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SHADE NETS ON TABLE GRAPES

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Abstract

The use of covering nets is widely diffused in horticulture in order to protect plants from adverse conditions such as hail, wind or light excess, pest attacks, bird injury, hence, several type of articles are available. Most of nets are transparent (white), aiming at allowing light penetration, or also black or green when shading effect is desired. In the last decade, photo-selective colored nets have been also experimented in order to assess the effects that the change in light spectrum may exert on leaf functioning, shoot growth and fruit quality. Nevertheless, all nets reduce the amount of light available for the crop; in many cases the leaf net photosynthetic rate is reduced, but, on the other hand, leaves and fruits are protected from damages caused by excess of irradiance. Besides decreasing incident solar radiation, nets modifies the crop microclimate in terms diurnal pattern of air temperature and humidity; they may lower daytime temperature and vapor pressure deficit, but increase night temperature, enhancing atmospheric stability. Under semi-arid conditions, to limit the solar irradiance at canopy level may be useful to lower the transpiration rate and thus the crop water deficit. Hence shade nets may be helpful to attenuate the effects of multiple environmental stresses. On table grapes, the net use of nets is quite largely diffused, but, on the whole, relatively little information is still available on their physiological effects on leaf functioning and grape quality. The most used net types reduce wind speed by 80-85%, and photosynthetic photon flux by 10-25% or even more, according to the net color. In many cases vine vigor and yield are increased; sometime, negative effects on berry characteristics have been noticed, such as a poorer skin color. To avoid possible detrimental effects, canopy management and other cultural practices should be adapted to match better the needs of vines grown under shade nets.

Key words: net types, shading factor, microclimate, net color, light quality.

Introductions

Net protection of fruit tree crops started as a technique apt to defend trees from hail storms and from insects or birds. Nevertheless, it was soon noticed that nets reduce solar irradiance, air temperature, wind speed, dust, and avoid leaf and fruit sunburn; hence, the net use was extended to microclimate manipulation. Studies on the secondary effects of hail nets were undertaken many decades ago in several countries, such as in Italy (Romisondo, 1968; Giulivo and Ganzini, 1971). Presently, the use of nets to protect foliage and fruits from excess of the irradiance and to lower air vapor pressure deficit and evapotranspiration has been largely increased. Sunlight limitation, besides to reduce air temperature, is known to increase the photosynthate partition to shoots rather than to fruits, especially during the phase of initial shoot growth, enhancing shoot vigor (Bepete and Lakso, 1998). However, either positive or negative effects of shade nets on fruit size are reported in scientific literature; they depend mostly on cultivar, environment and effective reduction of light availability at canopy level, as reported by Bastías and coauthors (2012).

Colored shade nets are able to select the wavelength ranges of solar radiation that pass through, thus they have been experimented as a tool for light-quality manipulation apt to modify shoot and fruit growth (Shahak *et al*., 2004). It is well-known that, besides UVA and UVB radiations, also Blue, Red, Far-red and their ratio modulate plant photomorphogenesis: i.e. red light may enhance fruit anthocyanin synthesis and low Red:Far-red ratio may stimulate shoot elongation and leaf expansion, via phytochrome response (Morgan et al., 1985; Zhou and Singh, 2002). However, also the effects of colored covering plastic materials are not univocal; they seem to interact with the cultivar sensitivity to the “color effect” and/or with the genotype vigor, as it has been pointed out by testing colored plastic films on tablegrapes (de Palma *et al*., 2012).

Net materials and types. There are several types of nets as concerns material, structure, radiometric properties including shading factor and light quality, besides mechanical properties.

The most used material is high density polyethylene (HDPE) added with anti-UV agents that increase the durability; polypropylene is utilized to obtain non-woven layers (Castellano *et al*., 2008); starch-based biodegradable materials are sometime utilized, but their higher cost and lower resistance limit the diffusion (Narayan, 2001**;** Castellano *et al*., 2008); the abaca natural fiber (*Musa textiles* var. Laylay) has been experimented (Bande *et al*., 2013).

Nets differ for type of thread and texture, mesh size, porosity/solidity, weight and color. These characteristics affect air permeability, light transmissivity and reflectivity; mesh size, texture and color affects also the net shading effect. The thread may be a monofilament or a flat tape; the single thread thickness varies from 0.25 to 0.32 mm. According to the texture there are three net types (fig. 1): flat or “Italian”, that is a mono-wire woven, is usually light and has a stable shape; “English”, which has a double thread perpendicular to the selvage, results to be stiffer and resists to hail storms; “Raschel”, that has a sort of chain perpendicular to the selvage and resists also to wind gusts without loosing. The mesh size varies from 2.5 to 4.0 mm for hail protection, from 1.8 to 7.0 for windbreak, from 30.0 to 40.0 mm for anti-birds purpose, and from 1.7 to 7.0 for shading (Castellano *et al*., 2008). Net porosity and air permeability depend on the aerodynamic resistance (Mistriotis and Castellano, 2012): *i.e.* whit 2.0 x 1.6 mm mesh, the windbreak value is 38%, while with 1.3 x 1.6 mm it is 50-55%, and with 1.8 x 1.0 mm it is 85% (Retiplast s.r.l.). The air movement below the cover influences air humidity, temperature and gas concentration inside the net-house, hence, in turn, the rate of leaf transpiration, net CO_2 uptake and related metabolic processes (Stamps, 2009). Nets may have several colors: transparent, black, green, pearl (grey), red, yellow, blue, the first three being the most used. The presence of any net reduces the solar irradiance available for the crop. Transparent nets are adopted when a minimum light lowering is desired; a transparent “crystal” mono-wire is utilized to obtain this article, that looks as “white”. Black nets have the highest shading effect. They are obtained by adding “carbon black”; this additive has also an anti-UV effect, thus prolongs the net life. Shading effect is defined by the shading factor, that is the ratio between light measurements with and without net, or the net property to absorb and reflect in the visible wavelength range (380-760 nm) (Castellano *et al*., 2008).

Colored nets are obtained by adding pigments in order to modify the spectral-radiometric properties of plastic material and thus, in turn, the light micro-envirromment and the photoreceptor response, trying to improve fruit quality and yield (Shahak *et al*., 2004; Castellano *et al*., 2008**;** Stamps, 2009; Amarante *et al*., 2011). Colored nets have effectively proved to exert a photo-selective action; changes in the amount of photosynthetically active radiation (PAR), Red:Far-red ratio and morphogenetically active radiation (MAR) have been found (Stamps, 2009).

In Italy, the most used net type is a white hail net having from 10% to 20% shading factor. However, net Industries produce articles having several shading capacity, according to net color and mesh density (tab. 1).

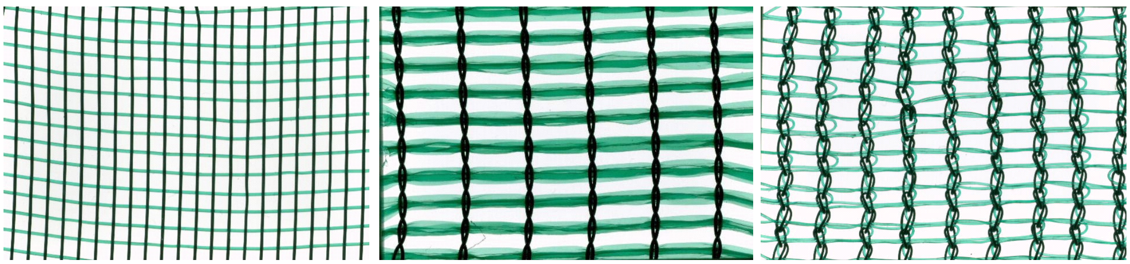

Fig. 1 – Italian texture (left), English texture (center), Raschel texture (right). (Modified from Castellano *et al*., 2008).

Tab. 1 – Characteristics of some plastic nets produced for agricultural purposes.

N. threads/cm mesh	**2.6-4** *	**4-4** *	**5-4** *	**6-4.5** **	**6-4.5** **	**6-5.5** **	**6-5.5** **	**6-5** ***	**6-5** ***	**6-8** ***	**6-10** ***	**6-14** ***
Color	crystal	crystal	crystal	black	green	black	green	black	green	black	black	black
Texture	English	English	English	Italian	Italian	Italian	Italian	Italian	Italian	Italian	Italian	Italian
Threads diam. (mm)	na	na	na	0.28	0.28	0.28	0.28	na	na	na	na	na
Porosity (%)	85	79	74.8	na	na	na	na	71	71	61	50	84
Shading factor (%)	8	11	13	75	55	90	70	45	35	60	75	90
Windbreak (%)	25	30	35	na	na	na	na	38	38	50	55	85
Weight (g/m2)	54	65	72	105	105	110	110	82	82	108	115	165

na: not available.
* http://www.annalenaplastic.it
** http://www.serroplast.it
***http://www.retilplast.it

Shade net effects on fruit tree crops

Apple. Tanny and coauthors (2009) proved that, in an apple orchard covered with nets having 16, 30, and 60% shading factor, wind speed decreased by 9% and air temperature at noon decreased by 1.5 °C; a lower vapor pressure deficit (VPD) was recorded during daytime suggesting a potential saving of water requirement. On cvs Gala and Fuji, a transparent net with 4 x 7 mm mesh reduced PAR availability at top canopy by 18.4%; nevertheless, it allowed to increase chlorophyll content per leaf area, specific leaf area mass and fruit weight, and to lower the incidence of sunburn and bitter pit during storage, respect to the uncovered treatment. However, fruits of covered trees showed a lower skin color, flesh firmness and TSS (Amarante *et al*., 2011). On cv Mondial Gala, Iglesias and

Alegre (2006) found that a black net, in comparison to a transparent (crystal) one (both having 3.0 x 7.4 mesh size), intercepted 13% more incident solar radiation (as PAR), increased shoot vigor, reduced fruit skin color and TSS, and had no influence on titratable acidity (TA) and fruit cracking; both net types lowered air temperature and fruit sunburn. In a trial on cv Fuji covered with 40% blue, red and grey shade nets, and with a 20% white net as a control, Bastías and coauthors (2012) found that both red and blue nets lowered PAR by 27%. Nonetheless, compared to the control, the blue net increased the light Blue:Red ratio by 30%, decreased Red:Far-red ratio by 10% and improved leaf photosynthesis (+28%), total leaf area (+30%) and fruit weight (+17%). On 'Pinova' and 'Fuji Kiku', a better fruit quality and taste were found when trees were grown under a red/white or a white net (Solomakhin and Blanke, 2010), while the highest anthocyanin and vitamin C content were found in fruits obtained in open air. In South Africa, a 20% black shade net reduced rates of leaf transpiration, stomatal conductance and net photosynthesis in cv Royal Gala. In cv Crips Pink tested in hot summer days, shade net decreased transpiration more than photosynthesis, improving leaf water use efficiency. In cv Fuji, 20% white shade net reduced fruit temperature by 5.6 °C, but also fruit skin color (Gindaba and Wand, 2007a, 2007b, 2008). In Italy, no significant difference of fruit quality was found in 'Golden delicious' and 'Royal Gala' grown under white, black, grey and green nets (Peano *et al*., 2001).

Peach and plum. Cling peaches cv Davis grown under black shade nets were found to develop less skin and flesh color, TSS, TA, TSS/TA ratio, and higher flesh firmness in comparison to fruits obtained in open air (Podestá *et al*., 2002), as well as nectarines cvs Supercrimson and Caldesi 2010 grown under black nets showed lower TSS and higher flesh firmness, especially at first and second picking (Peano *et al*., 2002). On one year old peach trees cv Messapia, the effects induced by five colored nets, that is, blue, red, pearl, grey and yellow, all having 40% shading factor, were compared with those obtained with a transparent net having 12% shading factor and with those obtained in open air. All nets, except for the blue and transparent ones, increased significantly the shoot elongation. This result was linked to the net radiometric properties: a low solar radiation transmissivity, observed in the yellow and grey nets, possibly act by reducing the summer stress; a low Red:Far-red ratio and Blue:Far-red ratio, noticed in the red and pearl nets, possibly induced photomorphogenetic effects (Schettini, 2011). On cv Hermosa, Shahak and coauthors (2004) found that, when compared to open air, grey net enhanced fruit size and red skin coloration, red and yellow nets improved fruit firmness, while blue net lowered fruit size. All nets increased shoot vigor; moreover, except for the grey one, they improved the number of flowers per branch and, except for the pearl one, the setting of high quality fruitlets. According to Arjona and coauthors (2002), black hail nets reduced TSS and skin color of plum 'Linda Rosa', and the size of 'Larry Ann'; similar results were found on cv Angeleno (Rodríguez *et al*., 2002).

Other tree fruit crops. In citrus trees grown under semi-arid conditions, dense shade nets proved to reduced midday net radiation by 53% and midday sap flow by 10-11% respect to open air: the related decrease in leaf transpiration was estimated about 25% (Cohen *et al*., 1997). In blueberry, colored shade nets were tested in order to alleviate environmental stresses, to increase yield and delay harvest respect to open air: 25, 50, 70% white, black and red shade nets retarded fruit development and increased final fruit weight, but decreased TSS (Lobos *et al*., 2009). On kiwi, four colored nets were tested to individuate eventual change of fruit quality related to the net photo-selective effect: white and red nets enhanced fruit dry matter accumulation; blue and grey nets showed a tendency to reduce dry matter and TSS accumulation; white and blue ones lowered flesh chlorophyll concentration and green color. Moreover, all nets decreased fruit polyphenol concentration and antioxidant activity at harvest (Basile *et al*., 2012). On cactus pear, it was observed that the longer the shading period the lower the fruit growth and final fruit size; fruit ripening was delayed without significant effects on TSS and flesh firmness (La Mantia *et al*., 1997).

Shade net effects on tablegrape vineyard

Growing tablegrape vines under transparent nets is very common in Southern Italy, especially in the Apulia region that is the first producer at a national level. The principal aim is to protect shoots, inflorescences and grapes from hail. Moreover, since nets are set up at bud-break, they protect young shoots (that are known to be very delicate in grapevine) from ruptures caused by strong winds.

In highly windy environments, vineyards may be completely closed by nets; different net colour can be used: i.e. black or green nets on the top, to protect from direct solar radiation, and white net around the laterals, to facilitate the entry of diffuse radiation (fig 2).

Fig. 2 – Net-houses on vineyards in Chile.

In Italy studies on the secondary effect of hail net were carried out in viticulture since the end of the ’60s. White and black nets were found to change maximum and minimum air temperature respect to open air. White nets proved to increase midday air temperature and decrease air relative humidity; black nets showed thermal inversion at dawn; both types, after a period of high humidity, such as after night, induced a slower decline of humidity respect to open air (Giulivo, 1979). Presently, the most used nets are white and have from 10 to 20% shading factor (fig. 3). When the vineyards are temporary covered with plastic film aiming to advance or delay grape harvest, the use of hail-net is often combined in order to protect vines during the entire growing season (Novello *et al*., 1999). Ecophysiological measurements taken on cv Redglobe grown under white hail net and trained to overhead “tendone” trellis showed that leaves at top canopy intercepted 80% of the available PAR; respect to these leaves, those localized along the wires supporting the shoots intercepted 75% less light, had lower temperature by 2°C and get 25% of net CO_2 uptake and 50% of transpiration rate per leaf area unit.

Fig. 3 – Hail net on cv. Michele Palieri grown in Southern Italy (Apulia).

In Turkey, in order to delay harvest and reduce grey mold disease in pre- and post-harvest of cv Sultani Cekirdeksiz, green nets having different shading density (35, 55 and 75%) were applied from veraison to harvest, combined with plastic films that were set up before the late-summer rainfalls; the best protection was obtained with 55 % shading net (Cangi *et al*., 2011).

In Argentina, Pugliese (2009) found that white net (10-15% shading) reduced berry and cluster weight and berry skin color in ‘Red Globe’; this result was attributed to the effect of light limitation on photo-assimilate production. However, the negative effects were overcome by applying appropriate techniques of canopy management, such as shoot topping and partial leaf removal, that are able to improve the penetration of diffuse light into the canopy and at cluster level.

Differently from what it normally occurs, an increase of 1-4 °C in air temperature was observed under net in the hot environment of Crete Island, during shooting and grape maturation, between 11:00 and 18:00, while no difference appeared in the other hours. The warmer temperature enhanced the shoot growth rate and advanced grape maturation in ‘Sultanine’; moreover, it stimulated a double harvest per year in cv Attiki (Nicolantonakis *et al*., 2007).

Shading nets (75% shading factor) are used in India (Maharashtra) where air temperature overcomes 41 °C and humidity is falls below 25 %, aiming to protect young shoots from the severe stress caused by the intense direct sunlight (NRC, 2008).

The application of white crystal net (80% porosity) on cv Italia trained to “tendone” trellis lowered by 20% the amount of solar radiation available at foliage level compared to the open air, reducing air temperature between 5:00 and 16:00 and increasing temperature in the other hours (+1.15 °C respect to open air); air relative humidity increased between 9:00 and 18:00 and between 20:00 and 02:00. Under these conditions, grape maturation was delayed by 9 days. The vine water status, assessed as predawn leaf water potential, showed small oscillations either in covered or uncovered vines (from -0.1 to -0.3 MPa), but the lowest value was reached after 9 days in open air and after 16 days under net-house. Net covering influenced also the stomatal conductance (CD) kinetics as related to the irrigation time: in the first 2 days after irrigation, vines under net had lower CD than uncovered vines; further, CD declined quickly in uncovered vines and less rapidly in the net covered ones. Net reduced evapotranspiration (ET): in between two irrigations, uncovered vines consumed 5,5 mm a day, while covered vines consumed 3,7 mm a day. It was also observed that, in days when strong wind increased ET dramatically, the wind effect was sensibly attenuated by the net cover (Rana *et al.*, 2004).

Under black shade net (30%), the crop water requirement was estimated 38% lower than in open air, due to a reduction of incoming radiation and of wind speed (Möller and Assouline, 2007). In a vineyard trained to "gable" system, covered with net having 12 mm^2 pores (2.2 x 5.4 mm) and having a black mulching along the rows, cv Red Globe resulted in 35% lower ET than in open air (Moratiel and Martínez-Cob, 2012). According to Suvočarev and Martínez-Cob (2012), ETo reduction under net may be estimated 63-67%.
In Israel, shade net reducing energy flux by 13 % proved to lower wind speed by 30-40 % and ET by 15%. Under these conditions, shaded vines improved water status, as indicated by a significantly higher stem water potential, and increased rates of stomatal conductance by 30% and of photosynthesis by 10-15%. Moreover, covered vines showed less photo-inhibition and a slower leaf senescence. As overall result, grape yield increased by 0.5-0.6 t/1000 m^2 (Bahat *et al*., 2010).

Using colored nets, that is, 30% shading red, blue, grey and pearl nets and 15% shading white and red/white nets, Shahak and coauthors (2008) found that 30% yellow net increased berry and cluster weight of cvs Superior Seedless and Red Globe, while the grey net did the opposite; since the fruit load was 40-50% lower than usual, the authors supposed the lower cluster weight was not due to a limiting leaf-to-fruit ratio. They found also that a light-dispersive 15-30% shading white and pearl nets advanced berry TSS accumulation in the early ripening cvs Prime, Superior, Perlette and Early Sweet, while red and yellow nets delayed grape maturation; moreover, blue net advanced berry ripening in 'Superior Seedless', while delayed it in 'Perlette'. Black and red nets delayed maturation in 'Red Globe', compared to uncovered vines, causing also a reduction in skin color (pinkish-red instead of dark-red). The authors concluded that the use of photo-selective shade nets is an interesting technique for modulating the maturation time and viticultural performance of tablegrapes; nonetheless, to achieve the best results, this technique should be optimized according to the cultivar and the practical purpose.

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