

# LIGHT QUALITY MANAGEMENT IN FRUIT ORCHARDS: PHYSIOLOGICAL AND TECHNOLOGICAL ASPECTS

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Light quality (sunlight spectrum) management promises to provide a new technological alternative to sustainable production in horticultural crops. However, little information exists about physiological and technological aspects on light quality management in fruit crops. Sunlight composition changes widely in orchard canopies, inducing different plant responses in fruit trees mediated by phytochrome (PHY) and cryptochrome (CRY) activity. High proportion of far-red (FR) in relation to red (R) light increases shoot elongation, while blue (B) light induces shoot dwarfing. Red and ultraviolet (UV) light increases fruit skin anthocyanin synthesis, while FR light shows a negative effect. Red and B light can also alter leaf morpho-physiological traits in fruit trees, such palisade thickness, stomatal aperture, and chlorophyll content. Besides improvement of photosynthetically active radiation (PAR) availability, the use of reflective films improves UV and R light proportion, with positive effects on PHY mediated-responses (fruit color, fruit weight, shoot growth), as reported in apple (*Malus domestica* Borkh.), peach (*Prunus persica* [L.] Batsch), and sweet cherry (*Prunus avium* [L.] L.). Colored nets widely alter spectral light composition with effects on plant growth, yield, and quality in apple, kiwifruit (*Actinidia deliciosa* [A. Chev.] C.F. Liang & A.R. Ferguson), peach, and blueberry (*Vaccinium corymbosum* L.) orchards. Mechanisms of colored nets seem to be associated to photosynthetic and morphogenetic process regulated by PAR availability, R/B light proportion, and CRY activity. Alteration of light quality affects significantly fruit tree plant responses and could be a useful tool for sustainable (e.g. lower use of chemicals and labor-practices) management of yield and quality in modern orchards.

**Key words:** Red, far-red and blue light, phytochrome, cryptochrome, photo-morphogenesis, reflective films, colored nets.

The sunlight use efficiency (i.e. converting light energy to dry matter) has long been the main research focus to obtain sustainable fruit production and quality in orchard systems. In the recent years, however, more technological innovation are required for adequate light management in fruit trees, due to changes of paradigm of efficiency in orchard systems, which must include other factors, such as climate change, energy cost, and need of reduction of environmental impact (Palmer, 2011; Blanke, 2011). Optimizing of sunlight use has been achieved in orchard systems thanks to research development in cultural practices such as pruning, training system, tree arrangement, and orchard design, directed toward the improvement of “quantity of light” (i.e. the amount of photosynthetically active radiation, PAR) intercepted and distributed by orchards (Jackson, 1980; Palmer, 1989; Bastías and Widmer, 2002; Corelli-Grappadelli, 2003; Corelli-Grappadelli and Lakso, 2007). However, alongside the PAR quantity that provide the energy

and carbon needed for sustained tree and fruit growth, plant growth and development also respond to subtle changes in the light quality (i.e. spectral composition of sunlight), processes regulated by specific pigment-based photoreceptors, including red (R) and far-red (FR) light absorbing phytochromes (PHY) and ultraviolet (UV) and blue (B) light absorbing cryptochromes (CRY) and phototropins (PHO) (Fankhauser and Chory, 1997; Kasperbahuer, 2000; Smith, 2000; Lin, 2002). More significant advances in light quality management have been achieved *in vitro* plant culture and greenhouse systems by using supplemental lighting sources (e.g. light emitting diodes, LEDs), colored soil mulches and photo-selective filters to manipulate the plant growth, yield and quality (Muleo *et al.*, 2001; Oren-Shamir *et al.*, 2001; Hemming, 2011). Nevertheless, due to the difficulty of conditioning the light environment of orchards, the management of light quality has been much less developed in fruit trees grown under field conditions, consequently more studied have been developed under controlled conditions (Erez and Kadman-Zahavi, 1972; Baraldi *et al.*, 1994; 1998; Rapparini *et al.*, 1999). Since in recent years, manipulation of plant responses by changes in the light quality composition promises to provide new technological alternatives for sustainable manipulation of growth, yield, and quality of harvest in agricultural and

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horticultural crops (Devlin *et al.*, 2007; Rajapakse and Shahak, 2007), the purpose of this article was to review the current status on light quality management in fruit trees under field conditions, with emphasis in physiological and technological aspects and its potential application for manipulation of plant growth, productivity, and quality in orchard systems.

### Light quality relations in orchards

**Light quality composition.** Sunlight reaching the earth surface changes its spectral and energetic profile in part due to the normal climate variability and, in recent years, because of man-induced causes, such as the loss of stratospheric ozone that affects UV light absorption, or atmospheric pollutants and CO<sub>2</sub> levels that affects infrared (IR) light absorption. In general the light spectra that concerns plant physiologists is between 280 and 800 nm, which includes UV-B (280-320 nm), UV-A/B (300-400 nm), PAR (400-700 nm), and FR (700-800 nm). The PAR radiation is subdivided into various bands and the most important for plant physiological processes are B (400-500 nm), green (G, 500-600 nm) and R (600-700 nm) light (Nobel, 1983; Grant, 1997; Combes *et al.*, 2000; Corelli-Grappadelli, 2003). In fruit orchards, the spectral distribution of solar radiation changes widely as the light penetrates and scatters within the tree canopy due to the structure and optical properties of the canopy components, such as leaves, fruits, and branches (Palmer, 1977; Baldini *et al.*, 1997). In general, the light environment inside the tree canopy is made up by two components: the unfiltered solar radiation (direct and diffuse) that has passed through gaps in the vegetation, and the filtered radiation that has been attenuated by the optical properties of reflectance and transmittance of the leaves, which have a crucial importance in the light spectrum modification in fruit trees (Grant, 1997; Baldini *et al.*, 1997).

In walnut (*Juglans regia* L.) leaves, values of leaf reflectance and transmittance in the FR spectrum are estimated to be near 50% and in the G spectrum around 20% for both optical properties (Combes *et al.*, 2000), while in apple (*Malus domestica* Borkh.) the reflectance and transmittance values in the G spectrum are 10% and 4%, respectively and in the FR spectrum are near 50% and 30% (Palmer, 1977). Awad *et al.* (2001) demonstrated that under sunny conditions, the inner position of apple tree canopy reduced 40-48% the UV, B, and G light proportion, while R light was reduced in 58% and FR light increased in 33%, which affects markedly the R/FR ratio. Thus, R/FR ratio reached values of 1.6 at different outside positions of the tree canopy, but near 0.5 in the inner canopy (Table 1).

Similarly, in peach tree (*Prunus persica* [L.] Batsch) canopies the R/FR ratio decreased with height of the tree and this effect was more marked with time, until full canopy development. Early in the season the R/FR values

**Table 1. Spectral composition of the sunlight at different canopy positions in apple orchards.**

Position of tree	Spectral composition (% of total available light)					R/FR ratio
	UV	Blue	Green	Red	Far-red	
Top	5.6	7.9	16.3	18.7	11.6	1.6
	2.9	4.1	9.5	7.9	15.4	0.5
Inner	(-48%)	(-48%)	(-41%)	(-58%)	(+33%)	(-68%)
Outer east	5.2	7.4	16.0	19.0	11.7	1.6
Outer west	5.9	8.0	15.9	17.8	11.4	1.6
F-test	***	***	**	***	***	***

Adapted from Awad *et al.*, 2001; \*\*p < 0.01; \*\*\*p < 0.001.

in the top and bottom of the tree canopy were around 1.1 in both parts, while later, near fruit harvest, they reached values of 0.5 at the top of canopy and 0.3 at bottom, almost a 50% of difference (Baraldi *et al.*, 1994).

**The role of photoreceptors.** The reduction of the R/FR ratio in the inner regions of the tree canopy may produce different morphological and physiological responses mediated by the photoreceptors called phytochromes (PHY) that are responsible for R and FR light signal transduction (Fankhauser and Chory, 1997; Smith, 2000; Devlin *et al.*, 2007). Phytochrome possesses the capacity of detecting wavelengths from 300 to 800 nm with maximum sensitivity in the R (600-700 nm) and FR (700-800 nm) wavelengths. Phytochrome activity can be changing continuously through the two interconvertible states that naturally occur: R absorbing (P<sub>r</sub>) and FR absorbing (P<sub>fr</sub>) forms, which absorb maximally near 660 and 730 nm, respectively (Sager *et al.*, 1988; Rajapakse and Kelly, 1994; Smith, 2000). Because the inner tree canopy has light rich in FR photons (Palmer, 1977; Baraldi *et al.*, 1994; Combes *et al.*, 2000; Awad *et al.*, 2001), the majority of the PHY pool is converted to the inactive P<sub>r</sub> form, with loss of the active P<sub>fr</sub> form. To estimate the PHY pool mediated responses, the R/FR ratio has been commonly used. However, most plant physiologists consider that the R/FR ratio does not accurately explain PHY-mediated plant responses and therefore mathematical models using spectral light information have been proposed to estimate the PHY photoequilibrium (Φ<sub>c</sub>): the equilibrium state of biologically active P<sub>fr</sub> form in relation to total PHY (P<sub>fr</sub>/P<sub>total</sub>) (Sager *et al.*, 1988; Rajapakse and Kelly, 1994; Kasperbahuer, 2000; Smith, 2000). Different reports demonstrate that Φ<sub>c</sub> provides a better indicator of expected photomorphogenic responses to a specific spectral light quality in orchard canopies (Baraldi *et al.*, 1994; 1998; Rapparini *et al.*, 1999; Combes *et al.*, 2000). In walnut orchards, the curve that relates the R/FR ratio with Φ<sub>c</sub> have shown a hyperbolic relationship between both components from the top to the inner canopy, with marked variations of R/FR ratio (from 0.3-1.2) and less important variations in Φ<sub>c</sub> (from 0.35-0.68), thus Φ<sub>c</sub> is especially sensitive to R/FR changes in the range of 0.2-0.7 (shade conditions), but insensitive indeed to R/

FR above about 1.0 (Combes *et al.*, 2000). Although PHY detects not only R and FR but also B and UV light, current research indicates the presence in the most plants of specific photoreceptors for the B and UV regions, denominated cryptochromes (CRY) and phototropins (PHO) (Lin, 2002; Devlin *et al.*, 2007). In peach trees, it has been shown that beside the effect of PHY on plant growth, the CRY is also involved either independently or in conjunction with PHY (Erez and Kadman-Zahavi, 1972; Baraldi *et al.*, 1998; Rapparini *et al.*, 1999).

### Plant responses to light quality in fruit trees

**Growth and development.** Under high relative proportions of FR light the  $\Phi_c$  is shifted toward the inactive Pr form. In these conditions, fruit trees exhibit different morphological changes, probably associated to “shade-avoidance” strategies evoked by decreasing  $P_{fr}$  form, such as shoot elongation, increased apical dominance and reduced leaf thickness (Baraldi *et al.*, 1994; Combes *et al.*, 2000). Indeed for many trees the elongation rate of the shoots has an inverse relationship with the  $\Phi_c$  ( $P_{fr}/P_{total}$ ) (Gilbert *et al.*, 2001). In a classic study, Erez and Kadman-Zahavi (1972) demonstrated that apical growth activity of peach plants was strongly affected by changes in the  $\Phi_c$  in  $P_{fr}$  form, but also demonstrated that B light are quite important role in these responses. These observations were confirmed more later, when, still in peach, was demonstrated that prolonged irradiation with B photons induced an inhibitory effect on shoot elongation, and the morphological responses to B light were widely modified and enhanced the inhibitory effect on stem elongation under lower level of  $\Phi_c$ , providing the evidence of the interaction of PHY and CRY in the regulation of shoot growth in fruit trees (Baraldi *et al.*, 1998; Rapparini *et al.*, 1999).

The role of light quality conditions, specifically R and FR light, on growth partitioning among fruit and shoots has been also suggested. In horticultural crops, long-term FR light exposure initiates events that result in more carbohydrates being partitioned to stems and less to leaves and roots as compared to plants that received R light, affecting the allocation to developing fruits (Kasperbauer, 2000; Glenn and Puterka, 2007). In apple trees, have been underlined the essential role of light quantity on carbohydrate partitioning patterns (Tustin *et al.*, 1992; Corelli-Grappadelli *et al.*, 1994; Corelli-Grappadelli, 2003), but the effects of light quality conditions in these patterns are not totally studied in fruit trees.

**Dormancy.** Different physiological studies indicate that perception of photoperiod is related to levels of PHY, which apparently interact with biosynthesis of plant hormones during control of dormancy-related processes in fruit trees (Olsen, 2006). However, the role of PHY and photoperiod on dormancy release has not been totally

understood in fruit trees. In general, it has been postulated that in a short day FR light is dominant, decreasing the bud meristematic activity, while in a long day, R light is dominant and has the opposite effect (Erez and Kadman-Zahavi, 1972). Previous reports in peach demonstrated that limitation of illumination affected bursting of vegetative buds when it occurred shortly before sprouting. In general R light is more active on bud break and its effects on buds are reversed by a subsequent FR illumination (Erez *et al.*, 1968). Baraldi *et al.* (1994) proposed in apple and peach that flower bud differentiation can be modulated by R/FR ratio. However, the spectral light composition has no effect on flower bud burst or flower bud differentiation, as was demonstrated by Erez *et al.* (1966) and Baraldi *et al.* (1998). Probably the relationship between PHY system, photoperiod and dormancy depends also on genetic factors. For example, photoperiod has no effect on growth cessation and dormancy induction in apple and pear, but a partial effect in *Prunus* species, such as peach and sweet cherry (*Prunus avium* [L.] L.), where a pronounced interaction of photoperiod and temperature exists on the regulation of growth cessation (Heide and Prestrud, 2005; Heide, 2008).

**Leaf morphology and function.** Many authors have shown the close relationship between orchard light conditions and morphological and physiological traits. Thus, in fruit species such as peach (Nii and Kuroiwa, 1988), olive (*Olea europaea* L.) (Gregoriou *et al.*, 2007), and apple (Tustin *et al.*, 1992; Corelli-Grappadelli *et al.*, 1994); sun leaves presented more leaf mass per area ratio, stoma density and palisade cell thickness compared to shade leaves. Although anatomical differences of sun and shade leaves can be attributed to light intensity changes, the role of light quality has been also postulated (Kim *et al.*, 2005). Examination of peach leaf expansion showed that the combination of B + FR light reduced significantly leaf area and the thickness of top and mesophyll palisade layers compared to R + FR light combination. In addition, leaves exposed to R + FR light presented greater thickness of the palisade mesophyll (Table 2) (Baraldi *et al.*, 1998).

The  $\Phi_c$  values demonstrated that, opposite to the argument that indicates that low  $\Phi_c$  generally increases leaf expansion, in this case leaf expansion was reduced

**Table 2. Effect of different light spectrum conditions on leaf peach morphology.**

Light treatment	Calculated $\Phi_c$	Leaf area cm <sup>2</sup>	Thickness ( $\mu$ m)		
			Top layer palisade	Palisade mesophyll	Spongy intercellular spaces %
Transparent	0.57	31.3a	28.8a	67.0a	61b
R/FR	0.49	33.2a	23.5b	46.2b	59b
BL/FR	0.13	24.3b	20.9c	38.5c	67a
Neutral	0.57	33.9a	20.5c	34.0d	67a

Adapted from Baraldi *et al.*, 1998;  $\Phi_c$ : phytochrome photoequilibrium.

under lower  $\Phi_c$  (Table 2). This behavior was confirmed in further experiments, concluding that probably the inhibitory effects of B + FR light on leaf expansion and thickness are controlled by a specific CRY independent of the PHY system (Rapparini *et al.*, 1999). Changes in leaf chlorophyll content were also detected under different light quality conditions in citrus trees: plants under nets with more B light proportion had the greatest leaf chlorophyll a, b and total chlorophyll content, compared to those with more R light proportion (Li and Syvertsen, 2006). In apple trees, leaf chlorophyll synthesis under nets with more R and G light transmission was up to 46% highest (Solomakhin and Blanke, 2008). Recent studies demonstrated prolonged exposition of apple leaves under nets with more light transmission in the B spectra increased the leaf stomatal conductance and leaf transpiration (Bastías *et al.*, 2011), probably by direct effect of B light on stimulation of stomatal opening has been previously reported (Farquhar and Sharkey, 1982; Shimazaki *et al.*, 2007).

**Fruit color development.** Fruit skin color depends on the concentration of various pigments, such as anthocyanins, chlorophylls, and carotenoids, but red color is due to anthocyanin pigments, mainly cyanidin 3-galactoside (Ju *et al.*, 1999; Awad *et al.*, 2001; Layne, 2001). Anthocyanin biosynthesis is another important light-depending process and has been widely used as a model to study the effect of light quality in vegetative tissues, while its formation is controlled by a high-energy photoreaction and has a photo-protective function to excess light (Mancinelli, 1985; Arakawa *et al.*, 1985; Arakawa, 1988; Steyn *et al.*, 2002). Different experiments demonstrated that simultaneous irradiation with white and UV-B light stimulated anthocyanin production synergistically in apple fruits. Although the effectiveness of R light was lower than that of UV-B, it produces a synergistic effect when given simultaneously with UV-B. Furthermore, long-term treatment with R and FR light showed a significant R-FR reversible response of photo-regulation of anthocyanin synthesis in apple skin, indicating a possible role of PHY system and that FR light could possibly even inhibit color development. This was confirmed under field conditions, where at low light levels and above a critical FR/R ratio ( $\sim 1$ ), there was no anthocyanin formation in apple fruits (Arakawa *et al.*, 1985; Arakawa, 1988; Awad *et al.*, 2001).

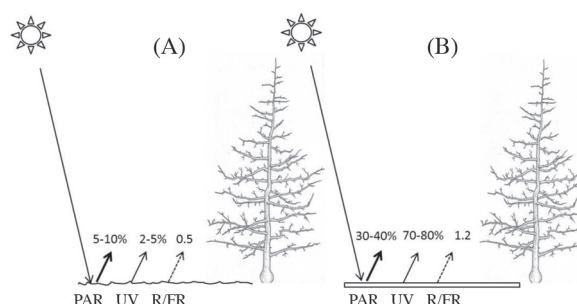
### Manipulation of light quality in orchard systems

**Light reflection management.** The use of reflective ground cover materials such as white woven plastics and aluminum foil is a good approach for improvement the light use in orchard systems (Ju *et al.*, 1999; Widmer *et al.*, 2001; Layne, 2001; Whiting *et al.*, 2008), while have also become tested with other reflective material such as straw, lime, and biodegradable white paint in organic orchards

(Blanke, 2007). Cover orchard floor with reflective materials produces important effects on improving of fruit color, fruit size, and return bloom in apple orchard (Ju *et al.*, 1999; Widmer *et al.*, 2001; Blanke, 2011), as well on better fruit firmness, sugar content, advanced in maturity and source:sink relationships in peach and sweet cherry (Layne, 2001; Whiting *et al.*, 2008).

The main effect of reflective film is the increases of PAR reflection by reflecting light incoming to floor back into the tree canopy, improving widely the light availability to shading parts of the tree canopy (Widmer *et al.*, 2001), as well helping to overcome the light deficiency generated in protected fruit orchards under hail nets or under shade nets (Blanke, 2011). In orchard with traditional grass ground cover, the PAR reflected is almost 5-10%, while with reflective ground covers PAR reflection incoming reached up to 30-40% (Widmer *et al.*, 2001; Layne, 2001; Glenn and Puterka, 2007; Blanke, 2007; Figure 1). Although, positive effects of reflective films on fruit quality and productivity are attributed to improving the PAR use for net C assimilation (Whiting *et al.*, 2008), the role of light quality conditions have been also proposed (Ju *et al.*, 1999; Layne, 2001). It was demonstrated that reflective films increases significantly the UV light component of sunlight. Indeed different reports have shown that reflection of UV light by reflective films was up to 80% of light incoming to orchard floor (Ju *et al.*, 1999; Blanke, 2007; Figure 1).

A greater UV light reflection was associated with increased of UDP-galactose:flavonoid-3-O-glucosyltransferase (UGalT), the most important enzyme in the anthocyanin synthesis pathway, but changes in carbohydrate assimilation were not observed (Ju *et al.*, 1999). Reflective films also increases R light component to inner parts of canopy, which affects largely the R/FR ratio (Figures 1). Data taken from different reports have shown that R/FR calculated in apple and peach orchards with reflective ground films was up two fold greater than grass (Layne, 2001; Glenn and Puterka, 2007). The combined effect of reflective



**Figure 1.** Quantitative values of photosynthetically active radiation (PAR), ultraviolet (UV) and red/far-red (R/FR) light proportion in fruit orchards with grass (A) and reflective ground covers (B) (data taken from Ju *et al.*, 1999; Widmer *et al.*, 2001; Layne, 2001; Glenn and Puterka, 2007; and Blanke, 2007).

films on increases of UV and R light proportion should be stimulating by synergistic effect the anthocyanin synthesis (Arakawa *et al.*, 1985; Arakawa, 1988) and can explain the better color development in fruits grown with reflective films (Layne, 2001; Widmer *et al.*, 2001; Blanke, 2007), whereas the large R/FR ratio can explain the enhanced the fruit weight, associated probably to the PHY mediated process affecting the dry matter partitioning to developing fruit (Glenn and Puterka, 2007).

**Light spectrum management.** Recently a new approach has been developed for manipulation of light quality in orchard systems, based on plastic photo-selective colored nets with special optical properties (Shahak *et al.*, 2004). Depending on type of color, photo-selective nets alter widely the spectral light composition (Figure 2). In general white and/or black nets are wavelength neutral and reduced by the same amount full sunlight over the entire range. In contrast, the red and blue nets altered widely the spectral light distribution. Red net increased the light transmission in R and FR spectra (600-800 nm), while the blue net enhanced the proportion of B light (400-500 nm) and reduced the R light proportion (600-700 nm) (Oren-Shamir *et al.*, 2001; Shahak *et al.*, 2004; Solomakhin and Blanke, 2008; Bastías *et al.*, 2011; Lobos *et al.*, 2012).

Horticultural effects of colored nets have been recently evaluated in fruit orchards. In apple orchards, red net improved fruit size compared to black net (Shahak *et al.*, 2008). Solomakhin and Blanke (2008) also reported increased apple fruit size under colored nets, but without effect on yield. In peach, fruit grown under red nets were firmer, sweeter and fruit size was also improved (Shahak *et al.*, 2008), while in highbush blueberries (*Vaccinium corymbosum* L.), red and white nets increased the number of fruits and yield per plant in comparison with traditional black net (Retamales *et al.*, 2008; Lobos *et al.*, 2012). Although the use of colored nets is already taking hold among fruit growers, physiological mechanisms involved

in this technology are still not totally understood. Possible explanations have been attributed to the effect of light conditions on leaf gas exchange process (Shahak *et al.*, 2004). The most important effect of colored nets is on reduction of PAR availability. Moderate shading, as was demonstrated in citrus and apple trees, would reduce plant radiation, heat and water stress, increase gas exchange and availability of carbohydrates for fruit and tree growth (Jifon and Syvertsen, 2003; Corelli-Grappadelli and Lakso, 2007).

The question is: Why does color of nets affect differentially vegetative and fruit growth? Colored nets altered gas exchange and morphological aspects in blueberries, but the effect was more linked to reduction of radiation load (PAR quantity), while light quality conditions under colored nets had a weaker effect on leaf gas exchange and morphological characteristics (Lobos *et al.*, 2012). However, changes in leaf chlorophyll content were detected by effect of spectral light composition under colored nets in citrus trees: plants under blue nets had the greatest leaf chlorophyll a, b, and total chlorophyll content, whereas leaves under red nets had the lowest (Li and Syvertsen, 2006). Solomakhin and Blanke (2008) also demonstrated that apple leaf chlorophyll synthesis under red and green nets was increased, but this did not affect leaf photosynthesis capacity.

Later, also in apple, was demonstrated that irrespective of PAR intensity, blue net was more effective than red net to increase leaf net CO<sub>2</sub> assimilation and transpiration (Bastías *et al.*, 2011). From the photo-morphogenetic point of view, the PHY and CRY action could be also involved (Rajapakse and Shahak, 2007). Solomakhin and Blanke (2008) underlined the possible role PHY on vegetative growth and development of apple trees grown under colored nets, but the R/FR ratio (principal component of PHY activity) does not change widely among colored nets. More clear differences have been found in the R/B ratio among blue and other net colors (Oren-Shamir *et al.*, 2001; Shahak *et al.*, 2004; Bastías *et al.*, 2011).

In kiwifruit (*Actinidia deliciosa* [A. Chev.] C.F. Liang & A.R. Ferguson), blue nets reduced significantly the vigor of vines, whereas the red net appeared to stimulate vigor (Basile *et al.*, 2008), while apple trees grown under red net presented greater shoot length in comparison to those grown under full sunlight and neutral white net (Figure 3). Intensity of PAR and R/FR ratio did not differ among red and white nets (Figures 3A and 3B); however, the B/R ratio under red net was 5-10% lower than white and full sunlight conditions, respectively (Figures 3C). Since changes in B/R ratio are associated to CRY photoreceptor regulating shoot dwarfing and/or elongation (Baraldi *et al.*, 1998; Rapparini *et al.*, 1999; Cummings *et al.*, 2008), management of B and R light proportions by colored nets could be an interesting tool to manipulate the vegetative growth and development in fruit orchards.

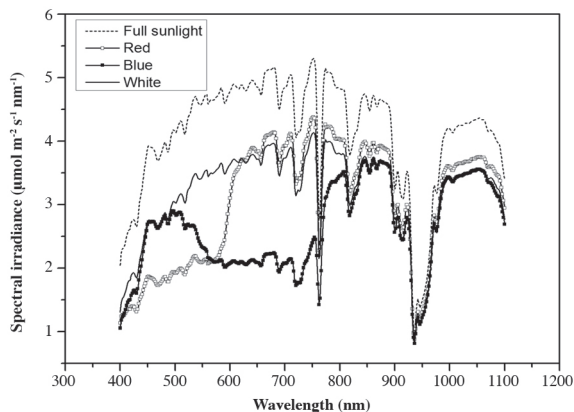


Figure 2. Spectral irradiance (visible plus near-infrared) pattern of full sunlight and different colored nets (Adapted from Bastías *et al.*, 2011).

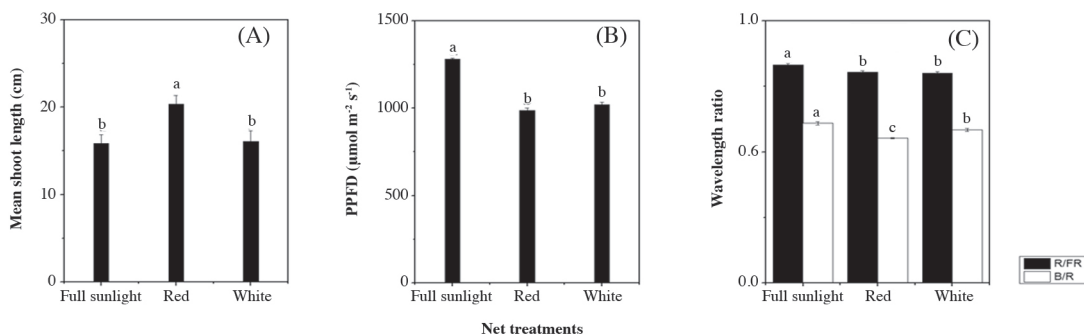


Figure 3. Mean shoot length (A); photosynthetic photon flux density, PPFD (B); and red/far-red (R/FR), and blue/red (B/R) light proportions (C); estimated in 'Fuji' apple trees grown under full sunlight and red and white nets (Bastías *et al.*, unpublished data).

## CONCLUSIONS

Orchard canopies present marked changes on light quality conditions and mainly in the R/FR ratio and PHY mediated plant responses.

Shoot growth and fruit color development are the most clearly plant response regulated by light quality conditions in fruit trees. Changes in the proportion in B, R, and FR light alter the pattern of shoot growth and anthocyanin synthesis, mediated by the interaction of PHY and CRY photoreceptors. However, the effect of light quality on leaf morphological and functional characteristics should be studied with more attention in further research.

Light quality manipulation could be achieved by reflective films and colored nets in orchard systems. Although the positive effects of this technology are normally associated to improving the PAR use for net C assimilation, different reports demonstrated that, irrespective PAR availability, reflective films and colored nets alter widely the light quality composition in the UV, B, and R light with ensuing effects on PHY and CRY plant mediated responses such as shoot growth, color development, and fruit growth.

On summary, alteration of light quality makes significant differences in fruit trees and could be a useful tool for sustainable (e.g. lower use of chemicals and labor-practices) manipulation of yield and quality in orchards. Since novel technologies such as reflective films and colored nets, which are already taking hold among fruit growers, alters widely the light quality conditions; more research and knowledge will be necessary in the future about interactions of plant and light quality under orchard systems.

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## Manejo de la calidad de la luz en huertos frutales: Aspectos fisiológicos y tecnológicos.

El manejo de la calidad de la luz (espectro de la luz solar) promete proveer una nueva alternativa tecnológica para la producción sostenible de cultivos hortícolas. Sin embargo, existe poca información acerca de aspectos fisiológicos y tecnológicos sobre el manejo de la calidad de la luz en cultivos frutales. La composición de luz solar cambia ampliamente en la canopia de los huertos, induciendo diferentes respuestas en la planta mediadas por la actividad del fitocromo (PHY) y criptocromo (CRY). Una alta proporción de luz roja-lejana (FR) en relación a la roja (R), incrementa la elongación de brotes, mientras que la luz azul (B) induce un acortamiento de brotes. La luz R y ultravioleta (UV) incrementan la síntesis de antocianinas en la piel de los frutos, mientras que la luz FR muestra un efecto negativo. La luz R y B también pueden alterar caracteres morfo-fisiológicos de la hoja en árboles frutales, tales como grosor de la palizada, apertura estomática y contenido de clorofila. Además de mejorar la disponibilidad de la luz fotosintéticamente activa (PAR), el uso de film reflectantes mejora la proporción de luz UV y R, con efectos positivos sobre respuestas mediadas por el PHY (color de fruto, peso de fruto y crecimiento de brotes), como se reportó en manzano (*Malus domestica* Borkh.), duraznero (*Prunus persica* [L.] Batsch) y cerezo (*Prunus avium* [L.] L.). Las mallas de color alteran ampliamente la composición espectral de la luz con efectos sobre el crecimiento de planta, rendimiento y calidad en huertos de manzano, duraznero, kiwi (*Actinidia deliciosa* [A. Chev.] C.F. Liang & A.R. Ferguson) y arándano (*Vaccinium corymbosum* L.). Los mecanismos de las mallas de color parecen estar asociados a procesos fotosintéticos y morfogenéticos regulados por la disponibilidad de PAR, la proporción de luz B/R, y actividad del CRY. La alteración de la calidad de la luz afecta significativamente respuestas de la planta en árboles frutales y podría ser una herramienta útil para el manejo sostenible (ej. bajo uso de químicos y prácticas laboriosas) del rendimiento y calidad en huertos modernos.

**Palabras clave:** luz roja, roja lejana y azul, fitocromo, criptocromo, foto-morfogénesis, film reflectantes, mallas de color.

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