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The influence of protective netting on tree physiology and fruit quality of apple: A review

Giverson Mupambi[a], Brendon M. Anthony[a], Desmond R. Layne[b], Stefano Musacchi[a,b], Sara Serra[a,b], Tory Schmidt[c], Lee A. Kalcsits[a,b,*]

[a] Tree Fruit Research and Extension Center, Washington State University, Wenatchee, WA 98801, United States
[b] Department of Horticulture, Washington State University, Pullman, WA 99164, United States
[c] Washington Tree Fruit Research Commission, 1719 Springwater Ave, Wenatchee, WA 98801, United States

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ABSTRACT

The use of protective netting (also called shade nets or anti-hail nets) is being increasingly adopted in apple (*Malus* × *domestica*) production. Protective netting is mainly used to prevent fruit sunburn and protect trees against hail damage. Netting can also be used for protection against damage from birds, fruit bats, insects, wind and sand storms. In recent times, protective nets have been modified into photoselective nets by incorporating chromatic elements into the netting material. These change the spectral characteristics of the solar radiation reaching the tree canopy below the net and can affect physiological pathways that respond to the altered light spectra. Protective netting primarily modifies light quantity and quality underneath by reducing light intensity by an approximately pre-determined percentage. Protective netting has also been reported to reduce wind speed and soil temperature with minimal impact on canopy temperature and relative humidity. Quantifying the influence of protective netting on tree gas exchange has been difficult due to variations in the environmental conditions at the time of measurement. Reductions in light intensity due to protective netting result in increased leaf area, shoot length, and total shoot fresh weight that increases as the net shading percentage increases. Fruit set, return bloom, and flower induction are all affected by protective netting. Ultimately, fruit quality is the critical factor determining whether protective netting is suitable for apple production. The reported results on the effect of protective netting on fruit quality have not been conclusive. It has been suggested that changes in fruit quality under protective netting are often more influenced by the environmental conditions in that specific growing season than the netting itself. For example, typical shade responses under netting can be exacerbated when the natural overall light intensity is reduced on cloudy days. In conclusion, protective netting provides an alternative to traditional approaches to protecting apple from sunburn, mechanical injury from hail and wind, and abiotic stress that limits tree productivity. However, the inconsistent reported results suggest a targeted approach is needed to identify specific physiological responses of apple under protective netting, and more specifically, photoselective netting as a strategy to protect apple orchards from adverse environmental conditions.

1. Introduction

The use of protective netting (also called anti-hail nets or shade nets) in apple (*Malus* × *domestica*) production is increasing as growers seek to protect both the tree and fruit from excessive solar radiation and hail damage (Do Amarante et al., 2011; Shahak et al., 2004a, 2004b). Excessive solar radiation leads to the development of sunburn in fruit, a physiological disorder that causes huge economic losses for growers (Racsko and Schrader, 2012). Hail damage is common in many apple production regions worldwide and protective netting can help protect the tree and fruit against hail (Iglesias and Alegre, 2006; Middleton and McWaters, 2002). Hail damage not only affects fruit production during the current growing season but also affects fruit yield the following season by damaging flower buds developing during the current season. Protective netting is a viable means to reduce tree stress during weather extremes. For this paper, the term protective netting will be used in the general sense. The terms shade netting, anti-hail netting and photoselective shade netting will be used as specified in original literature.

Protective nets are also used for protection against damage from birds, fruit bats, insects, and strong winds (Arthurs et al., 2013; Shahak

* Corresponding author at: Tree Fruit Research and Extension Center, Washington State University, Wenatchee, WA 98801, United States.
E-mail address: lee.kalcsits@wsu.edu (L.A. Kalcsits).

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et al., 2004b; Smit, 2007). In recent years, protective nets have been further developed into photoselective nets by incorporating chromatic elements (Shahak, 2008). Photoselective nets are designed to alter the spectral characteristics of solar radiation by the addition of targeted light dispersive, absorptive and reflective elements into the netting material (Shahak et al., 2008a, 2016). Other benefits of using protective netting in apple production include yield increases, increased income from an increased percentage of clean fruit with no sunburn symptoms (Kalcsits et al., 2017), reduction in irrigation costs from reduced soil water loss (McCaskill et al., 2016), reduced hand thinning costs if protective netting is put up during pollination and reduced spraying costs due to increased spray efficacy (Whitaker and Middleton, 1999).

Protective nets are mostly made of high-density polyethylene (HDPE) (Castellano et al., 2008, 2006). The fibers making up the net are often woven in different ways to improve net flexibility and mechanical resistance to breakage (Castellano et al., 2006). The shading factor is equal to the percentage of incoming radiation that is not transmitted through the protective net (e.g., a 20% protective shade net means that light passing through it is only 80% of full sunlight). The composition of the HDPE, the thread density and weaving style will affect the shading percentage.

Most of the research into the use of protective netting has focused on one or two applied aspects of netting and different environments produce different responses to netting. Therefore, a critical review would be useful to integrate the extensive research detailing the effects of protective netting on apple tree physiology and fruit quality and identify gaps in research that would help clarify contrasting responses and questions that have arisen in past experiments. The aim of this review is to provide a critical appraisal of current research on the use of protective netting in apple production. Here, information on protective netting on the orchard environment, tree physiology, and fruit quality is assembled to identify research gaps that can address future research on the use of protective netting for apple production and other production systems.

2. Environmental conditions under protective netting

One of the primary benefits of protective netting is the reduction in solar radiation reaching the orchard environment underneath it. Protective netting has been reported to modify the orchard environment with respect to light intensity and quality, canopy temperature, relative humidity, and soil temperature (Bastías and Corelli-Grappadelli, 2012; Iglesias and Alegre, 2006; Kalcsits et al., 2017). A summary of the effect of protective netting on the apple orchard environment is given in Table 1 and on light quality in the orchard is given in Table 2.

2.1. Light quantity and quality

The perception of light by plants depends on both the intensity and the spectral signature. Plants utilize light cues at specific wavelengths to regulate processes involved in their growth and development. These light responses include germination, hormone regulation, photomorphogenesis, flowering, shade avoidance, phototropism, stomatal movement and photosynthetic efficiency (De Wit et al., 2016; McDonald, 2003). Through the alteration of the total amount of solar radiation reaching the tree canopy and the quality of light, physiological responses to light cues may change. The changes in light quality through the use of protective netting has been studied in other horticultural species (Stamps, 2009; Basile et al., 2012; Zoratti et al., 2015). However, the most extensive research identifying the impact of colored protective netting on perennial horticultural species has taken place in apple production systems.

For apple production, the shading factor is an important consideration in deciding the type of netting that is suitable for specific growing environments. Protective nets reducing incident photosynthetically active radiation (PAR) by 12%, 15%, 17%, and 30% have been tested in apple (Shahak et al., 2004a), along with some nets being able to reduce up to 90% of the solar radiation (Zibordi et al., 2009). Although protective netting can be designed for specific PAR reduction percentages, 15–30% shading is most commonly used for tree fruit (Shahak, 2014). The age of the net also influences the shading factor. With time, dust particles collect on the shade net affecting light transmission through the net. Blanke (2009) reported a 2% reduction in PAR transmission through the net per year. With time, black and crystal white translucent shade nets become increasingly grey whilst red shade nets become orange because of pigment degradation (Blanke, 2009). Improvements in the quality of thread and pigments used in the manufacturing of protective netting has resulted in potential life-span of 11 years, with the next generation of protective netting having potential life span of up to 15 years (Blanke, 2009). Reduction in PAR under protective netting depends on the type of net, the mesh size, and color of the net (Middleton and McWaters, 2002). The architecture of the net installation may also have an effect on light quality and quantity. Light scattering under a partial angled/louvered netting installation will likely different from a flat structure of the top of the canopy. Other important design characteristics include whether the net is woven or knotted, the number of threads in the net, the thickness of the thread and the material used for the thread (Castellano et al., 2006).

Protective nets change the quality of light passing through them by altering light diffusion, reflectance, transmittance and absorbance (Basile et al., 2008; Ganelevin, 2008). Light scattering contributes to increased diffuse radiation providing a better distribution of light that improves light penetration both vertically and horizontally into the tree canopy (Shahak et al., 2004b). The physical composition of netting can influence spectral transmissivity (Castellano et al., 2006). Protective netting and more specifically, photoselective shade netting can change the light microclimatic conditions in the orchard (Stamps, 2009). Shade nets modify light quality in the ultraviolet (UV) (100–400 nm), photosynthetically active radiation (PAR) (400–700 nm) and near infrared (NIR) (760–1500 nm) wavelength ranges (Castellano et al., 2006). Additionally, the transmission of diffuse radiation is increased under protective netting by 17–170% depending on the physical makeup of the net (Abdel-Ghany and Al-Helal et al., 2010). These changes to light quality can induce physiological responses in the tree (Folta and Carvalho, 2015). Spectral modification by photo selective nets is a more recent technological advancement for protective shade nets that is now being extensively studied.

2.2. Canopy air and soil temperature

Protective netting is a partial physical barrier that reduces both wind speed and the amount of solar radiation passing through it. As a result, the temperature dynamics of canopy air and the soil underneath are inevitably altered. Other factors affecting the measured temperature under protective shade netting include the location of sensor (i.e. above canopy or inside the canopy) and the shading factor (Iglesias and Alegre, 2006). The interactions between these factors may have contributed to the contradicting reported results in how netting affects air temperature. Air temperature under shade nets can either be reduced from reduced radiant heating, i.e. a 'shade effect' under nets, or can be increased due to reduced air circulation under shade nets, i.e. a 'greenhouse effect' (Iglesias and Alegre, 2006). Air temperature readings from a sensor that is exposed directly to solar radiation have been reported to be 4–6 °C higher than temperature readings from inside a "Stevenson Screen" (Middleton and McWaters, 2002). The use of temperature probes without radiation shields could also explain some of the contrasting results reported in the literature. Elevated air temperatures were reported under 50% red, blue, and pearl shade nets compared to an uncovered control and 50% black shade net (Arthurs et al., 2013). In contrast, a 1–3 °C reduction in air temperature under shade nets has also been reported (Iglesias and Alegre, 2006; Middleton and