

## Shade nets effect on canopy light distribution and quality of fruit and spur leaf on apple cv. Fuji

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### Abstract

The upper region of the Río Negro and Neuquén valley, Argentina (latitude: 38° 55' South) experiences high temperatures and light intensities before the apple harvest. This hinders these fruits turning red and increases the risks of them becoming sunburnt. In the December of two growing seasons (when the fruits were about 43 mm in diameter), still some 80 days before harvest, 15% and 55% density shade nets were placed over 'Fuji' apple trees. At harvest time, light distribution was determined at two canopy heights (1 and 3 m) on either side of the trees. Fruiting spurs were examined, and colour, sunburn damage, weight, soluble solid content and flesh firmness of the fruits determined. Specific leaf weight (SLW) was also established. Shade nets notably decreased the amount of photosynthetically active radiation (PAR) available; they also reduced fruit colour (redness), soluble solid content and flesh firmness, and the SLW. The 55% density net decreased fruit sunburn, but no differences were found between the 15% density net and control treatments. Spurs at the bottom of the canopy received less light, and the SLW, as well as the colour and soluble solid content of their fruit, was lower than observed for the higher spurs. The impossibility of exporting fruits damaged by high temperatures and intense solar radiation during ripening requires shade nets be used, their density depending on the conditions experienced.

**Additional key words:** photosynthetically active radiation, specific leaf weight, sunburn.

### Resumen

#### Efecto de la malla de sombreo sobre la distribución de la luz y la calidad de frutos y hojas de dardos de manzano cv. Fuji

La región del Alto Valle de Río Negro y Neuquén, Argentina (latitud 38° 55' Sur) presenta temperaturas e intensidades lumínicas altas durante los meses anteriores a la cosecha. Esto dificulta el desarrollo de color rojo y aumenta el riesgo de golpe de sol en los frutos. Durante dos temporadas, en diciembre, con los frutos en estado fenológico de crecimiento (43 mm de diámetro) y a 80 días de la cosecha, se colocaron mallas de sombreo de densidades 15 y 55% sobre plantas de manzano cv. Fuji. Durante la cosecha, en cada árbol y a ambos lados de la fila se determinaron dos alturas (1 y 3 m) para la medición de luz y muestreo de frutos y hojas de dardos, evaluándose golpe de sol, color rojo de la piel, peso del fruto, contenido de sólidos solubles, firmeza de pulpa y peso específico de hoja. Las mallas redujeron notablemente la radiación fotosintéticamente activa (PAR) disponible para las plantas, observándose un menor color de los frutos, contenido de sólidos solubles, firmeza de pulpa y peso específico de hoja (PEH). La malla de 55% redujo el golpe de sol, no observándose diferencias entre la malla de 15% y el testigo. Dardos en alturas inferiores de la copa del árbol presentaron menor cantidad de luz, frutos con menor color, contenido de sólidos solubles y PEH respecto a los dardos de las partes altas de la planta. La imposibilidad de exportar frutos de calidad por falta de color o golpes de sol debido a la influencia de la radiación, la temperatura y la amplitud térmica durante la maduración del fruto, determina la colocación de mallas de sombreo y la densidad de las mismas en el cv. Fuji.

**Palabras clave adicionales:** golpe de sol, peso específico de hoja, radiación fotosintéticamente activa.

### Introduction

Sunburn is a major cause of apples (*Malus domestica* Bork) being discarded in those parts of the world with

high temperatures and intense solar radiation (Yuri *et al.*, 1998). The most obvious symptom is discoloration. The red colour is weakened while yellow tones increase, and the waxy cuticle is dissipated. Sunburn also leads to the establishment of sugar and mineral gradients within the fruits, e.g., calcium is found in greater concentrations on the shaded side (Andrews and Johnson,

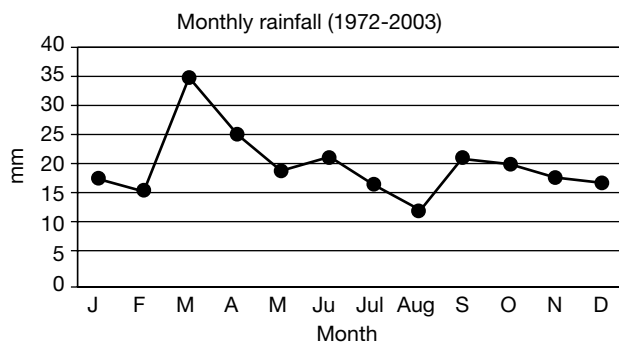
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1996; Curry, 1996; Yuri *et al.*, 1996). Generally, intense sunlight leads to changes in the ripening characteristics of the side affected, the softening of the fruit, and rotting during storage (Yuri *et al.*, 1996).

One way to reduce sunburn is to provide water via raised sprinklers when conditions so demand; this reduces the temperature by simulating rainfall (Parchomchuk and Meheriuk, 1996; Dussi *et al.*, 1997). Chemical sun protectants can also be used (Yuri *et al.*, 2000; Schupp *et al.*, 2002). «SunShield», for example, prevents the passage of UV radiation (Curry, 1996), and the use of antioxidants can eliminate the free radicals produced during exposure to intense sunlight (Curry, 1996).

In Chile and Europe, shade nets are now being tested as a practical means of reducing sunburn damage to fruit crops; in the USA, the same types of net are used for a number of reasons (Andrews and Johnson, 1996; Yuri *et al.*, 1996). The costs associated with this technique are high, but in Argentina the damage caused to apples cvs. Braeburn and Fuji by the sun means a large percentage of the crop cannot be exported. Fuji is the most susceptible to this kind of damage; Colavita (2003), who studied the problem in the upper valley of the Río Negro, reports 20.8% of the crop to suffer mild damaged and 34.8% to suffer severe damage. However, even mild damage means these apples cannot be exported, and there is no domestic market for the Fuji variety.

In the upper valley region of Río Negro and Neuquén, Argentina, rainfall is scarce, the majority falling in autumn and winter (Fig. 1). Low rainfall at times of high temperatures only increases the sunburn damage suffered by cv. Fuji, although it does help prevent cracking.



**Figure 1.** Rainfall data provided by the Agrometeorology Station, Facultad de Ciencias Agrarias, Universidad Nacional del Comahue, Río Negro, Argentina.

Certain environmental (mainly temperature and light levels) and physiological factors affect the development of colour in apples, which is largely due to the accumulation of anthocyanins (Arakawa *et al.*, 1988; Lancaster, 1992; Dussi and Huysamer, 1995). Shading reduces the specific leaf weight (SLW), and this can be used as an indicator of the distribution of light in the crown of the tree (Barden, 1978; Dussi and Huysamer, 1995; Dussi *et al.*, 2004). The amount of light available affects photosynthesis and determines productivity. It also affects the initiation of flowering and fruit quality (e.g., colour, taste, acids/soluble solids ratio) (Arthey, 1975), and via its effect on the formation of flowering branches it influences the amount of fruit that can be produced in the following year (De Jong and Day, 1991).

The aim of this work was to determine the effects of different density shade nets (at the start of the summer) on light penetration in the crowns of 'Fuji' apple trees, on the level of sunburn suffered by the crop, and on the characteristics of the spur leaves and fruits.

## Material and Methods

The study was performed in the upper region of the Río Negro and Neuquén valley (Argentina) (latitude 38° 55' South) over two growing seasons (1999-2000 and 2000-2001). The climate of the area is cold-temperate and semiarid, with a Mediterranean rainfall pattern (200 mm per year). During the months prior to the apple harvest, temperatures and sunlight levels are high (maximum mean temperature 29.15°C; solar radiation in full sunlight 1,400  $\mu\text{mol cm}^{-2} \text{s}^{-1}$ ).

The study was conducted in an orchard containing seven year-old 'Fuji' (clone Iguafo 10) apple trees growing on M9 rootstocks. Trees were placed 4 × 2.50 m in North-South rows and trained to a central leader 3.5 m high.

Three treatments were tested during the month of December, when the fruits were 43 mm in diameter and harvest was still 80 days away. The orchard was divided into three equal plots. The rows of one plot were covered with black shade netting (pores 3 × 6 mm, lifespan 8 years) (Polysack Plastic Industries, Israel) to provide 55% shading. In the second plot the rows were covered with a similar netting (pores 4.5 × 6 mm, 4 year lifespan) to provide 15% shading. The third plot was left uncovered (control).

At the time of commercial harvesting, when refractometer readings showed a value of 14°Brix and the starch content had been degraded by 35% (20<sup>th</sup> March), five trees were randomly selected from each treatment. These held some 200-250 apples each. On the same day, the light reaching the leaves of all 15 trees at heights of 1 m and 3 m from the ground, and on both sides of the rows, was measured. The fruits and leaves of the spurs were also sampled. Light levels were measured as the amount of photosynthetically active radiation (PAR, 400-700 nm) available, using an AccuPAR PAR 80 ceptometer with 80 linearly-arranged photodiode sensors on an 80 cm probe. Readings were taken at midday ( $\pm 1$  h) over the top of each tree, and within the canopy at the two specified heights, and on either side of the row. The probe was kept at right angles to the trellis and placed horizontally within the canopy. The instrument was configured to take 20 readings over the probe length at intervals of 20 ms. The mean of these 1600 individual readings was taken as the PAR.

At harvest, PAR readings were taken on either side of the row at the two specified heights. The means were calculated and compared to the PAR recorded above the trees. This allowed the amount of light available to be calculated and the percentage interception occasioned by the two types of shade net. At the same time (midday), the temperature of the air surrounding the covered and uncovered trees was recorded (25.62°C for the control, 22.16°C under the 15% netting, and 21.02°C under the 55% netting).

The minimum and maximum daily temperatures and thermal amplitude for the month of February were recorded during both growing seasons; during this month, Fuji apples begin to change colour.

Five spurs with one fruit and a number of leaves were selected from the upper and lower parts of each tree, i.e., at 3 m and 1 m, and from both sides of the row. Sunburn damage of each fruit was assessed and the percentage area of red coloration measured subjectively. Fruits were weighed, their soluble solid contents determined using a Bertuzzi refractometer (scale 0-32° Brix), and the firmness of their flesh measured with an Effegi model FT 327 manual penetrometer (scale 0-13 kg cm<sup>-2</sup>). Sunburn damage was taken to be manifested by any discoloration that reduced the aesthetic quality of the fruit (similar assessments are made at packing plants). Colour was determined on a scale of 1-5 (1 = fruits with 0-20% red coloration, 5 = fruits with 80-100% red coloration).

Five leaves were removed from each spur and discs were cut from them using an 18 mm borer. These were dried in an oven for 24 h and the SLW of each determined.

In the second year, the sunburn damage classification of the fruits was determined (by the authors) at a packing plant.

Statistical analyses were undertaken using the SAS statistical package (2004). Analyses were based on a four-factorial mixed linear design: year (1 and 2), treatment (15% density shade net, 55% density shade net, control), side of row (East, West), and growing height (low or high).

ANOVA was used to examine the data for PAR, red coloration, fruit weight, soluble solid content, flesh firmness and SLW. The percentage of fruits not affected by sunburn damage under the different treatments and years was analysed using a generalised linear model (GLM).

$$Y = \mu + \alpha_i + B_j(\alpha) + \gamma_k + \alpha\gamma + B(\alpha)\gamma + \delta_l + \alpha\gamma + B\delta + \gamma\delta + \alpha\gamma\delta + B\gamma\delta + \epsilon_{ijklm}$$

where:

$\alpha$  = treatment;  $i = 1-3$ ;  $B$  = tree;  $j = 1-5$  (random);  $\gamma$  = height;  $k = 1-2$ ;  $\delta$  = side of row;  $l = 1-2$ ;  $\epsilon$  = error;  $m = 1-5$ .

## Results and Discussion

In the analysis of the results, interactions with the factor «year» were significant; each year was therefore analysed separately.

### Fruit weight

In the first year, neither treatment, side of row, nor growing height affected the fruit weight (Table 1). This agrees with that reported by Erez and Flore (1986) in peaches cv. Redhaven exposed to different levels of sunlight. In the second year, the interaction *treatment*  $\times$  *growing height* was significant (Fig. 2), although shading had no notable effect. This agrees with the results of Podestá *et al.* (2002) for peaches grown under anti-hail netting. However, Lakso and Corelli Grappadelli (1992) found an immediate reduction in fruit growth of around 30% under moderate levels of shade at 4 weeks post-flowering. This lasted until harvest time.

**Table 1.** Effect of shade nets (treatment) on fruit weight, soluble solid content, flesh firmness, fruit colour, SLW and PAR in apple trees Fuji

Source of variation	DF	Weight (g)		Soluble solids (°Brix)		Flesh firmness (kg cm <sup>-2</sup> )		Colour (%)		SLW (mg cm <sup>-2</sup> )		PAR (%)	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Treatment (T)	2	ns	ns	**	ns	ns	**	ns	*	*	ns	**	**
Side (S)	1	ns	ns	*	**	ns	*	ns	ns	ns	ns	**	**
Growing height (H)	1	ns	ns	*	**	ns	ns	**	**	**	**	**	**
T × H	2	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	**	**
T × S	2	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	**
S × H	1	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
T × S × H	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

DF: degrees of freedom. ns: not significant. \*: significant at/above 5% level. \*\*: significant at/above 1% level. SLW: specific leaf weight. PAR: photosynthetically active radiation.

### Soluble solid content

In both growing periods, the height at which the fruit grew, and the side of the tree it grew on, significantly affected its soluble solid content (Table 1). In year 1, shading also had an effect. The control fruits, those from the East side of the trees, and those from the higher position, had a greater content of soluble solids (Table 2). These results confirm that shading reduces the soluble solid content of fruits (Heinicke, 1966; Seeley *et al.*, 1980; Robinson *et al.*, 1983; Yuri *et al.*, 1996), delaying their ripening.

### Flesh firmness

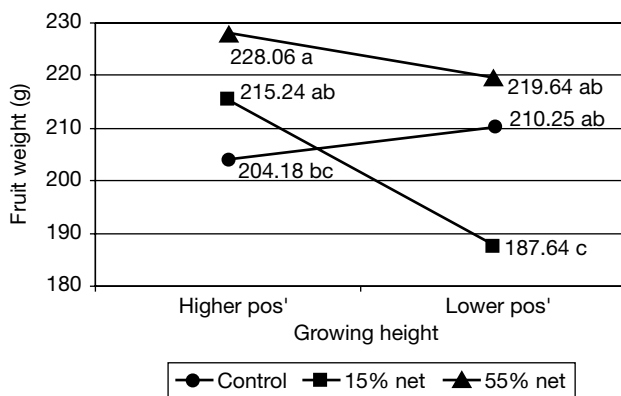
During the first year, flesh firmness was not affected by the shading treatments, the side of the tree, nor the

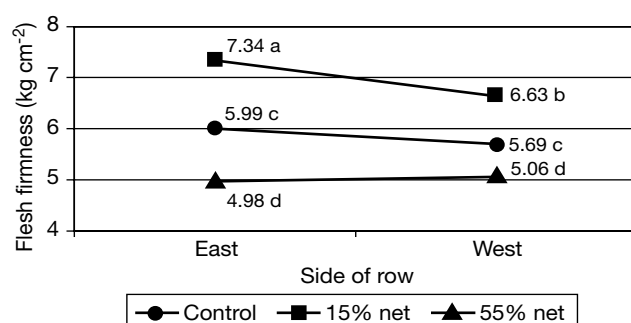
growing height of the fruit (Table 1). Similarly, Campbell and Marini (1992) found the light levels they tested to have no significant effect on flesh firmness in Red Prince Delicious apples. However, in year two, flesh firmness was lower in fruits grown under the 55% shade netting (Fig. 3). Yuri *et al.* (1996, 2000) reported flesh firmness in fruits from plants grown under shade nets to be lower than that of the fruits of uncovered trees. Loreti *et al.* (1993) reported similar results for peaches shaded during the last phase of ripening. These authors attribute this to the reduced light the plants received, leading to poor cell wall formation and a greater influx of water into the cells forming the flesh. In year two, however, greater flesh firmness was recorded for the fruits under the 15% shade netting (compared to the controls) (Fig. 3).

**Table 2.** Influence of treatment, growing height and side of row on soluble solid content (°Brix) in both years

Treatment	Year 1	Year 2
Control	15.17a	13.22
15% net	14.15b	12.19
55% net	12.74c	12.78
<i>Height</i>		
Higher	14.18a	13.12a
Lower	13.86b	12.35b
<i>Side</i>		
West	14.14a	12.99a
East	13.89b	12.46b

Figures in the same column followed by the same letter are not significantly different (LSD test) at the 5% probability level.

**Figure 2.** Influence of interaction *treatment* × *growing height* on fruit weight in year 2. Figures followed by the same letter are not significantly different (LSD test) at the 5% probability level.



**Figure 3.** Influence of interaction *treatment*  $\times$  *side of row* on flesh firmness in year 2. Figures followed by the same letter are not significantly different (LSD test) at the 5% probability level.

### Fruit colour

Fruit colour was influenced by the growing height of the fruits in both years, although the treatment only had an effect in year two (Table 1). The apples with the largest percentage of red coloration were those from the control trees and at the higher position (Table 3). This agrees with the results of Heinicke (1966), Jackson (1968), Jackson *et al.* (1977), Wertheim *et al.* (1986) and Yuri *et al.* (1996) among others. According to Proctor and Loughheed (1976), an increase in the concentration of anthocyanins only occurs when apples are exposed to adequate sunlight for 20 days before harvest. In the February (when Fuji apples change colour) of the first year, the minimum temperature was lower and the thermal amplitude wider than in the second year, and this probably caused the apples in all treatments to develop more colour (Table 3, Figs. 4 & 5). Between 15–20°C has been reported the optimum temperature range for the production of anthocyanins in these fruits, depending on their maturity (Arakawa,

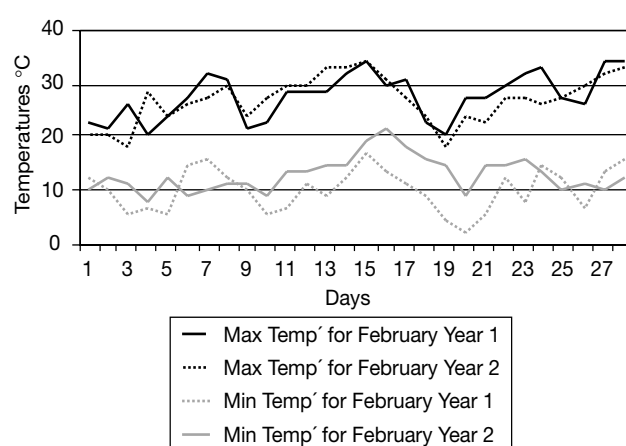
**Table 3.** Influence of treatment and growing height on the percentage of fruit surface coloration (area) in both years

Treatment	Year 1	Year 2
Control	62.93	38.38a
15% net	55.40	32.05a
55% net	52.85	21.60b

<i>Height</i>		
Higher	68.07a	37.23a
Lower	52.63b	23.87b

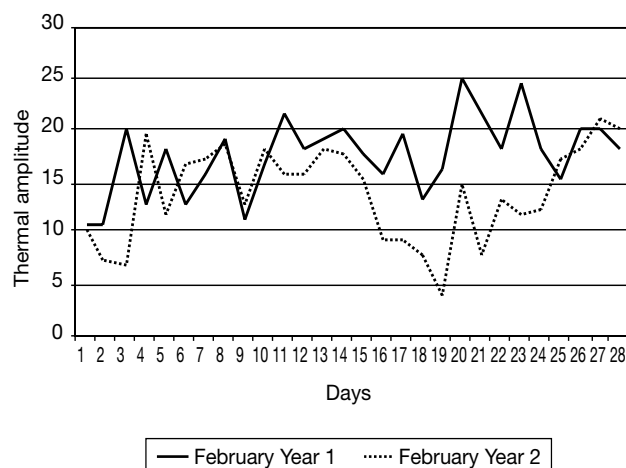
Figures in the same column followed by the same letter are not significantly different (LSD test) at the 5% probability level.



**Figure 4.** Maximum and minimum daily temperatures for February of both years. Data provided by the Agrometeorology Station, Facultad de Ciencias Agrarias, Universidad Nacional del Comahue, Río Negro, Argentina.

1991; Arakawa *et al.*, 1999). Certainly, temperature variations are known to affect anthocyanin accumulation in apples (Gil, 1981; Arakawa *et al.*, 1985; Saure, 1990).

The side of the tree had no effect on fruit colouration in either year (Table 1). Although significant differences were seen in the amount of light available to the different sides of the trees (Table 5, Fig. 7), even the highest PAR recorded was insufficient to allow good fruit colouration. According to Faust (1989), satisfactory colour development requires more than 70% of the total sunlight available. Rom (1993) reported similar results.



**Figure 5.** Daily thermal amplitude for February in both years. Data provided by the Agrometeorology Station, Facultad de Ciencias Agrarias, Universidad Nacional del Comahue, Río Negro, Argentina.

**Table 4.** Influence of treatment and growing height on specific leaf weight (SLW, mg cm<sup>-2</sup>) in both years

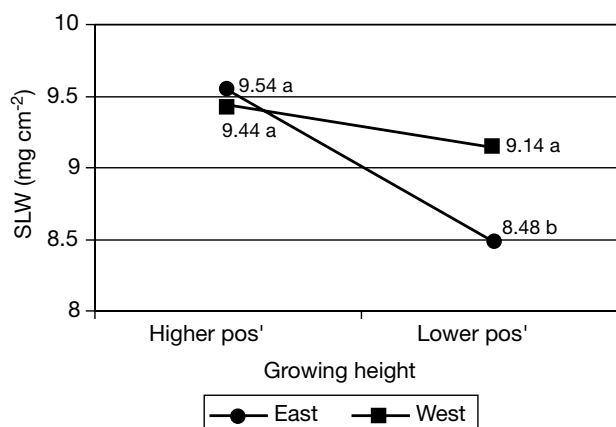
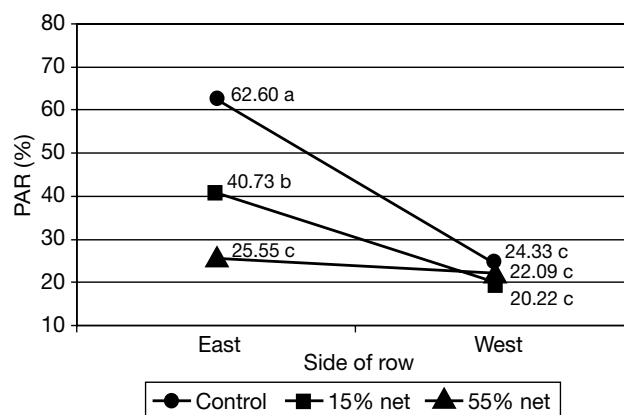
Treatment	Year 1
Control	9.62a
15% net	9.13ab
55% net	8.69b
Height	Year 2
Higher	7.97a
Lower	7.30b

Figures in the same column followed by the same letter are not significantly different (LSD test) at the 5% probability level.

### Specific leaf weight

SLW of the control spur leaves was the greatest, this value diminishing with shade netting density, although only in year one (Table 4). In both growing seasons, SLW was greater for the higher spur leaves (Fig. 6, Table 4). This agrees with results reported by Barden (1978) and Dussi and Huysamer (1995), and due to the greater amount of light intercepted by the higher leaves. Nii and Kuroiwa (1988), who worked with peaches, showed that leaves exposed to 100% of the solar radiation available had an SLW 2.6 times greater than that of leaves with received only 10% of the PAR.

Sansavini and Corelli (1992) reported low light levels to negatively affect spur leaves and flowering branches; this may explain the reduction of SLW seen in the second year. Shading in one year would therefore seem to affect fruit production in the next.

**Figure 6.** Influence of the interaction *growing height* × *side of row* on specific leaf weight (SLW) in year 1. Figures followed by the same letter are not significantly different (LSD test) at the 5% probability level.**Figure 7.** Influence of the interaction *treatment* × *side of row* on photosynthetically active radiation (PAR) available in year 2. Figures followed by the same letter are not significantly different (LSD test) at the 5% probability level.**Table 5.** Influence of treatment, growing height and side of row on percentage of photosynthetically active radiation available in both years

Treatment	Year 1		Year 2	
	Higher position	Lower position	Higher position	Lower position
Control	79.03a	34.59c	65.40a	21.53c
15% net	50.99b	16.52d	42.27b	18.68c
55% net	33.88c	16.24d	36.89b	10.71d
Side of row	Year 1		Year 2	
East	42.67a		42.72	
West	34.42b		22.11	

Figures in the same column followed by the same letter are not significantly different (LSD test) at the 5% probability level.

## Photosynthetically active radiation (PAR)

In general, the availability of light in the two seasons was greater for the control plants than for those that were shaded, and at the higher rather than the lower position. This agrees with the results of Dussi and Huysamer (1995). In addition, the light available was greater on the East side of the trees in all treatments (Fig. 7, Table 5). In the second year, the PAR was not significantly influenced by the side of the tree. Similar results were reported by Khemira *et al.* (1993) who worked with pear trees cv. Beurre D'Anjou.

## Sunburn

The percentage of fruits not affected by sunburn differed significantly between treatment and years.

The 55% shade netting significantly reduced sunburn damage; 99% of fruits were healthy in year one, and 100% in year two. No significant differences were seen in this respect between the 15% shade and control treatments in either year (Table 6), although there was a trend towards less damage among fruits grown under the net. Yuri *et al.* (1996), who worked with 'Gala' apples, found that 17% shade nets significantly reduced the number of fruits damaged by sunburn, although the development of a red colour was not affected. In the present study, however, the 55% netting did reduce red coloration compared to the control fruits in year two (Table 3). This led to a lower percentage of the crop being deemed acceptable at the packing plant. However, the number of fruits discarded because of sunburn was lower than for the control fruits (Table 7).

In conclusion, both nets notably reduced the PAR available to the plants (Table 5, Fig. 7), fruit coloration was less complete (Table 3), the soluble solid content of the shaded fruits was reduced (Table 2), their flesh

**Table 6.** Influence of treatment on the percentage of apples not affected by sunburn in both growing seasons

Treatment	Year 1	Year 2
Control	60b	80b
15% net	63b	89b
55% net	99a	100a

Figures in the same column followed by the same letter are not significantly different (LSD test) at the 5% probability level.

**Table 7.** Effect of treatment on fruit classification at the packing house in year 2

Classification	55% net	15% net	Control
Class I	69.40	74.70	65.50
Class II	14.20	8.00	13.20
Discarded	16.50	17.30	21.20

firmness was poorer (Fig. 3), and the SLW was diminished (Table 4, Fig. 6).

The 55% shade netting significantly reduced sunburn damage; no differences were seen between the 15% net and the control treatments (Table 6).

The lower spurs received less light (Table 5), had a lower SLW (Table 4, Fig. 6), and produced fruits with less colour (Table 3) and a lower soluble solid content (Table 2) than did the higher spurs. Shading did not significantly affect the weight of the fruits (Fig. 2).

Given the large numbers of fruits under the 15% netting that were affected by sunburn, and the significant reduction in the colour of those grown under the 55% netting, it might be advisable to use a netting of intermediate density. This might reduce sunburn damage without seriously affecting fruit colour.

The impossibility of exporting fruits damaged by high temperatures and intense solar radiation during maturation requires shade nets be used with this cultivar, their density depending on the conditions experienced.

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