Combination of black shading nets and its effect on radiation intensity and quality

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Abstract: The use of shading nets in agronomy is a common method to create protected environments for plant acclimation and production. Climate changes increased the use of shading nets and it is common to find builds with combined or overlapped layers whereas the resulting attenuation is unclear. This work aimed to study the radiation intensity and attenuation inside shaded environments created by combining black shading nets. Shading environments were build with a base 30% black shading net and the combinations of 30%+50% and 30%+70% nets, plus, shaded environments were compared to unshaded condition. The experimental design was completely randomized with four treatments and five replicates. Radiation intensity was measured with a spectroradiometer at ultraviolet (UV), ultraviolet-C (UVC), ultraviolet-B (UVB), ultraviolet-A (UVA), photosynthetically active radiation (PAR) and near infrared (IR) bands. Attenuation was calculated for each shading condition as compared to unshaded treatment. The combination of shading nets reduced the intensity of photosynthetically active radiation, near infrared and ultraviolet-A bands. Ultraviolet-C and ultraviolet-B intensities were unaffected by the combination of shading nets. The combination of shading nets summed their individual attenuations, but these were lower than expected. Thus, the combination of shading nets increases the attenuation of UVA, PAR and IR intensities whereas had no effect on UVC and UVB attenuation.

Keywords: protected environments, UV-radiation, light intensity, photosynthetically active radiation

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1 Introduction

The build of protected environments for plant growth at different seasonal conditions is one of the oldest methods in agriculture (Yoon and Woudstra, 2007). Crop production in protected environments has increased in recent years in order to obtain higher yields under adverse environmental conditions (Shamshiri and Ismail, 2013). In fact, crop production has been favored using shading nets in regions with high temperatures and radiation intensities (Díaz-Pérez, 2013). According to Kingra and Singh (2016), climate changes will bring negative consequences to crop yield in many parts of the world and Ballaré et al. (2011) alert for the possibility of increased ultraviolet (UV) intensities in the tropics as a consequence of such changes. Alternative crop systems for horticulture are essential for food safety and shaded environments secure horticultural production in areas with unfavorable environmental factors (Despommier, 2011). In addition, according to Vergé et al. (2007), alternative crop systems are essential to minimize the impact of the agriculture on environment. The use of protected environments for seedling and young plant production is a common method (Rodrigues et al., 2004).

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Moreover, climate changes are already limiting crop production (Kingra and Singh, 2016) and protected environments as those built with shading nets may favor plant production during initial developmental stages (Conforto and Contin, 2009; Gonçalves et al., 2016). The demand for seedlings for reforestation is also increasing worldwide and building shaded environments for its production, near to reforestation areas, may benefit these systems (Rodrigues et al., 2004).

Efficiency on controlled environments requires understanding and adjusting their microclimate variables (Castellano et al., 2006; Teitel et al., 2012). Horticultural systems in hot climates also take advantage of reduced maximum and mean temperatures under shading nets (Díaz-Pérez, 2013; Kittas et al., 2012; Santos et al., 2010). Shaded environments lower water consumption as plants under these conditions show reduced water loss. There are many examples where shaded environments can benefit horticultural production. For instance, shaded environments increased the yield of tomato plants which showed higher number of fruits, increased leaf area and fewer diseases (Kittas et al., 2012). Ornamental horticulture can take benefit from shading nets because these environments favor shoot growth and delay flowering (Alhajhoj and Munir, 2016). Furthermore, crop production inside shaded environments prevent the invasion by insects, significantly reducing the application of pesticides providing healthy conditions for producers and safety for products (Castellano et al., 2006; Muñoz et al., 1999).

Black shading nets provide efficient radiation reduction at lower costs when compared with the expensive aluminum-coated ones (Santos et al., 2010). Moreover, it is possible to find different types of shading nets with different levels of attenuation and colors (Kotilainen et al., 2018; Morales et al., 2018; Nesi et al., 2013). However, the necessity of shaded environments for the production of many species remains unclear (Mazzini-Guedes and Pivetta, 2014). Producers or researchers often appeal to overlapping shading nets in order to obtain desired shading intensities (Souza et al., 2016). However, one question comes from this situation: how overlapping shading nets affect the refracted radiation?

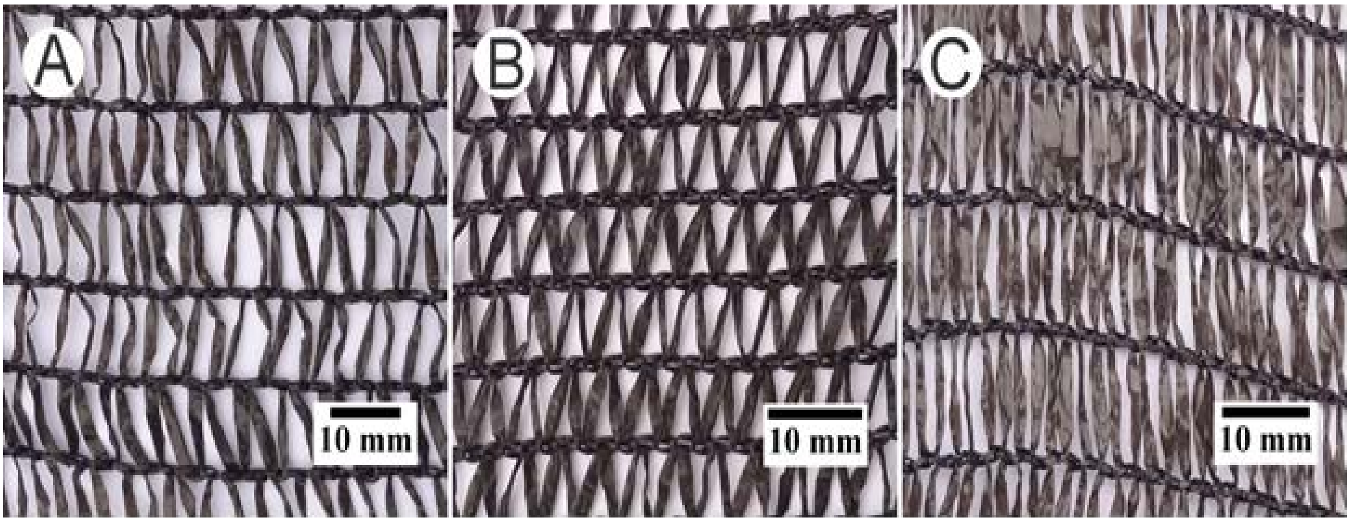
The hypothesis of this work is that, by overlapping shading nets, their attenuation capacities will be partially summed and both radiation intensity and quality inside the shaded environment will be modified. Thus, the objective of this work was to investigate the radiation quality and intensity inside shaded environments built by combining black shading nets.

2 Materials and methods

The study was carried out at the experimental area of the Universidade Federal de Alfenas, located at the Alfenas city, in the State of Minas Gerais, at the southeast region of Brazil (21°25'15.54"S - 45°58'55.76"W). The climate type is humid subtropical with dry winter and temperate summer (Cwb) according to Köppen classification (Alvares et al., 2013). Black shading net with 30% atteuation was used to build a shaded environment of 150 m^2 and 1.9 m in height. The structure was then sundered in three sections as follows: 1) 30% shading net, 2) combined 30%+50% shading nets, 3) combined 30%+70% shading nets. Thus, we evaluated four radiation conditions: unshaded (outside the shaded environment), 30%, 30%+50%, 30%+70% shaded conditions. Black shading nets used in this experiment were composed of polyethylene with mesh arrangements as shown in Figure 1.

The radiation intensity was measured with a portable spectroradiometer SPR-4002 (Luzchem Research Inc., Ottawa, Canada) with spectral amplitude between 230-870 nm. Measurements were performed at a height of 1.5 m, between 12-13 p. m. and under cloudless sky. Table 1 shows climatic data for sampling dates collected from a weather station located close to the experimental area (Sismet, 2019). The experimental design was completely randomized with four treatments and five replicates. Samples were taken at each 30 s intervals for 2 min. Further, data were separated into three sections as follows: ultraviolet radiation (UV = 230-400 nm), photosynthetically active radiation (PAR = 400-750 nm) and infrared (IR = 750-870 nm). The UV section was also subdivided as follows: ultraviolet-C (UVC; 230-280 nm), ultraviolet-B (UVB; 280-300 nm) and ultraviolet-A

(UVA; 315-400 nm).



(A) 30% attenuation capacities (B) 50% attenuation capacities (C) 70% attenuation capacities

Figure 1 Black shading nets used in the experiment

Table 1 Environmental data at sampling dates

Sampling Date	T (°C)	T_{max} (°C)	T_{min} (°C)	RH (%)	Wind Speed (Km h^{-1})
19-04-2018	20.9	25.8	17.4	63	19.3
22-08-2018	19.6	25.4	14.3	49	9.7

Note: T = Daily mean temperature; T_{max} = Maximum temperature; T_{min} = Minimal temperature; RH = Air relative humidity.

The shading effect of each environment was considered as the attenuation of the radiation intensity as compared with unshaded condition. Thus, for each wavelength band the attenuation was calculated as follows:

$$AT=[(FS-SE)/FS] \times 100 \qquad (1)$$

Where,

AT= attenuation at a given band (%);

FS = radiation intensity in unshaded condition of a given band;

SE= radiation intensity under each shaded conditions at a given band.

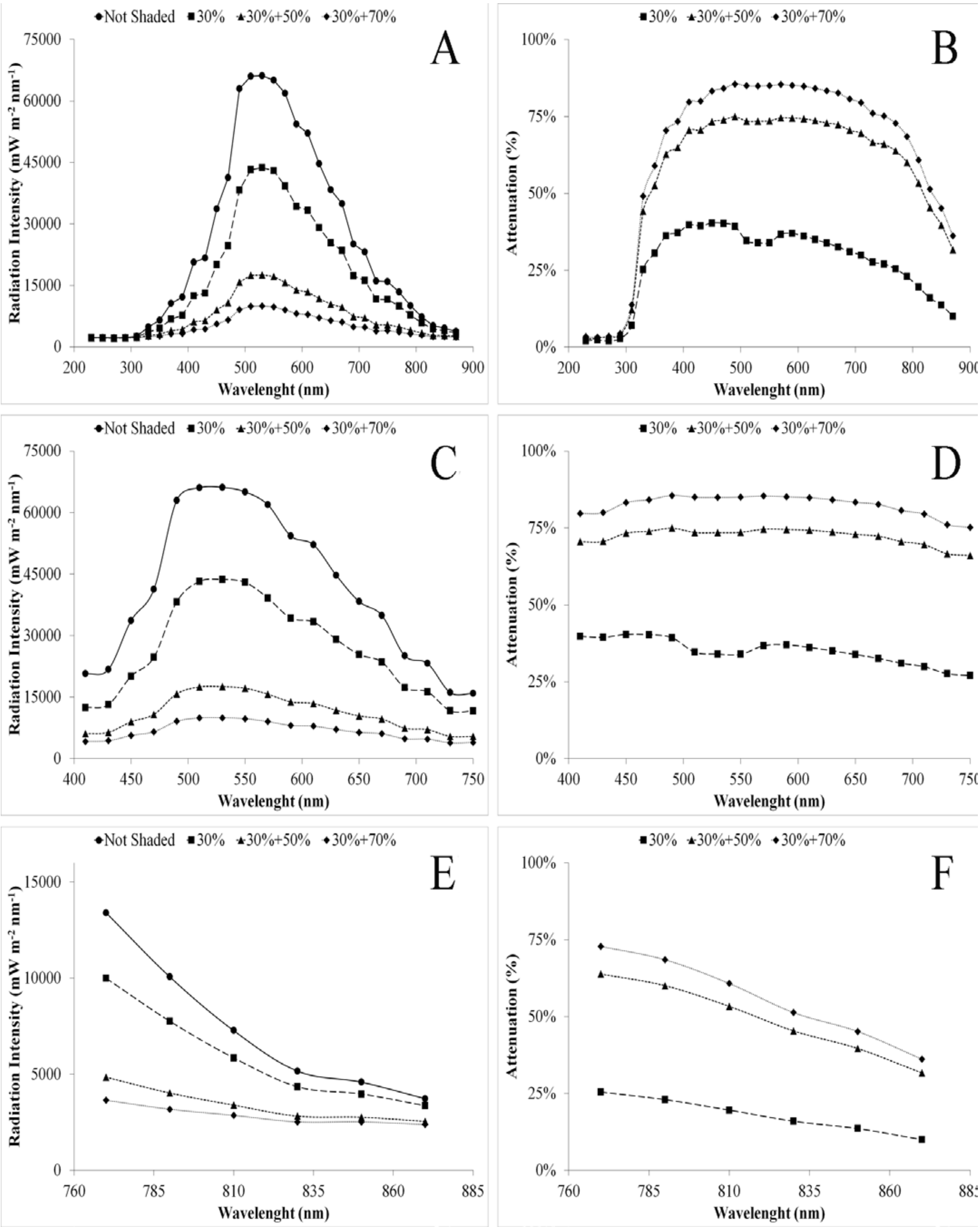
The predicted shading capacity for combined nets was considered as the sum of individual shading capacities of each net, since it is common to find such calculations.

Data were first evaluated for the normal distribution by the Shapiro-Wilk test (all variables showed normal distribution) and then submitted to one-way ANOVA. Means were compared by the Scott-Knott test to $p<0.05$, or regression analysis using Sisvar Software version 5.6 (Ferreira, 2019).

3 Results

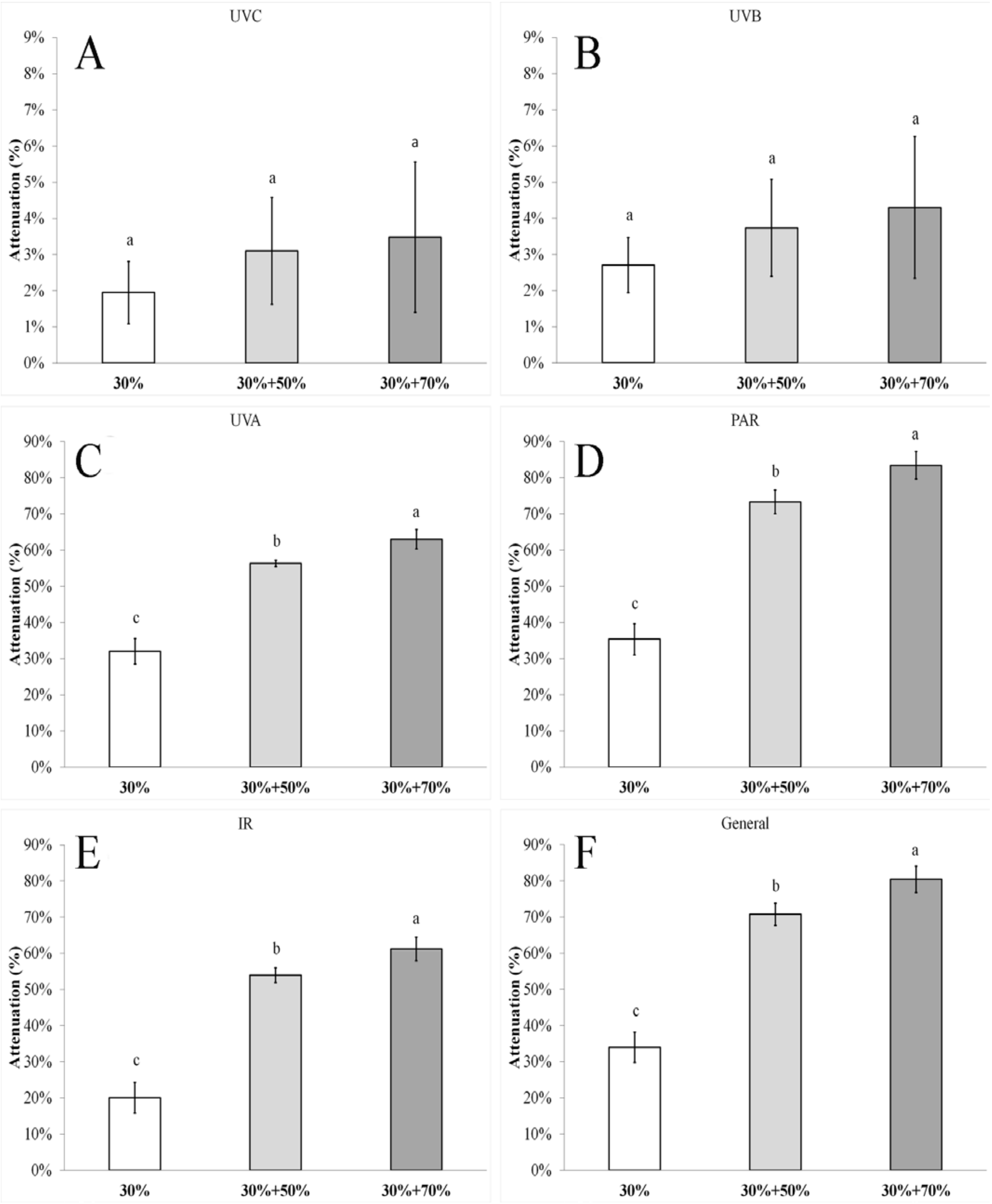
Shading nets significantly reduced the radiation intensity as compared to unshaded condition (Figure 2a). Curve slopes show that all treatments provided higher intensities at PAR as compared to IR and UV bands (Figure 2a). Moreover, attenuation depends on the radiation band as it was much higher for PAR as compared to UV or IR bands (Figure 2b).

Combination of shading nets showed partially summed effects (Figure 2c and Figure 3d). Although values of 30% shading were close to their predicted attenuation (Figure 3d), the 30%+50% treatment showed 73.10% attenuation and 30%+70% treatment promoted 83.69% attenuation (Figure 2d and Figure 3d). In addition, attenuation did not show significant variation along wavelengths on PAR band (Figure 2c and 2d). Combined shading nets also reduced IR intensity with partial summed attenuation (Figure 2e and Figure 3e). Attenuation under IR band was also increased by combined shading nets, and shorter wavelengths in IR showed higher attenuation as compared to longer ones (Figure 2f and Figure 3e). Attenuation in the general band shows results similar to PAR band (Figure 3f).



(A) Detailed general radiation intensity (B) Detailed general radiation attenuation (C) Detailed PAR radiation intensity (D) Detailed PAR radiation attenuation (E) Detailed IR radiation intensity (F) Detailed IR radiation attenuation

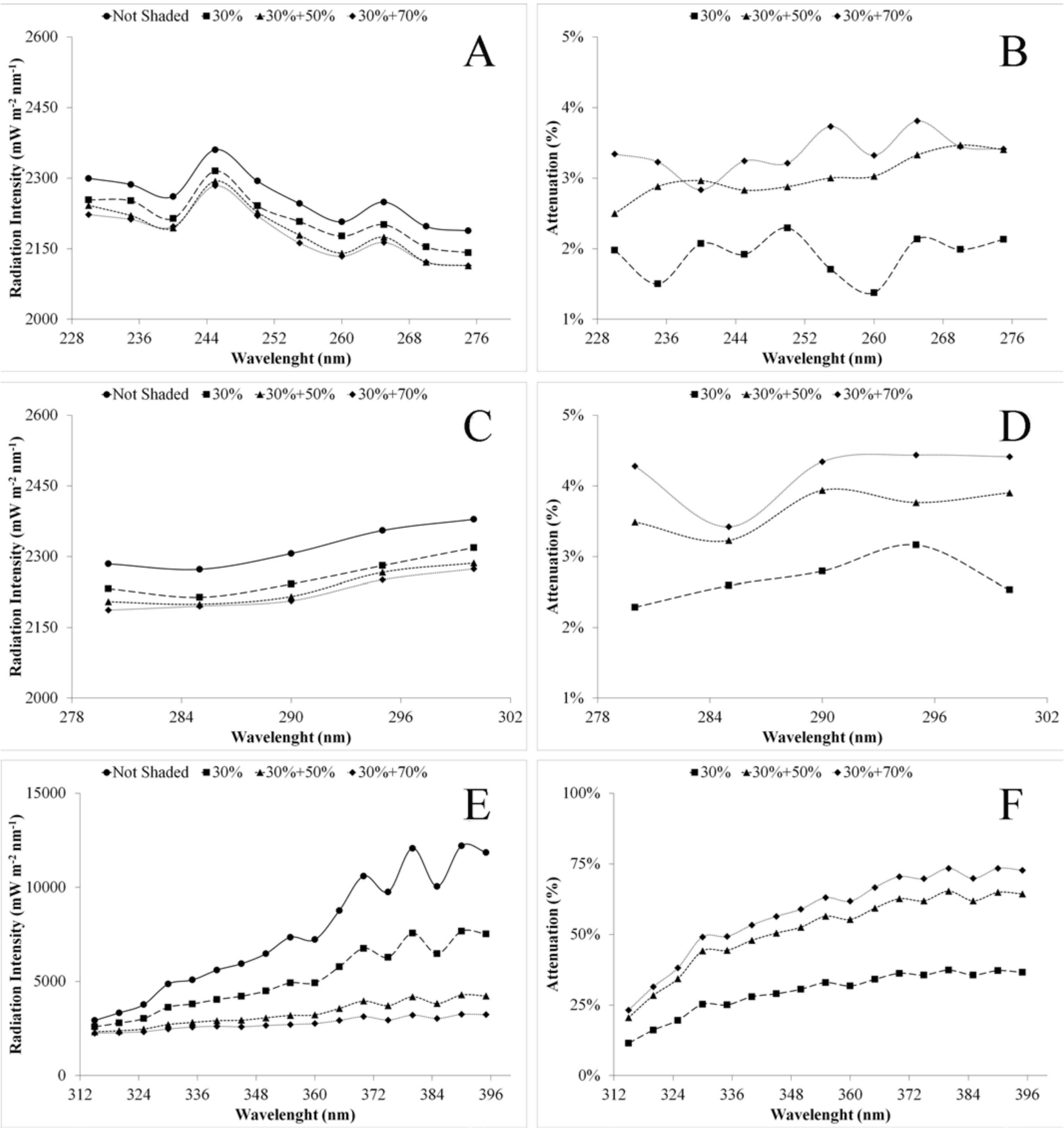
Figure 2 Radiation's intensity and attenuation spectra for General, PAR and IR bands.



(A) attenuation of UVC band (B) attenuation of UVB band (C) attenuation of UVA band (D) attenuation of PAR band (E) attenuation of IR band (F) attenuation of general spectrum

Figure 3 Mean attenuation of radiation intensity at different shading conditions and wavelength bands.

Note: UVC (230-280 nm); UVB (280-300 nm); UVA (315-400 nm); PAR = Photosynthetic Active Radiation (400-750 nm); IR = Infrared (750-870 nm); General = All Spectre (230-870 nm). Data is shown as means ± standard deviation. Different letters are significantly different according to Scott-Knott test for *p*<0.01.



(A) Detailed UVC intensity (B) Detailed UVC attenuation (C) Detailed UVB intensity (D) Detailed UVB attenuation (E) Detailed UVA intensity (F) Detailed UVA attenuation

Figure 4 Radiation intensity and attenuation spectra for UVC, UVB and UVA bands.

The UVC intensity showed higher means at shorter wavelengths (Figure 4a). Attenuation of UVC showed fluctuations along wavelengths but combination of shading nets promoted no significant modifications for this variable (Figure 3a and Figure 4a). In addition, longer wavelengths decreased UVC intensity whereas increased UVB and UVA intensities (Figure 4). Shading nets did not decrease UVB intensity as well as the combination of shading nets not increased attenuation at this band (Figure 3b, Figure 4c and Table 2). Attenuation for UVB band showed fluctuations along the wavelengths (Figure 4d). Shading nets reduced UVA intensity and their combination increased the attenuation effect (Figure 3c, Figure 4e, Figure 4f and Table 2). The UVA band showed fluctuations along wavelengths, and increased attenuation at longer wavelengths (Figure 4f).

Combination of shading nets reduced the UV, PAR and IR intensities (Table 3). Nonetheless, the UV reduction was related to a lower UVA intensity since no effect was found for UVC and UVB intensities (Tables 2 and 3). The combination of shading nets promoted higher attenuation in PAR intensity when compared to UV bands (Figure 5).

Table 2 Detailed UV intensities measured at different shading conditions with combined shading nets

Treatments	UVC ($W\ m^{-2}\ nm^{-1}$)	UVB ($W\ m^{-2}\ nm^{-1}$)	UVA ($W\ m^{-2}\ nm^{-1}$)
Unshaded	2.26 ±0.16 a	2.32 ±0.17 a	7.52 ±0.80 a
30%	2.22 ±0.17 a	2.26 ±0.18 a	5.09 ±0.37 b
30%+50%	2.19 ±0.19 a	2.23 ±0.19 a	3.28 ±0.39 c
30%+70%	2.18 ±0.20 a	2.22 ±0.21 a	2.76 ±0.18 d

Note: UVC = Ultraviolet-C (230-280 nm), UVB = Ultraviolet-B (280-300 nm) and UVA = Ultraviolet-A (315-400 nm). Data is shown as means ± standard deviation. Different letters are significantly different according to Scott-Knott test for $p<0.01$.

Table 3 Radiation intensity measured at different bands and combined shading nets

Treatments	General ($W\ m^{-2}\ nm^{-1}$)	UV ($W\ m^{-2}\ nm^{-1}$)	PAR ($W\ m^{-2}\ nm^{-1}$)	Ir ($W\ m^{-2}\ nm^{-1}$)
Unshaded	25.28 ±2.41 a	5.09 ±0.51 a	41.35 ±3.91 a	7.37 ±0.75 a
30%	16.64 ±1.52 b	3.76 ±0.27 b	26.67 ±2.49 b	5.88 ±0.49 b
30%+50%	7.45 ±1.44 c	2.79 ±0.29 c	11.12 ±2.34 c	3.40 ±0.47 c
30%+70%	4.88 ±0.68 d	2.50 ±0.18 c	6.75 ±1.19 d	2.85 ±0.25 d

Note: General = All Spectre (230-870 nm); UV = Ultraviolet (230-400 nm); PAR = Photosynthetic Active Radiation (400-750 nm); Ir = Near Infrared (750-870 nm). Data is shown as means ± standard deviation. Different letters are significantly different according to Scott-Knott test for $p<0.01$.

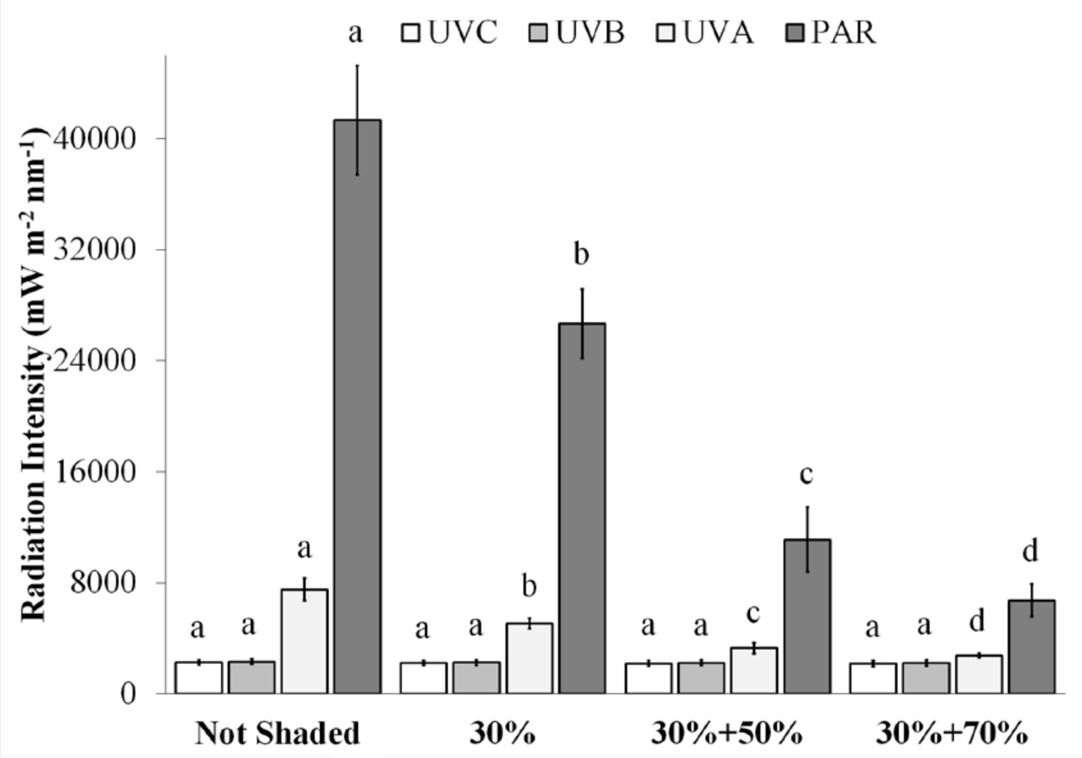


Figure 5 Radiation intensities for UV and PAR bands under different shading conditions.

Note: Data is shown as means ± standard deviation. Different letters are significantly different according to Scott-Knott test for $p<0.01$.4

4 Discussion

Results showed that variation was found for predicted and real attenuation depending on the wavelength band. In fact, real attenuation is often different from predicted shading effect in commercial shading nets (Castellano et al., 2006; Santos et al., 2010). Although PAR and IR bands were efficiently attenuated by all combinations of shading nets, most of UV bands showed little or no reduction. Thus, it is important to properly choose the shading net type for specific purposes as long as combining shading nets do not effectively sum their attenuation for UV band.

Apart from the type of shading net, other variables may influence its attenuation capacity. For instance, Castellano et al. (2006) showed that the shading capacity varies along the day depending on the course of the sun. According to Montero et al. (2001), the attenuation of shading nets is related to the angle of incidence of the radiation. Cohen and Fuchs (1999) also reported the influence of the three-dimensional structure of shading nets in their radiometric properties. In this study, midday times were preferred for measurements because the solar radiation was at the most perpendicular angle of incidence. Morales et al. (2018) showed higher radiation intensity at noon in measurements taken along the day. Thus, sun position may not have influenced the results of this work because evaluations were taken at midday.

The reduction of UV intensity is always of interest to protect plants against its damaging effects. In fact, UV radiation damages DNA structure, cell membranes and photosynthetic apparatus and plant survival depends on metabolic adjustments under UV stress (Jansen et al., 1998; Nawkar et al., 2013; Neugart and Schreiner, 2018; Romanatti et al., 2019). It is important to note that UVC and UVB bands were not significantly reduced by any combination of shading nets used in this experiment. Moreover, significant reduction of PAR or general bands may be misleading, causing health risks and even errors in the interpretation of experimental data. A proportional increase in UV in relation to PAR can induce progressive damage to plants grown under shaded environments because energy balance is altered. Thus, the energy produced by photosynthesis may not be sufficient to repair UV-induced damage and still promote growth. On the other hand, modifications on UVB: PAR ratio promotes changes in canopy architecture, organ morphology and metabolism (Robson et al., 2015). In addition, Vidović et al. (2015) show alterations in photosynthesis, phenols content and antioxidant system in plants submitted to different UVB: PAR ratio. According to Kotilainen et al. (2018) considerable variation at the ratio between radiation bands is caused by shading nets. Therefore, it is highly recommended to investigate the attenuation properties of shading nets used and, if possible, radiation measurements must be performed.

The IR band was significantly reduced by combinations of shading nets, and this may contribute for lowering the temperature inside shaded environments. Several studies showed that shaded environments reduce internal temperatures providing conditions to grow temperate species (Cohen and Fuchs, 1999; Díaz-Pérez, 2013; Santos et al., 2010). In addition, the arrangement of the shading nets showed little effect on the increase of internal temperature because it still permits adequate ventilation (Teitel et al., 2012). Thus, the combination of different shading nets may also reduce the internal temperature and still permits ventilation which is important for plant production.

Previous works showed that physical properties of the shading nets significantly affect its shading capacity. Color, texture, porosity and the type of material are the main characteristics which determine shading efficiency (Abdel-Ghany et al., 2016; Abdel-Ghany and Al-Helal, 2010; Al-Helal and Abdel-Ghany, 2011; Castellano et al., 2008, 2006). Castellano et al. (2008) used comprehensive models to show the correlation between the net porosity and shading capacity. The three-dimensional structure of the shading net affects the refracted and reflected radiations (Abdel-Ghany and Al-Helal, 2010). The attenuation capacity of shading nets varies along the day, under different climates and seasons, among other factors (Al-Helal and Abdel-

Ghany, 2011). According to Stagnari et al. (2018), changes in the quality of radiation inside shaded environments can produce effects on plant morphology, physiology and biochemical content. Likewise, Morales et al. (2018) reported changes in the morphology and productivity in *Physalis ixocarpa* in response to changes in the quality of radiation. Thus, further studies must be performed to investigate the effects of combined shading nets in plants.

5 Conclusions

Combination of black shading nets provides partial summation of individual attenuations and is effective to reduce UVA, PAR and IR intensities. Combination of shading nets promotes no effects in UVC and UVB bands. It is necessary to measure the actual shading level promoted by the combination of shading nets to avoid misleading interpretation of experiments or plant growth conditions. The combination of shading nets can be an effective method to promote higher shading levels in experimental and agricultural systems.

Declaration of Interests

The authors declare no conflict of interest

Acknowledgments

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