Scientia Horticulturae 172 (2014) 300–307

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Regulation of the vegetative growth of kiwifruit vines by photo-selective anti-hail netting

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ARTICLE INFO

Article history:
Received 10 February 2014
Received in revised form 8 April 2014
Accepted 10 April 2014
Available online 15 May 2014

Keywords:
Colored nets
Shoot growth
Vine vigor
Light interception
Dormant prunings
Preformation

ABSTRACT

The regulation of vegetative growth is very important in the management of commercial fruit tree orchards. Photo-selective netting has been demonstrated to be an effective method to induce photomorphogenic vegetative responses in several plant species. We report here on a three-year study of the effect of four types of low-shading, photo-selective anti-hail nets (blue, gray, red, and white) on the vegetative growth and development of open-field grown mature kiwifruit vines. The modification of light quantity and quality induced by these nets differentially affected numerous aspects of vegetative growth of kiwifruit vines (e.g. shoot growth, leaf size, petiole length, node preformation). In general, the blue net restrained the vine vigor, compared to un-netted vines, whereas the red and the gray nets stimulated vegetative growth. Vine vigor under the white nets was intermediate. Additionally, the photo-selective netting differentially affected the growth model of kiwifruit shoots (determinate vs. indeterminate growth), as well as node preformation, as indicated by the decrease in terminating shoot node number induced by the blue net. Taken together with our previously reported positive effects of the red net on fruit size and dry matter, this net is probably the most cost-effective of the tested nets, in spite of its vigour stimulating effects. Photo-selective netting can hypothetically affect vegetative growth both (a) indirectly modifying air temperature and/or vine fertility (crop load) and (b) directly inducing photomorphogenic responses to changes in light quantity/quality. Our results suggest that most of the effects of these nets were explained by their spectral properties, whereas indirect effects did not appear to play a central role. It is proposed that the photo-selective netting represents a suitable technology for merging the need for protecting kiwifruit orchards from environmental hazards, together with an advanced use of solar energy.

1. Introduction

The regulation of vegetative growth is an important element in commercial cultivation of fruit trees (Kozlowsky and Pallardy, 1997). On one hand, tree vigor should not be excessive in order to improve light distribution inside the canopy, to reduce competition with reproductive growth, to decrease the amount of labor required to carry out important practices such as pruning and harvest, to decrease tree susceptibility to diseases, and to improve pesticide distribution in the canopy. Current orchard management strategies are combining numerous practical approaches to decrease tree vigor. These include dwarfing rootstocks, plant growth regulators, pruning strategies, deficit irrigation, and more (Miller and Tworkoski, 2003). On the other hand, the vegetative growth must be active enough to allow fruiting shoot renewal and a sufficient foliage development for supporting fruit growth (Lai et al., 1989) and for reaching the desired fruit composition (Snelgar et al., 1998).

Plant growth and development are highly regulated by light. Plants can sense the intensity, spectral composition, and direction of light and respond accordingly. Light-dependent regulation is conveyed by the photosynthetic system, as well as by photomorphogenesis processes. Over a decade ago, photo-selective netting has emerged as a new technology for manipulating light quality and quantity under practical field conditions (Rajapakse and Shahak, 2007). This technology aims to combine the light manipulation, together with physical protection from environmental hazards (e.g. excessive radiation, hail, wind, flying pests), and with mitigating the microclimate (Shahak et al., 2004b). The different photo-selective net products provide the plants with spectrally

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http://dx.doi.org/10.1016/j.scienta.2014.04.011
0304-4238/

modified light, which is transmitted via the colored plastic threads, mixed together with the natural, unmodified light that is passing through the holes of the net. Since the colored threads are translucent, their transmitted light is not only spectrally modified, but also highly scattered (diffused).

During the last decade, many field studies have demonstrated that photo-selective shade nets (50–75% shading in Photosynthetically Active Radiation, PAR) can differentially affect several aspects of vegetative and reproductive growth of numerous cultivated species (recently reviewed by Stamps, 2009; Shahak, 2014). Red and yellow nets enhanced vegetative growth, the blue nets induced dwarfing, whereas the gray and pearl shade nets promoted branching in ornamental crops (Nissim-Levi et al., 2008; Oren-Shamir et al., 2001; Ovadia et al., 2009). Differential vegetative responses can be also obtained in open-field grown fruit trees even under very low shading (15–30%) nets, such as the anti-hail photo-selective nets. For instance, Solomakhin and Blanke (2008) reported that the vegetative growth of apple trees was enhanced by different types of colored hail-nets (especially the green-black net) compared to uncovered trees. Bastías et al. (2012) found that apple shoot growth rate was stimulated by blue nets compared to red, gray and white nets. On the other hand, tree vigor of nectarine trees was increased by red hailnets (Giaccone et al., 2012). Therefore, plant responses to colored nettings appear to be species-specific.

Kiwifruit vines are very sensitive to direct damage caused by hailstorms (de V Lötter, 1990), that in some cases can even have negative carry-over effects on the next-season yield (Shaw, 1987). Consequently, the use of hail protection systems is recommended for kiwifruit vines located in agricultural areas where windy conditions and hailstorms occur at high frequency (de V Lötter, 1990; Reil, 1994). Since the use of anti-hail nets for protecting kiwifruit vineyards is becoming a common management practice in Italy, we designed a 3-year field trial to test whether the use of photo-selective (blue, gray, red, and white) anti-hail nets would promote any beneficial photomorphogenic responses, on top of their mere hail and wind protective functions. In our previous papers we had reported on significant differential effects of these nets on fruit yield, size, quality, and phytonutrient composition (Basile et al., 2008a, 2012). Both the white and the red nets were found to promote a high percentage of dry matter in the fruit. This resulted in a high soluble solids concentration in the fruits during cold-storage. The blue and gray nets tended to affect negatively the percentage of dry matter and soluble solids content of fruit. Furthermore, fruit fresh weight under the red nets was similar to un-netted vines independently of crop load. In addition, the white and blue nets had a slight negative effect on flesh chlorophyll concentration and color. The current paper is focusing on the effects of the same four experimental photo-selective anti-hail nets on the vegetative growth and development of kiwifruit vines.

2. Material and methods

2.1. Experimental site and plant material

The experiment was carried out at a private kiwifruit vineyard located in Battipaglia (Salerno, Southern Italy, 40°35′N, 14°56′E). Vines were 'Hayward' cultivar grafted on Bruno and were planted with a north-south row orientation and 3.0 m × 4.5 m spacing (≈741 vines/ha), and trained to a T-bar (with 2 permanent cordons oriented along the row at 2 m above the ground). Vines were winter-pruned to leave 18–20 canes/vine and 17–19 buds/cane (corresponding to a total of around 220,000–280,000 buds/ha). The pollinator cultivar was 'Tomuri' (planted in a 1:6 ratio). Routine horticultural care was provided according to the protocol for commercial fruit production (Testolin and Ferguson, 2009). During flower thinning, lateral flowers of each cluster and fan flowers were eliminated.

2.2. Spectral properties of the photo-selective nets

Four photo-selective anti-hail nets were studied: blue, gray, red, and white (Polysack Plastic Industries Ltd., Nir Yitzhak, D.N., Negev, Israel). All four products were knitted from HDPE (High Density PolyEthylene) combined flat and round threads, suitable for hail protection.

The spectral properties of the photo-selective nets were measured before starting the experiment in a simulation construction of 4 m × 4 m × 4 m at the Volcani Center (Bet-Dagan, Israel). Spectra of the total solar light (consisting of direct plus indirect light) transmitted by the nets were measured on clear days at solar noontime with a spectroradiometer (LI-1800, LI-COR Inc., Lincoln, NB, USA) with a scan interval of 1 nm in the range of 300–850 nm. During the measurements the simulation construction was oriented to place the net orthogonal to sun beans. Photon flux density (PFD) in the PAR, Blue light (B), Red light (R), and Far-Red light (FR) ranges were measured integrating PFD values over the following wavelength ranges: 400–700 nm (PAR), 420–500 nm (B), 640–680 nm (R), 690–750 nm (FR). On the same measurement day, incident sunlight (measured with no net) had the following spectral characteristics: PAR = 1902 μmol m^{-2} s^{-1}, B = 455 μmol m^{-2} s^{-1}, R = 288 μmol m^{-2} s^{-1}, FR = 403 μmol m^{-2} s^{-1}. The relative transmittance of PAR (400–700 nm) through the nets was 79.6%, 77.2%, 73.1%, and 72.7% (corresponding to shading factors of 20.4%, 22.8%, 26.9%, and 27.3%) for the white, red, blue, and gray nets, respectively. All the nets increased the percentage of scattered/total light ratio in the PAR range from 10.7% in the un-netted control, to 13.1%, 12.2%, 16.4%, and 23.0% for the blue, gray, red, and white nets, respectively) (Basile et al., 2012). The spectral differences between the nets were mostly expressed by the scattered light component. The blue and red spectral regions were the most affected. Thus, the blue/red ratio of the scattered light component was markedly higher under the blue net (5.16), compared to natural sunlight (3.76), whereas this ratio was significantly lower under the red net (1.14). The red/far-red ratio in scattered light decreased under the nets, particularly under the red net, compared to sunlight. Moreover, the PAR/UV ratio of the scattered light was significantly higher under the white (11.7) and red (8.2) nets than in full sunlight (5.2). Additional information about the nets can be found in Basile et al. (2012).

2.3. Net installation and experimental design

The four photo-selective anti-hail nets were placed horizontally above the vines 4 m above the ground (2 m above the plants' permanent cordons) in the first week of April 2004.

The experimental design was a randomized complete block with five treatments (four photo-selective nets and an un-netted control), three blocks (repetitions). Each photo-selective net treatment covered 91 vines (a surface of 1228.5 m^2) within each block, but data collection was performed only on the 12 central vines (a total of 180 vines = 12 vines × 5 treatments × 3 blocks), whereas the other vines were considered as borders to avoid the effect of mixed light. Measurements were carried out during the growing seasons 2004, 2005, and 2006.

2.4. Air temperature measurement

Air temperature was measured in full air and under the nets (1.5 m below the nets) with 5 temperature sensors equipped with data loggers (TinytagUltra, Gemini Data Loggers, Chichester, West Sussex, UK) (one per treatment). The data loggers were