Netting in Fruit Cultivation

Subjects: Agronomy

Contributor: Marko Vuković, Slaven Jurić, Luna Maslov Bandić, Branka Levaj, Da-Qi Fu, Tomislav Jemrić

The use of nets is considered an indispensable measure in the cultivation of many fruit species. This is especially true, as modern agriculture is experiencing a need to protect crops from their cultivation environment due to global climate changes and their resulting extreme climatic events. Furthermore, urbanization processes are thrusting agriculture towards less amenable environments, and, on the other hand, there is a need to meet rising market demands for better product quality, reduced chemical applications, food safety, and sustainability of the production processes. The usage of nets in agriculture is not a novelty. The oldest net applications were in fruit cultivation (grapes, peaches, apricots, apples, and cherries) and ornamental plant production (cut flowers).

Keywords: photoselective nets ; light quality ; light quantity ; sustainability ; sustainable food production ; netting ; fruit cultivation

1. Introduction

The use of nets is considered an indispensable measure in the cultivation of many fruit species. Nowadays, this is especially true, as modern agriculture is experiencing a need to protect crops from their cultivation environment due to global climate changes and their resulting extreme climatic events. Furthermore, urbanization processes are thrusting agriculture towards less amenable environments, and, on the other hand, there is a need to meet rising market demands for better product quality, reduced chemical applications, food safety, and sustainability of the production processes [1]. However, the usage of nets in agriculture is not a novelty. The oldest net applications were in fruit cultivation (grapes, peaches, apricots, apples, and cherries) and ornamental plant production (cut flowers) [2].

2. Main netting concepts

Plastic nets present a product made of plastic threads (usually made of high-density polyethylene) connected in a woven or knitted way, forming a regular porous geometric structure and allowing fluids (gases and liquids) to pass through [3]. The main reason for using nets is the protection of cultivated plant species from various natural disasters, such as hail, heavy rain, snow, wind, excessive solar radiation, birds [2][3][4][5][6][7][8], and, more recently, insects (anti-insect nets) [9][10][11][12]. Anti-insect nets are similar to anti-hail nets, but they differ from anti-hail nets in mesh size and mode of application [10]. Thus, they overlay a fruit tree canopy and the edge parts of the orchard, thus creating a physical barrier that disrupts the propagation of pests by preventing their flight [12]. As consumer awareness regarding pesticide usage and ecology grows, this environmentally friendly pest control method has huge potential applications. However, each net creates a certain amount of shade and, therefore, reduces the intensity of available solar radiation to plants grown below them. In normal growing conditions, this can potentially harm some fruit quality traits. This is especially true for the traditionally used black anti-hail net, which, according to Arthurs et al. [13] and Ilić and Fallik [14], is completely opaque and, therefore, does not scatter or modify solar radiation. Due to the smaller mesh size and consequently greater shading, anti-insect nets can potentiate this negative effect on radiation. At the beginning of this millennium, a new technology concept was developed in Israel to improve the utilization of solar radiation for cultivated crops, with standard protection against various disasters [6][15][16]. This approach was initially developed for ornamental plant species, and the main goal was to develop a “smart shade” that would surpass the traditionally used black net [16]. The technology is based on the incorporation of various chromophores and light-dispersive and -reflective elements into plastic nets during production [17]. This technology aims to stimulate the desired photomorphogenic or physiological plant responses by spectral manipulation and to enhance the penetration of light into the inner part of the canopy by light scattering [1][17]. Relative enrichment in the intercepted light by productive components of the spectrum and reduction in the less productive ones allows for better and more productive utilization of the solar energy by horticultural crops [18]. In addition to the promotion of desired plant responses, according to Shahak et al. [1], some insects variously respond to the differently colored nets. In **Figure 1** can be seen an example of a predator (*Asilidae* sp.) preying on an insect possibly attracted by the yellow net color. Initially, this technology was named “colored nets”; however, afterward, the term “photoselective nets” has been standardly used

[6][17]. Considering that not all colored net products look colored to the human eyes, this terminology is used, as well as the fact that it derives from technology that deals with light quality modification in its broadest sense, including the filtration of spectral bands in the UV, visible, FR, and beyond as well as light scattering [17]. For example, photoselective nets can be divided into two groups: "colored photoselective nets", which include red, yellow, green, and blue nets and which are "visibly colored", and "neutral photoselective nets", which include pearl, white, and gray nets [1][17]. A combination of these two technologies (anti-insect photoselective nets) presents a notable contribution to the sustainable food production concept, since this approach has the potential for a notable positive impact on agroe cosystems due to its non-pesticide pest protection of cultivated plants and, at the same time, promotion of special beneficial morphological and physiological plant responses.

Figure 1. An example of a predator (*Asilidae* sp.) preying on an insect possibly attracted by the yellow net color.

3. Light manipulation

The influence of nets on the quality and quantity of solar radiation is of prime importance, due to its crucial role in plant life. In general, the radiation spectrum relevant to plants ranges from 280 to 800 nm, which includes UV-B (280–320 nm), UV-A/B (300–400 nm), photosynthetically active radiation (PAR, 400–700 nm), and far-red radiation (TC, 700–800 nm) [19]. Primarily, light manipulation nets influence the vegetative and generative traits of plants cultivated underneath them. To explain the effect of nets on light manipulation, basic net characteristics must be described. Agriculture nets are primarily produced from high-density polyethylene, which has good UV stability if certain additives are added to it [3][20]. Nets consist of single threads that are connected in such a way that they form a regular porous geometric structure, the mesh [3]. Therefore, solar radiation can come into contact with the threads and be affected by their properties or pass unchanged through the meshes (the space between threads). Manipulation of solar radiation by nets depends on the net type. Due to their opacity properties, traditionally used black nets only reduce light quantity [6][13][14][15][17]; transparent nets scatter light but do not spectrally modify it [17], while photoselective nets reduce the light quantity, scatter it, and spectrally manipulate it [6][15][17][21]. Therefore, photoselective nets create a mixture of natural (non-modified) light that passes through meshes and diffused (spectrally modified) light that is scattered by threads [6][22]. In low-shading nets (shading around 20%), most of the light (approximately 80% of sunlight) is not modified, in contrast to the rest, which is [18].

Light quantity reduction primarily depends on net texture (thickness of threads and mesh size) and its light-scattering properties, e.g., net color. It is defined by the producer of each net. However, in production conditions, certain deviations are possible in relation to producer-defined values [23][24][25]. Since photoselective nets contain partially transparent threads, differences in shadiness are related to the light manipulation ability (thread color) in addition to the effect of the "true shadow" caused by the light interference of the threads [13][26]. This means that differently colored photoselective nets with the same mesh size will not possess the same shading factor. Thus, in relation to black nets, higher thread counts are needed to create the same shade factor, which results in smaller holes and less open area [13]. Therefore, when trying to determine the effect of net color on certain parameters, two approaches are possible. One is to use nets with the same mesh size (which will probably result in different shading factors between nets), and the other is to use nets with the same shading factor but, hence, different mesh sizes.

In a few studies with the same mesh size between studied nets, it was reported that black nets more notably reduced PAR (photosynthetically active radiation) or photosynthetic photon flux density compared to a white nets [26][27][28]. Contrary to this, in a different study, the black net showed the smallest PAR reduction [29]. In a few studies where nets with the same shading factor were comparable, similar differences could be found [13][30][31]. Although, as mentioned above, some authors reported that, among tested nets, the black net reduced PAR intensity the most, this was not the case in studies conducted by [6][15]. Oren-Shamir et al. [15] attributed the slightly higher effect of shading in photoselective nets compared to neutral nets (including black) to dust retention due to higher weave density. In studies where mesh size or shading factor varied between nets, the following was reported. Solomakhin and Blanke [32] observed a negative correlation between the number of black fibers in nets and light permeability, and Lobos et al. [5] reported that, in three different shading levels, black nets more significantly reduced PAR intensity than white net. Similarly, Blanke [33] reported that, among tested nets, the black net reduced PAR intensity the most. According to Agrintech [34], with the same mesh size (2.4 mm × 4.8 mm), the following PAR shading percentages were stated: pearl, 13–16%; yellow, 13–18%; blue, 15%; red, 17–21%; and gray net, 20%. In a study conducted by Arthurs et al. [13] where all nets had the same nominal shade factor (50%), the observed PAR values were reduced the most under black nets (55% to 60%) and least under red nets (41% to 51%), with blue (51% to 57%) and pearl (52% to 54%) nets intermediate. Retamales et al. [31] reported that there were no notable differences in PAR levels between white (35 and 50% shading), gray (35 and 50% shading), and red (35% shading) nets, with the exception of the red net with 50% shading, where a notable reduction occurred. According to the aforementioned, it is evident that the ability of nets to scatter radiation presents an important factor in light quantity manipulation. Diffuse light is a broad term and includes all non-direct light [16][18], and the capacity of each net to scatter radiation is also determined by its texture [18]. The light rays that pass through and are selectively filtered by the colored plastic threads come out of the threads in a fully diffused mode [18]. In a few studies, it was reported that the proportion of diffuse light was higher under photoselective nets than under a black net or in natural conditions [6][15][16]. Light scattering represents an important part of the technology of photoselective nets, since it improves the penetration of this spectrally modified light into the inner canopy, thus amplifying the photoselective effect [6][16][18]. In addition, radiation utilization efficiency increases when the diffuse component of direct radiation is increased in the shadow [35]. Therefore, plants cultivated under colored nets with a shading factor of 30% in reality "see" more light than those under black nets with the same shading factor [6]. Photoselective nets scatter less ultraviolet (UV) than photosynthetically active radiation due to the absorption of UV light by pigments embedded in their threads [15]. When it comes to light scattering, PAR is most often discussed, due to its crucial role in plant development. According to the available literature, it can be summarized that the pearl net has the highest and gray net the lowest light-scattering potential, while other nets (white, yellow, blue, green, red) are in between [6][15][16][21]. Regarding the light-scattering possibilities in the UV section, there are uneven reports. According to Oren-Shamir et al.[15], green nets notably increased light scattering of UV spectra in comparison to other nets (black, gray, red, blue, aluminet). Shahak et al. [16] reported that only the application of a pearl net caused notable UV scattering (in comparison to gray, red, blue, red-blue, and white nets), while Basile et al. [21] reported a lack of significant difference between tested nets (gray, red, blue, white).

The impact of photoselective nets on light quality is probably smaller than on light quantity [25]. It is important to additionally emphasize that photoselective nets modify only the fraction of sunlight rays that pass through the plastic threads, while the rays passing through the holes of the net remain unchanged, i.e., identical to the spectral and direct/diffuse composition of the natural sunlight prevailing at any particular time of the day/season [18]. Thus, light quality modifications are realized mainly in diffused light [6][21]. The possibility of each net manipulating light quality is defined by the pigments that are embedded in the plastic material [18]. In addition, it can be assumed that the extent of light spectral manipulation also depends on all of the parameters affecting the contact net–light surface (mesh size or weave density, thickness and shape of the threads, dust accumulation and so on). The blue net has a broad transmission peak in the blue-green region (400–540 nm), while it absorbs UV and red spectra [6][15][25]. The green net has a broad transmission peak at 520 nm as well as gradual transmittance in the far-red (FR) [15], while Blanke [36] reports that, under this net, transmission of spectra above 500 nm increased by 3%. Unlike blue and green nets, the red and yellow nets operate as cut-off filters, absorbing light below a specific wavelength range while transmitting light thereafter [18]. Oren-Shamir et al. [15] reported that the red net had the highest transmittance beyond 590 nm and a minor peak around 400 nm; Shahak et al. [6] reported that it transmitted from 590 nm onwards, and Bastías et al. [37] reported that it peaked in light transmission at all wavelengths above 620 nm. Blanke [36] stated that light spectrum transmission above 570 nm increased by 2–5%, and Zoratti et al. [25] reported a lack of blue spectrum or UV-A radiation under this net. The yellow net transmits light from 500 nm onwards [6]. While the red net transmits light above 580 nm (only the red + FR spectra), the yellow net transmits light above 515 nm, i.e., allowing the passage of green and yellow spectra along with the red and FR spectra [18]. Three neutral nets (black, gray, and aluminet) do not modify light in the visible spectrum [15], but the gray net absorbs infrared radiation more efficiently than other colored nets [6]. Although, in two studies [6][17], it is stated that the white net absorbs UV radiation, Zoratti et al. [25] reported a higher presence of the UV-A spectrum below this net than in natural conditions.

With the exception of the stated light quality manipulations in many studies, these effects are represented as a ratio between different radiation spectra, due to easier interpretation and their importance in the morphogenetic plant reactions. Due to their high number and differences in results between studies, only the red to far-red ratio (R:FR) will be mentioned, since it has a crucial role in plant morphogenesis (**Table 1.**). This ratio is often used to quantify the spectral distribution of photon fluxes of red and dark red wavelengths [38]. Such conflicts between studies in terms of the overall net light manipulation ability can be contributed to the different agroecological conditions, net properties (other than color), and experiment methodologies.

Table 1. Effect of applied nets on R:FR ratio (↑—increase, ↓—decrease, m.d.—minimal differences).

Netting	Source	R:FR Ratio	
		Diffuse Light	Total Light
Black	[6]	↓ *	m.d.
Blue	[6][21]	↓	
	[16]	small ↑	
	[6][15][16][21]		m.d.
Green	[15]		↓
Gray	[6][16][21]	↓	
	[6][15][16][21]		m.d.
Pearl	[6][16]	↓ (mostly highest)	↓ (mostly highest)
	[25]		m.d.
Red	[6][16][21]	↓	
	[6][15][16][21]		↓
	[25]		m.d.
White	[21]	↓	m.d. **
Yellow	[6]	↓	↓

* minimally in comparison to other nets; ** similar to the blue and gray nets, with the exception of the red net

At the end of this chapter, a few additional factors must be mentioned that can play an important role in net light manipulation possibilities. Net durability, in terms of the changes that occur in them during aging, which can affect their long-term capacity to successfully bear the load and transfer it to the supporting structure [2] as well as their characteristics regarding manipulation of light quantity and quality [6][39]. According to Briassoulis et al. [2], the most critical property affected by the aging of nets (tensile strength) drops down to one-third of its initial value after 10 years of exposure under the conditions of the Netherlands. The authors [2] state that it should be expected that, under south European climatic conditions with much higher UV radiation, the weathering effects would be more dramatic. The durability of black nets is greater than transparent nets due to the carbon black additive that is added to those nets (which also acts as a UV-stabilizer) [3], while photoselective nets have been developed and tested to be stable for 5–8 years under field conditions [6][6]. The tendency of the nets to fade after prolonged exposure to the sun, the accumulation of dust on their threads, and agrochemicals are the main reasons why, with the length of use of the nets, there are changes in their manipulation of light [6][33][39]. Blanke [36] stated that the aging of colored polyethylene nets with narrow meshes caused an annual reduction in PAR transmission of 2%, independent of wavelength. Additionally, over time, nets transmit less UV radiation than PAR [33]. The reduction in PAR transmittance due to dust accumulation in Israel varied from 5–6% to 18–19% (greater dust impact on a more transparent thread) [6]. The authors [6] stated that washing dust from nets could solve this problem; however, this is not practical to carry out. In addition, during the installation of the nets, or later due to temperature changes, stretching of the nets may occur [6][6], which can also cause a reduction in their light manipulation capabilities.

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