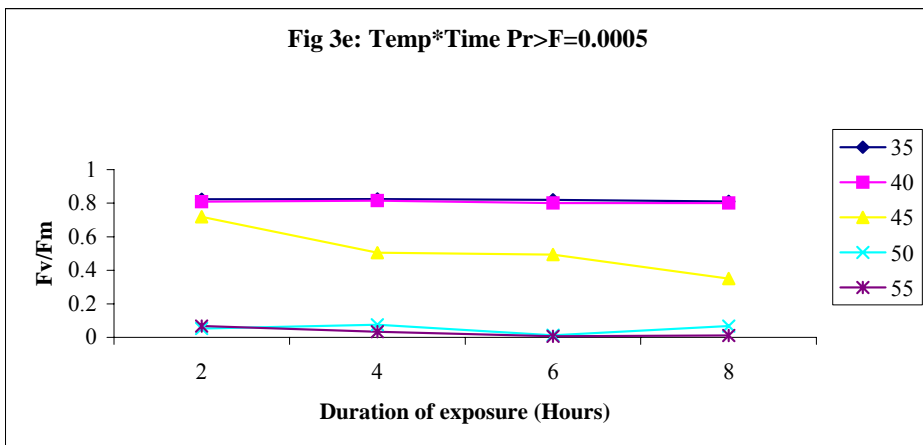
Fig 3a: Trt*Time Pr>F=0.1526

Fig 3b: Temp*Time Pr>F <0.0001

Fig 3c: Trt*Temp Pr<F=0.0041

Figure 3abc. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Cripps' Pink' apples immediately following heat treatment
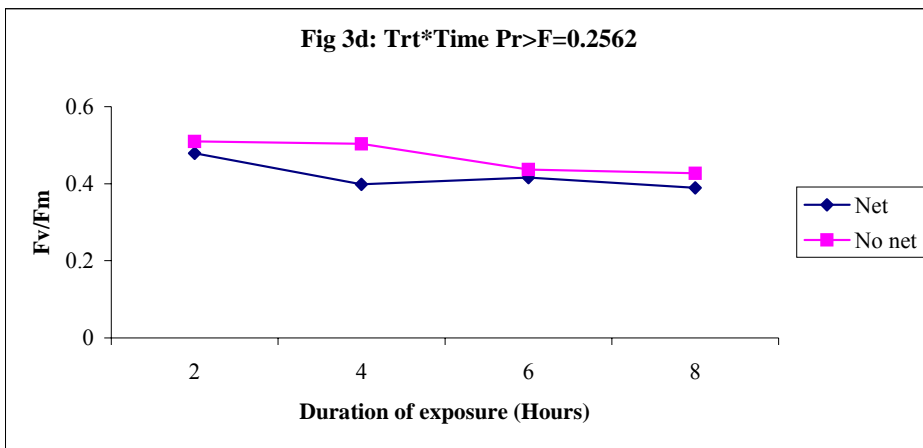
Fig 3d: Trt*Time Pr>F=0.2562

Fig 3e: Temp*Time Pr>F=0.0005

Fig 3f: Trt*Temp Pr>F <0.0001

Figure 3def. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Cripps' Pink' apples immediately following heat treatment and recovery

Fig 4a: Trt*Time Pr>F=0.0052

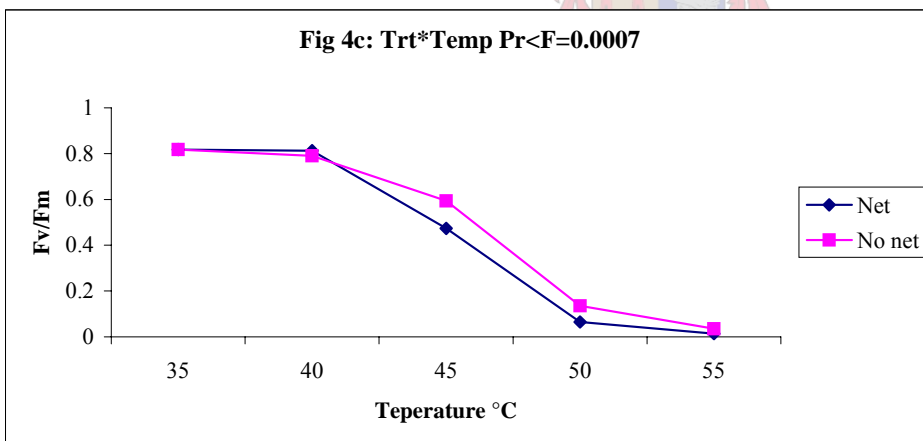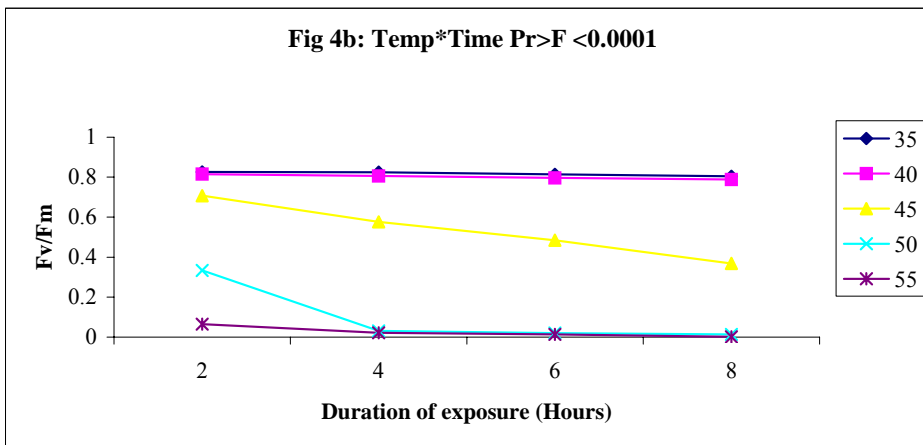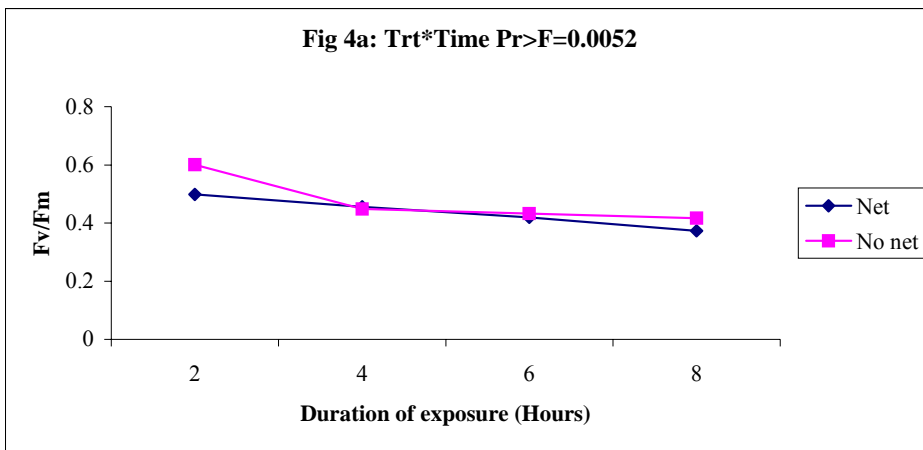**Fig 4b: Temp*Time Pr>F <0.0001**

Fig 4c: Trt*Temp Pr<F=0.0007

Figure 4abc. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Fuji' apples immediately following heat treatment
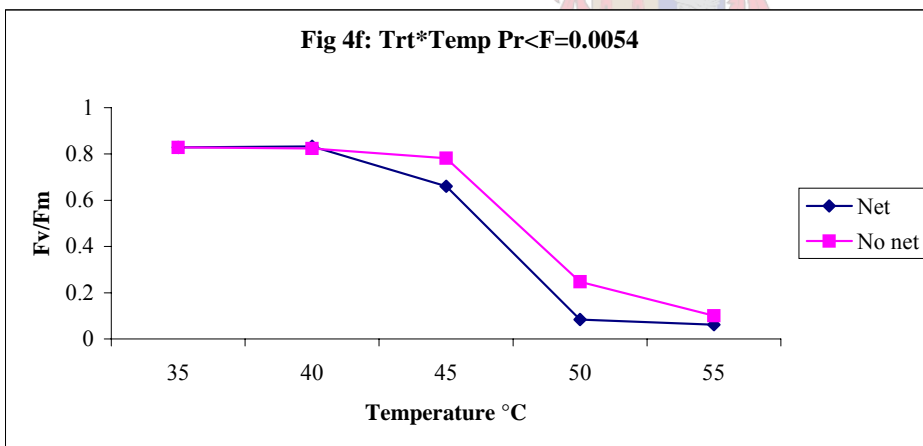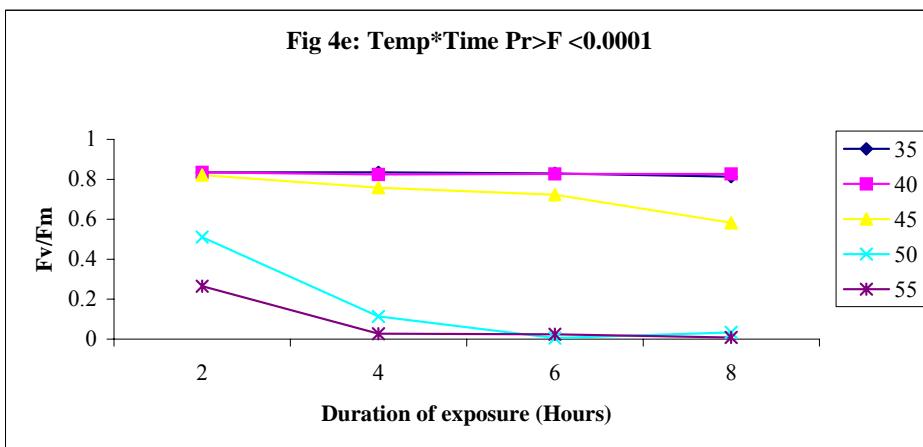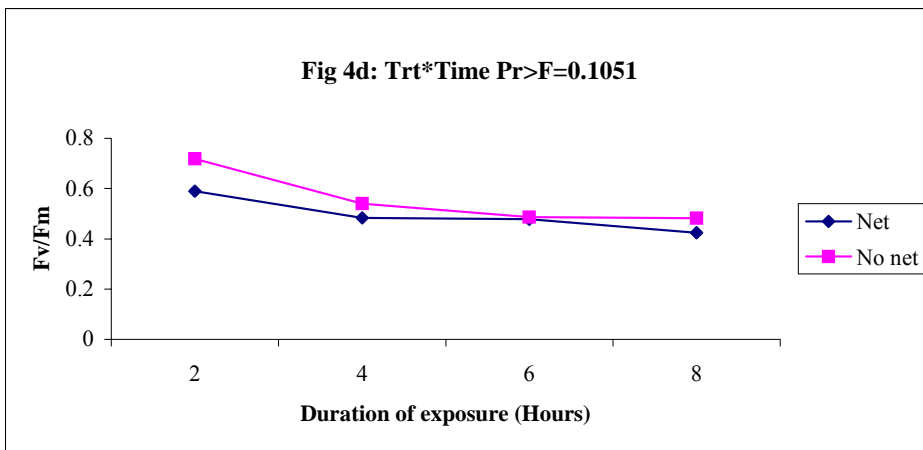
Figure 4def. Two-way interaction effects of temperature, time of heat treatment and field netting treatment on Fv/Fm of 'Fuji' apples immediately following heat treatment and recovery

CHAPTER 6 – The effect of different colour shade netting on fruit quality of 'Granny Smith' apple.

ABSTRACT

The effect of black, blue and grey netting on fruit quality at harvest was investigated for 'Granny Smith' apple during the 2003/04 and 2004/05 seasons. Sunburn was significantly reduced from 20% to zero under black and blue netting in 2003/04 and reduced from 17% to 2% under the black netting during 2004/05. Blue and grey netting showed no statistically significant results during 2004/05 although mean sunburn incidence decreased from 17% to 6 and 7%. Red blush was significantly reduced under the black netting compared to the control. Fruit mass was increased during 2004/05 under all three netting treatments, and firmness was lower under black and grey netting but not under blue netting. A significant reduction in TSS was found under black and blue netting during 2003/04 and under black and grey netting during 2004/05. Percentage unviable seed, green skin colour, titratable acidity, percentage starch breakdown, stem end russet and the occurrence of *Fusicladium pyrorum* damage were unaffected by the installation of the netting.

Keywords: fruit quality, 'Granny Smith', shade netting, photosynthetic photon flux density, sunburn.

INTRODUCTION

The green apple cultivar 'Granny Smith' is the main export apple cultivar planted in South Africa. Being a green apple, blush colour formation is unwanted on the fruit skin and blushed fruit are rejected during packing. The appearance of red blush on the fruit skin near ripening is due to the accumulation of anthocyanins. The synthesis of these pigments is stimulated in particular by high light intensity and moderate temperatures (Reay, 1999; Grappadelli, 2003). 'Granny Smith' is also very sensitive to sunburn damage as described by Schrader et al. (2003). With the production of large volumes of high quality apples becoming the producer's main goal, producers are experimenting with control mechanisms such as over tree irrigation, reflective particle film application, protective netting and cultural practices such as urea spray applications to reduce blush colour formation and lower sunburn damage (Scott, 1989; Griessel et al., 1992; Parchomchuk and Meheriuk, 1996; Reay, 1999; Iglesias et al., 2002; Leite et al., 2002; Middleton and McWaters, 2002; le Grange et al., 2004; Schupp et al., 2004). Apple orchard productivity varies greatly between different climates or different years,

and it is difficult to determine the critical factors over such a range of climatic conditions (Lakso et al., 2001). With the installation of netting we would expect a decrease in the amount of photosynthetic photon flux density (Middleton and McWaters, 2002; Shahak et al., 2004) and fruit quality parameters such as fruit mass, total soluble solids and firmness could be negatively affected as reported for various apple cultivars (Scott, 1989; Campbell and Marini, 1992; Wagenmakers and Tazelaar, 1999; Stampar et al., 2001; Middleton and McWaters, 2002). This would however depend on the level of light reduction.

In this study we investigated the effect of 20% black, 30% blue and 20% grey netting on the light environment and fruit quality parameters of 'Granny Smith' apple. We hypothesized that there would be reductions in sunburn and red pigmentation under the netting and no negative effects on other fruit quality characteristics.

MATERIALS AND METHODS

Plant material

The trial was established in a commercial orchard located on the Du Toit Group farm, Vastrap, situated in the Witzenberg Valley in the Western Cape Province of South Africa (33°15'S 19°15'E, 901 m altitude), and was carried out during the 2003/04 and 2004/05 growing seasons. 'Granny Smith' apple trees (*Malus domestica Borkh*) planted during 1951 on seedling rootstock in a north-east by south-west row orientation with spacing of 6.71 m x 3.35 m and trained to a vase system, were used. Micro-jet sprinklers were used for irrigation and scheduling was based on neutron moisture probe measurements taken outside the netting. Due to drought conditions and thus water scarcity during 2004/05, irrigation was reduced to 40% of the required amount from December until harvest. Crop loads were not determined for this trial.

Treatments and experimental design

In 2002 the orchard was covered with 20% black netting over 7 rows, 30% blue netting over 4 rows, and 20% grey netting over 3 rows, in a 45° pitched roof structure (Addendum A, Fig 3, 4). The netting was installed over the centre of the orchard leaving trees to the outside of the orchard open to use as control. All three net types were installed in the same orchard. Trees were thinned using the normal thinning program stipulated by the farm management.

Photosynthetic photon flux density measurements

During both seasons the photosynthetic photon flux density (PPFD) was measured under the nets using a hand held light meter (LI-250 with LI-190SA quantum sensor, Li-Cor, Lincoln, Nebraska, USA). During the first season, measurements were done on 11 March 2004, a cloudless day, from 10h00 until 16h00 at 45 min intervals, alternating between treatments. This resulted in 8 sets of measurements during the course of the day. During the second season, measurements were done on 1 March 2005, from 10h00 to 16h00 at 30 min intervals, giving 12 sets of measurements for the day.

Fruit quality determination at harvest

Fruit samples of 60 fruit per replicate were randomly taken from three trees per row under the netted and non-netted area, over three rows. Trees covered by black and blue shade netting and from their respective controls were harvested on 18 March 2004, and during 2005 trees covered by black, blue and grey netting and from the control were harvested on 23 March. During 2004 control fruit sampling was done for each net type individually using six trees well away from the netted area to minimize any edge effect that could be caused by the netting. During 2005 only one control sample was taken for all net types using trees in the middle of the experimental control block.

Fruit samples were kept in a cold room until analysis could be done not more than one week after harvest. Before analysis the fruit were taken out of the cold room and left to reach room temperature. Sunburn damage was rated on a scale of zero to three, where Class 0 had no sunburn, Class 1 had light sunburn browning, Class 2 had darker sunburn browning, and Class 3 had necrotic sunburn as described by Schrader et al. (2003). In each class the percentage of sample apples having sunburn are reported. Individual fruit mass was determined using an electronic scale. Ground colour was assessed using a colour chart (Unifruco Research Services Ltd, Bellville, South Africa) with values 0.5-5.0 where 0.5=dark green and 5=yellow. Blush colour was determined using a colour chart (A32 Deciduous Fruit Board, Bellville, South Africa).

Fruit firmness was measured on opposite peeled cheeks of each fruit with a penetrometer (Southtrade fruit pressure tester, FT 327, Alphonsine, Italy), fitted with an 11mm diameter tip. During the second season fruit were cut in half and the number of viable and unviable seeds counted. During both seasons slices were cut from each fruit and juiced together and a TSS (total soluble solids) reading taken with a hand held refractometer (Atago PR-100 9501, ATAGO CO. Ltd., Tokyo, Japan). The same juice was used for the titratable

acid concentration (TA) analysis which was done during the second season only, by titration with 0.1 M NaOH to a pH of 8.2 using the automated titrator (Tritino 719S and Sample Chamber 674, Metrolum Ltd., Herisau Switzerland). Results were expressed as percentage malic acid (g 100g^{-1} juice). The percentage starch breakdown of the apples was determined by placing one half of the fruit in an iodine solution and evaluating the starch breakdown using the starch conversion chart for pome fruit (Unifruco Research Services, Bellville, South Africa). Stem-end russet was evaluated by using the respective USS chart. The fruit were individually rated (present/absent) for damage by *Fusicladium pyrorum* during the second season.

Statistical analysis

Due to the similarity in conditions between treatments (slope, soil type, tree density, irrigation, angle to sun – refer to Chapter 2 for similar approach) statistical analyses were done using ANOVA (P≤0.05) and the General Linear Models (GLM) procedure of SAS (SAS release 6.12P; SAS Institute, 1996, Cary, NC. USA) even though treatments were not randomised. Means comparisons were performed using Tukey's test at P≤0.05.

RESULTS

There were significant differences in PPFD under the netting treatments and the non-netted control (Table 1). The grey netting showed reductions in PPFD of 38 – 39% (Table 1) blue netting reduced PPFD by 32 – 38% and black netting by 31%.

During 2004 sunburn was eliminated under the black and blue netting, in all sunburn classes (Table 2), compared to 20% sunburn in the control fruit. During 2005, there was a significant reduction in sunburn under the black netting but the reductions under the blue and grey netting were not significant except under the grey netting for class 1 (mild browning) (Table 2).

No significant differences in fruit mass were found between treatments during 2004 (Table 3). Fruit mass was, however, significantly larger under the blue, grey and black netting compared to the controls, during 2005 (Table 3). Blush colour was reduced during 2004 under black and blue netting. Fruit firmness was significantly lower under the black netting during both seasons and under the grey netting during 2005 (Table 3). No difference was found under the blue netting. Significant reductions in TSS were found during both seasons under all the netting treatments except under the blue nets during 2005 (Table 3). No significant differences were found between treatments for percentage unviable seeds, ground (green)

colour, TA, percentage starch breakdown, incidence of stem end russet and damage by Fusi (*Fusicladium pyrorum*) (Table 3).

DISCUSSION

The uncertainty around the possible effect of shade/hail netting on fruit quality has been one of the reasons for the hesitation of apple producers in the Western Cape in installing protective netting. This study shows that netting of various colours affects certain fruit quality parameters on 'Granny Smith' apples.

Sunburn on apples has been defined as tissue damage caused by radiant heating of the fruit surface when directly exposed to sunlight (Parchomchuk and Meheriuk, 1996). Sunburn can be divided into two categories, namely sunburn necrosis, caused by the thermal death of epidermal and sub-epidermal cells when the peel reaches about 52ºC or higher, and sunburn browning, which is sub-lethal and results in a yellow, bronze or brown spot on the fruit skin surface (Schrader et al., 2001). Sunburn damage is one of the biggest causes of exportable yield losses for apple growers in warm areas. Our results show that netting reduces sunburn damage on 'Granny Smith' under black and blue netting. Sunburn was eliminated under the black and blue netting during the first season compared to the 20% sunburn found in the control. Similar results were reported by Middleton and McWaters (2002). Sunburn is caused by overheating of the fruit surface due to excessive levels of incoming solar radiation in combination with high ambient air temperature (Wünsche et al., 2001; Wünsche et al., 2004). Netting does not reduce the air temperature significantly but reduces the fruit surface temperature (See Chapter 2), suggesting that the reduction in sunburn under the netting is probably due to a reduction in direct sunlight reaching the fruit, including ultraviolet (UV).

The presence of red colouration (blush) is a very important consideration for the market value of the 'Granny Smith' apple cultivar. The cultivar is marketed as a green apple and is exportable only without blush. Producers from cooler areas with high light levels sometimes struggle to prevent blush colour formation on the fruit skin. The amount of light (visible and UV) that reaches the apple skin surface is largely responsible for the accumulation of anthocyanins and thus red colouration of the apple skin, and this is thought to serve a photoprotective function (Reay, 1999; Grappadelli, 2003). Installing shade netting over 'Granny Smith' orchards could thus serve a dual purpose: to prevent sunburn damage and to prevent blush colouration of the fruit skin. Blush colour as measured during the 2003/04 season was significantly reduced under the black netting, although from low levels in the control (Table 1). Reay (1999) found that the temperature combination of 4°C (induction)

followed by 20°C (synthesis) together with high UV-B and visible radiation was the most effective at stimulating the accumulation of anthocyanins in the skin of 'Granny Smith'. Reay (1999) also suggested that fruit temperatures above 30°C as often found in orchards, inhibits red colouration of 'Granny Smith' apples. Reduction in the light levels due to netting together with the correct temperatures in the orchard should aid in reducing red colouration. In this study it was found that the green ground colour was unaffected by the installation of the netting suggesting that chlorophyll concentration was unaffected by the change in the microclimate. To further ensure fruit of optimum colour, apples that are going to be held in long term storage should be picked as close as possible to the optimum harvest maturity stage to ensure maximum green fruit colour as indicated by Griessel et al. (1992), who found that chlorophyll a and b concentration declined after the optimum harvest date.

Exposure to sunlight plays an important role in the determination of final fruit size as found by Dennis (2003). Middleton and McWaters (2002) found that reduced fruit size and increased shoot growth occurred on vigorous trees under netting. However, fruit size was increased in trees under netting where vigour was controlled. The vigour of apple trees grown under netting should be easier to control if dwarfing rootstocks are used and the negative effect of the netting on fruit size and yield is reduced. Bepete and Lakso (1998) showed that early season fruit growth rates could be reduced by up to four times the normal when 60% or more shade is introduced early in the season. A slight reduction was found in fruit size for 'Jonathan' when covered by 20% black netting (Gardner and Fletcher, 1990). Shoot tips then dominate fruit growth for assimilates. During 2005, sampled fruit from under the netting was significantly larger than the fruit from the control. Previous studies show varying results on fruit size as effected by netting or altered light conditions. In spite of a heavier fruit load, an increase of about 5mm in fruit size was found for 'Smoothee' apples covered by several colour nets with shading factors of 15-30% (Shahak et al., 2004). The same results were found for 'Topred RD' where the mean fruit size was greater under netting than in fully exposed trees, although the differences were not statistically significant (Shahak et al., 2004). The positive effect was also ascribed to reduced water stress in the netted trees, as was indicated by their midday stem water potential.

Total yield per tree was not measured during this study, therefore it cannot accurately be stated what effect yield had on fruit size or mass under the netted areas. Out of previous studies we do, however, know that fruit mass tends to decrease as the crop load increases (Link, 2000). This was also found in Chapter 2. Since the 'Granny Smith' orchard was thinned uniformly and crop loads appeared to the eye to be similar on trees under and outside

the nets, it is unlikely that yield differences were accountable for the larger fruit during the 2004/05 season. However, this should be measured in future trials. It is more likely that netting alleviated the serious drought which was experienced during this season, thus reducing tree water stress and increasing fruit growth rates. The size of control fruits was very low, indicating that these trees were experiencing stress.

Fruit firmness is regarded as an indicator of fruit maturity and is often associated with fruit colour (Raese et al., 1997). In this study, fruit firmness was significantly reduced under the black netting during 2003/04 and under the black and grey netting during 2005. These results suggest that fruit from under the netting could mature earlier than fruit not covered by netting. Scott (1989) found black and white netting to have no effect on fruit firmness of 'Granny Smith' and 'Jonathan' apples. Firmness of 'Elstar' was also shown to be unaffected when covered by white or black netting (Wagenmakers and Tazelaar, 1999). Possible reasons for a decrease in fruit firmness other than maturity could be factors such as larger fruit with increased cell size (DeEll et al., 2001) and higher water content, or differences in crop load, which were not measured.

TSS was reduced during both seasons and under all net types. These results correspond with the findings of Middleton and McWaters (2002) showing TSS for 'Granny Smith' to be up to 1.5% lower under netting, and those of Scott (1989) who also found TSS levels in 'Granny Smith' to be lower under black netting. Results of studies done on red apple cultivars found lower TSS in covered trees for 'Jonagold' and the opposite trend for 'Elstar' (Stampar et al., 2001). This could possibly be due to reduced carbohydrate availability under the lower light conditions, or increased competition for carbohydrates between vegetative and reproductive sinks. In the absence of yield data it is not possible to attribute the reductions in TSS to any possible differences in crop load under and outside the netting.

No significant differences were found in TA levels during this study, suggesting that netting does not have an effect on the acidity of 'Granny Smith' apples. Wagenmakers and Tazelaar (1999) also found that TA was unaffected by netting. However, Stamper et al. (2001) showed significant increases in malic acid for 'Elstar' covered by 20% white netting. It is well documented that starch levels in apple fruit decrease as fruit mature (Fan et al., 1995). The starch levels of fruit could thus be used to determine maturity of the fruit. In this study no significant difference in starch breakdown was found and it is thus unlikely that maturity development was changed.

Deleted: ¶

The results of this study show that black, blue and grey protective netting had a positive effect on reducing sunburn in 'Granny Smith' apples resulting in better quality fruit. No negative effects were found except for reductions in TTS.

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Table 1: Mean photosynthetic photon flux density (PPFD, μmol m^{-2} s^{-1}) as measured under 20% black, 20% grey and 30% blue protective netting on cloudless days.

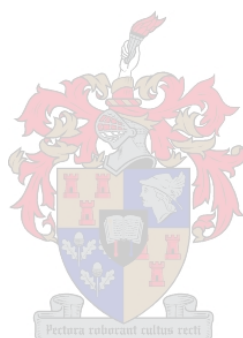|	11-Mar-2004			01-Mar-2005	
	Black	Grey	Blue	Grey	Blue
Net	897	1029	1063	1100	1196
No net	1297	1699	1705	1769	1769
% Reduction	31	39	38	38	32
P-value	<0.0001	<0.0004	<0.0001	<0.0001	<0.0001

Table 2: Sunburn damage on 'Granny Smith' apples grown under 20% black, 20% grey and 30% blue netting. Class 0 = percentage fruit with no sunburn, Class 1 = percentage fruit with mild skin browning, Class 2 = percentage fruit with severe skin browning, Class 3 = percentage fruit with sunburn necrosis.

|	Class 0	Class 1	Class 2	Class 3
2003/04 black netting				
Net	100.0	0.0	0.0	0.0
No nets	79.1	10.2	6.7	4.0
P-value	0.0022	0.0070	0.0077	0.0400
2003/04 blue netting				
Net	100	0.00	0.00	0.00
No nets	80.4	12.44	5.78	1.33
P-value	0.0100	0.0081	0.0499	0.0805
2004/05 black netting				
Net	97.6	1.9	0.0	0.7
No nets	82.8	8.3	3.9	5.0
P-value	0.0496	0.1042	0.0431	0.2940
2004/05 blue netting				
Net	92.8	2.2	1.7	3.3
No nets	82.8	8.3	3.9	5.0
P-value	0.1866	0.1547	0.3466	0.7732
2004/05 grey netting				
Net	93.6	3.0	1.6	2.1
No nets	82.8	8.3	3.9	5.0
P-value	0.1227	0.0383	0.2420	0.5576
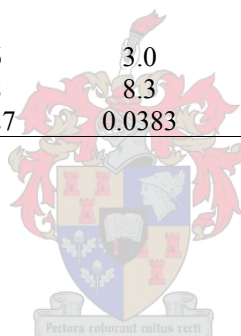
Table 3: 'Granny Smith' fruit quality parameters at harvest when grown under 20% black, 20% grey and 30% blue coloured protective netting during the 2003/04 and 2004/05 seasons.

	Mass (g)	Seed unviable (%)	Ground colour (chart)	Blush colour (%fruit)	Firmness (MPa)	TSS (%)	TA (%)	Starch % breakdown	Stem end russet (%fruit)	Fusi damage (%fruit)
2003/04 black netting										
Net	170.6		1.1	0.1	6.96	12.0		63.5	7.5	
No net	190.9		1.2	0.3	7.27	13.4		55.3	7.1	
P-value	0.0856		0.2842	0.0305	0.0187	0.0005		0.2287	0.8259	
2003/04 blue netting										
Net	153.3		1.1	0.0	7.04	11.7		69.1	6.9	
No net	158.0		1.2	0.2	7.22	13.4		61.4	5.6	
P-value	0.6105		0.3087	0.0530	0.4179	0.0005		0.2068	0.4964	
2004/05 black netting										
Net	137.6	0.2	1.7		8.11	12.6	0.764	18.9	1.1	6.3
No net	106.9	0.2	1.8		8.79	14.0	0.579	16.3	1.0	11.1
P-value	0.0446	0.3747	0.7007		0.0165	0.0055	0.3460	0.4470	0.8504	0.1514
2004/05 blue netting										
Net	133.8	0.1	1.6		8.67	13.3	0.757	15.7	1.0	13.3
No net	106.9	0.2	1.8		8.79	14.0	0.779	16.3	1.0	11.1
P-value	0.0453	0.1738	0.3390		0.6279	0.1036	0.5879	0.8482	1.0000	0.6091
2004/05 grey netting										
Net	141.8	0.1	1.6		8.06	12.6	0.753	22.7	1.1	12.083
No net	106.9	0.2	1.8		8.79	14.0	0.579	16.3	1.0	11.111
P-value	0.0451	0.1040	0.1173		0.0026	0.0015	0.3463	0.0997	0.7205	0.8560

Addendum A

Figure 1: Installation of 20% protective netting over four blush apple cultivars.

Figure 2: Harvesting of blush apple under 20% protective netting

Figure 3: Installation of 20% black, 20% grey and 30% blue protective netting over 'Granny Smith'.

Figure 4: 'Granny Smith' orchard under 20% black, 20% grey and 30% blue protective netting.