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ORIGINAL PAPER

Vineyard microclimate and yield under different plastic covers

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Abstract

The use of plastic cover in vineyards minimizes effects of adverse weather conditions. The northwest of São Paulo State is one of the largest grape producing regions in Brazil; however, few studies investigate the effects of different plastic covers on vineyards in this region. This study compared the effect of black shading screen (BSS) and braided polypropylene film (BPF) on *BRS Morena* vineyard microclimate, grown on an overhead trellis system in the northwestern São Paulo. The experiments were carried out during three growing seasons (2012–2014). BSS allowed superior incoming solar radiation (SR) transmissivity, resulting in higher net radiation (Rn), and higher ratio between photosynthetically active (PAR) and SR. No differences were observed between the average air temperatures (T) and relative humidity (RH) of covered environments (BPF and BSS) and outside condition (automatic weather station–AWS), due to high air circulation, despite wind speed (WS) reduction caused by plastic covers. BPF provided better conditions for vineyard growth with higher fruit yield than vineyard under BSS regarding the number of shoots with bunches per plant, bunch and stem weights, longitudinal diameter of berries, quantity of fertile buds per shoot, and yield per shoot and per plant. BPF covers also influenced leaf size and growth speed of plants in vineyards.

Keywords Black shading screen · Braided polypropylene film · *BRS Morena* · Leaf wetness duration · Yield

Introduction

The climate diversity in Brazil allows agriculture to be practiced under different systems, requiring specific management practices, mainly where climatic conditions is limiting for growth, development, and quality (Galande et al. 2015). In the last decade, there was an expressive expansion of vineyards growing under plastic and shading covers, as the use of these materials is one of the most important strategies to minimize effects of adverse weather conditions (Ilić et al. 2011). Plastic covers change light intensity and radiation spectrum in the covered environment, due to the photo-selective and light-dispersive capacity of the material used (Kittas et al. 2009). These covers alter the temperature at crop canopy (Grant et al. 2016) and radiation balance in greenhouses, reducing air temperature drops during nighttime and increasing absolute air humidity (El-Saeed et al. 2015).

Changes in quantity and quality of solar radiation caused by the cover directly influence plant physiology and morphology (Vanden Heuvel et al. 2004), greatly affecting the total production system (Ilić et al. 2011), increasing crop growth and development (Kittas et al. 2009) with considerable quality improvement (Pedro Júnior et al. 2011; El-Saeed et al. 2015). Therefore, knowing how different covers and their characteristics influence microclimate conditions for the crop is highly important. The real-time monitoring system of microclimates has been used to obtain such information (Galande et al. 2015).

Due to these advantages, grapevine production under plastic covers is expanding in Brazil. In the state of São Paulo, mainly in the northwestern region, most commercial vineyards are grown under shading screen for protection against hail or attacks of birds and bats (Conceição 2009). However, the use of polyethylene or polypropylene plastic films is not a common practice among grape growers in northwestern São Paulo, despite its advantages to table grapes. Plastic covers prevent rainfall from reaching the plants and, therefore, avoid free water on leaves and bunches, greatly reducing disease incidence and severity, thus, fungicides applications (Pedro Júnior et al. 2011).

The seedless grapevine cultivar *BRS Morena* (*Vitis vinifera*), launched in 2003 by the Embrapa Grape and Wine

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breeding program (Camargo et al. 2010), has high susceptibility to fungal diseases, especially downy mildew, powdery mildew, anthracnose, and grape rots. Considering that grape growers of northwestern São Paulo still do not use polyethylene or polypropylene plastic films in their vineyards, this study investigated the effects of plastic covers on cv. *BRS Morena* grapevine microclimate, cultivated in an overhead trellis system in Jales, northwestern São Paulo, Brazil, in order to identify the main changes caused on crop yield.

Materials and methods

The experiments were carried out at the Tropical Viticulture Experimental Station of Embrapa Grape and Wine in Jales, São Paulo State, Brazil (20° 16′ 08′ S lat, 50° 32′ 45′ W long, 478-m altitude). The climate of the region is Aw (Köppen classification), with tropical humid climate with rainy season in the summer and moderate drought in the winter (Alvares et al. 2013). Table 1 shows the monthly climatic data for Jales for the period between 1995 and 2012, as found at Embrapa website (www.cnpuv.embrapa.br). The predominant soil in the experimental area is the Haplic Lixisol (Loamic) (FAO 2014).

In the region of Jales, grape production is directed to off-season periods of other traditional grape producing regions of São Paulo State (June–November), when the production potentially reaches better prices (Costa et al. 2008). Thus, the experiments were performed from April to August in 2012, 2013, and 2014 in plants that were pruned with six to eight buds per shoot. The pruning was performed on April 18, April 09, and April 10, for 2012, 2013, and 2014, respectively. As the experimental period has low rainfall (Table 1), irrigation was applied using microsprinklers with nominal flow rate of 50 L h^{-1}. Three rows of 120 m of seedless grape cv. *BRS Morena*, oriented North-South, with 3.0 m between plants, were used as the experimental plot, with 2.5 m between the first and second rows and 5.0 m between the second and third rows, covering an area of 900 m^2. Half of the plants in the vineyard were covered with braided polypropylene plastic film installed over a metallic arc-shaped structure (BPF) and the other half with black screen, with 18% of shading (BSS). According to the manufacturer, braided polypropylene plastic film is waterproofed with low-density polyethylene, added with anti-ultraviolet (anti-UV) filter, with 200 μm of thickness, 185 g/m^2 of specific weight and solar radiation transmissivity ranging from 70 to 80%. The black shading screen is a high-density polyethylene monofilament with 5.3 × 2.1-mm mesh, 150 g/m^2 of specific weight, 80 to 82% of solar radiation transmissivity, and also added with anti-UV filter.

A set of automatic meteorological sensors were installed in each of the covered environments (BPF and BSS) for microclimate characterization. The air temperature (T) and relative humidity (RH) sensors were positioned between the canopy and the plastic covers. For solar radiation (SR) and photosynthetically active radiation (PAR), the sensors were installed on an acrylic base set just above the canopies to measure the radiant energy that reached the plants under the covers. Wind speed sensors (WS) were installed at 0.80 m above the canopies and below the covers. The net radiation (Rn) was measured by sensors installed at 0.80 m above the canopies to capture the short- and long-wave radiation balance between the canopy and the cover. All sensors mentioned above were connected to a datalogger (Campbell Scientific, CR23X). An automatic weather station (AWS) (Campbell Scientific, CR510) was also installed at 100 m from the experimental area to provide meteorological data of the external conditions, including rainfall.

Biometric evaluations were performed in 30 plants, distributed in each environments (BPF and BSS). Phenological assessments were performed daily, using the scale proposed by Lorenz et al. (1995), from budding to fruit maturation. The leaf area estimation (m^2 per shoot) occurred weekly, according to methodology described in Beslic et al. (2010), using as basis the leaf area estimation of the largest and the smallest leaf as well as the number of leaves per shoot. The number of branches per plant and the percentage of fertile buds per shoot were determined a month prior to harvest, which occurred on August 21 (2012), August 14 (2013), and August 01 (2014). After harvesting, bunches were counted and weighed, and three bunches per plant were evaluated for stem and berries weight and width determination.

Comparisons between AWS, BPF, and BSS microclimates and biometric variables obtained from the covered vineyards were submitted to data variance analysis using the Tukey and Kruskal-Wallis tests, at levels of 5 and 1% of probability, respectively, using SAS statistical software (ver. 9.3; SAS Institute, Cary, NC).

Results

Significant differences ($P < 0.05$) were observed between incoming solar (SR) and photosynthetically active (PAR) radiation transmitted into each covered environment (BPF and BSS), also between them and the external condition (AWS) (Table 2), in all periods. SR under BPF was greater than at the AWS, on average, 1.9, 5.2, and 4.3 MJ/m^2 day, for 2012, 2013, and 2014, respectively. Under BSS, the SR differences in comparison to the external condition were, on average, 1.1, 4.4, and 3.5 MJ/m^2 day for each year, respectively. Therefore, BSS allowed higher transmissivity of SR incident at the cover top compared to BPF. The same occurred for PAR in which the differences in comparison to the external condition, in the three evaluated years, were 2.7, 4.5, and 3.3 MJ/m^2 day for BPF and 1.5, 3.2, and 2.0 MJ/m^2 day for BSS. PAR under

Table 1 Monthly climatic data for Jales, SP, Brazil, for the period between 1995 and 2012

Month	SR[2] MJ m^{-2} day^{-1}	T avg[1] °C	T max[1]	T min[1]	RH avg[1] %	WS avg[2] m s^{-1}	R total[1] mm
Jan	19.7	25.1	31.5	20.5	83.0	1.02	289.6
Feb	20.8	25.5	32.0	20.3	82.0	0.99	196.7
Mar	19.0	25.3	31.7	19.7	82.0	0.98	174.1
Apr	17.4	24.5	31.3	18.2	78.0	1.00	59.3
May	15.0	21.4	28.4	15.3	77.0	0.99	62.5
Jun	14.4	20.7	28.1	14.4	74.0	1.02	28.6
Jul	15.3	21.0	29.0	14.5	69.0	1.06	12.0
Aug	18.2	22.8	31.3	15.9	63.0	1.10	18.5
Sep	19.3	24.0	32.2	17.8	65.0	1.13	61.6
Oct	19.4	25.2	32.8	19.5	71.0	1.09	89.9
Nov	21.2	25.1	32.0	197	75.0	1.06	130.6
Dec	20.9	25.3	32.0	20.6	79.0	1.00	196.7
Total	–	–	–	–	–	–	1319.9
Average	18.4	23.8	31.0	18.1	75.0	1.04	–
Maximum	21.2	25.5	32.8	20.6	83.0	1.13	289.6
Minimum	14.4	20.7	28.1	14.4	63.0	0.98	12.0

SR incoming solar radiation, *T avg.* average air temperature, *T max* maximum air temperature, *T min* minimum air temperature, *RH avg.* average relative humidity, *WS avg.* average wind speed, *R total* sum of monthly rainfall.

Months highlighted in gray represent the time at which the experiments were performed

[1] Averages from 1995 to 2012

[2] Averages from 2004 to 2012

BPF was, on average, 28.8, 29.2, and 29.1% lower than under BSS, for 2012, 2013, and 2014, respectively, due to the higher SR transmissivity into BSS.

Figure 1 shows linear regressions between SR under the covered environments and outside conditions. The angular coefficients represent SR transmissivity of plastic covers. SR attenuation was observed at the top of the canopy inside BPF from 18.1 to 33.9%, over the three growing seasons. Under BSS, the average SR attenuation increased from 12.6 to 29.3% in the 3 years of experiment, which was lower than that observed under BPF. The coefficient of determination (R^2), a measure of linear regression adjustment, was slightly higher in the graphic for BPF and AWS, especially in 2012 and 2013. This shows that the relationship between SR under BPF and at AWS had a better fit. In other words, SR at AWS has a more direct relationship with SR variations that occur under BPF that under BSS.

The average PAR/SR ratio under BPF ranged from 0.32 to 0.36, between 2012 and 2014. Steidle Neto et al. (2008) found similar values of PAR/SR ratio (0.36) with transparent polyethylene, which was close to the results obtained by Cardoso et al. (2008). Under BSS, PAR/SR was higher compared to under BPF and varied from 0.40 to 0.47 (Fig. 2). There was a significant difference ($P < 0.05$) of the average PAR/SR ratio in each covered environment.

Because BSS allowed greater SR transmissivity, causing higher radiation balance (short and long waves), the average daily net radiation (Rn) in this environment was significantly greater than that in BPF ($P < 0.05$) (Table 2). On average, this difference was 30.1, 31.1, and 35.1%, respectively, for 2012, 2013, and 2014. The angular coefficients from the equations presented in Fig. 3 refers to Rn proportion (short and long waves) retained in the covered environment in relation to SR transmitted through the plastic covers. Under BPF, Rn represents, on average, 43% of SR transmitted into this environment. Under BSS, this value increased to 53%, on average 25% higher than under BPF. The daytime Rn (Fig. 4) followed the same trend as the average daily Rn presented in Table 2, with very pronounced differences between the environments. Under BSS, the positive daytime Rn was 43.2% higher than under BPF. Conversely, nighttime Rn values were, on average, 2.7 times more negative under BSS than BPF.

Throughout the experiment, *T* average was similar comparing the three environments (Table 3), except for 2014, when *T* under covered environments was lower than outside during half of the crop cycle. *T* differences ($P < 0.05$) between BPF and AWS ranged from 0.9 to 1.8 °C, and between BSS and AWS from 0.8 to 1.6 °C. In general, the highest maximum *T* (Tmax) and the lowest minimum *T* (Tmin) were found under covered environments when compared to outside, with

Table 2 Incoming solar (SR), photosynthetically active (PAR), and net (Rn) radiation measured in each studied environment and in each experimental year, being braided polypropylene film (BPF), black shading screen 18% (BSS), and automatic weather station (AWS)

Stage	DAP	SR (MJ/m^2 day)			PAR (MJ/m^2 day)			Rn (MJ/m^2 day)	
		BPF	BSS	AWS	BPF	BSS	AWS*	BPF	BSS
	2012								
0	5–16	10.62 c	11.72 b	12.96 a	3.27 c	4.45 b	6.48 a	4.21 b	5.33 a
1	17–30	7.86 c	9.05 b	9.29 a	2.65 c	3.63 b	4.64 a	3.51 b	4.64 a
5	31–37	8.63 c	9.24 b	9.90 a	2.92 c	4.19 b	4.95 a	4.37 b	5.62 a
6	38–56	7.13 c	8.04 b	8.77 a	2.47 c	3.48 b	4.39 a	3.48 b	4.70 a
7	57–91	9.94 c	10.74 b	11.94 a	2.81 c	3.98 b	5.97 a	3.98 b	5.32 a
8	92–124	12.20 c	12.66 b	14.92 a	3.42 c	4.94 b	7.46 a	5.42 b	6.76 a
	2013								
0	4–13	11.29 c	11.98 b	16.80 a	3.42 c	4.82 b	8.40 a	4.88 b	6.55 a
1	14–24	11.31 c	12.66 b	16.89 a	4.09 c	5.75 b	8.44 a	4.86 b	6.16 a
5	25–30	11.08 c	12.96 b	16.87 a	3.90 c	5.48 b	8.44 a	4.53 b	5.71 a
6	31–51	9.00 c	10.83 b	13.95 a	2.74 c	3.88 b	6.98 a	4.18 b	5.90 a
7	52–90	9.10 c	10.12 b	13.26 a	2.37 c	3.37 b	6.63 a	4.00 b	5.25 a
8	91–126	10.78 c	11.51 b	15.89 a	3.14 c	4.44 b	7.99 a	4.64 b	5.91 a
	2014								
0	4–12	9.83 c	10.62 b	14.77 a	3.70 b	5.21 b	7.38 a	4.22 b	5.15 a
1	13–27	10.29 c	11.05 b	16.24 a	3.81 c	5.35 b	8.12 a	4.23 b	5.29 a
5	28–35	10.30 c	11.06 b	14.74 a	3.83 c	5.39 b	7.37 a	4.47 b	5.54 a
6	36–50	7.83 c	8.75 b	10.45 a	2.81 c	3.98 b	5.22 a	3.29 b	3.95 a
7	51–80	8.58 c	9.45 b	12.69 a	2.99 c	4.22 b	6.35 a	3.79 b	4.51 a
8	81–112	8.63 c	9.50 b	12.47 a	3.10 c	4.38 b	6.23 a	3.71 b	4.45 a

Phenological stages of vine development (Lorenz et al. 1995): *0* budding, *1* leaf development, *5* inflorescence emergence, *6* flowering, *7* fruit development, *8* fruit maturation. *DAP* days after pruning

For each main factor separately, averages followed by different letters in the same line differ statistically from each other by Kruskal-Wallis test ($P < 0.05$)

*PAR at AWS estimated from incoming solar radiation (Assis and Mendez 1989)

significant differences ($P < 0.05$). These differences between the three environments ranged from 0.1 to 1.2 °C for Tmax and from 0.1 to 2.8 °C for Tmin.

For average RH (RH avg), the three environments presented no differences ($P < 0.05$) in 2012 and 2013 (Table 4). However, in 2014, values under BPF were higher than those obtained under BSS, with differences ranging from 6.2 to 6.9%; and AWS obtained intermediate values between the covered environments. For maximum RH (RHmax), BPF presented similar values to AWS, except for 2014, when during half of crop cycle, BPF had higher RHmax than AWS (3.3%, $P < 0.05$). For minimum RH (RHmin), AWS presented higher values compared to BPF only in 2012 (2.7%, $P < 0.05$). Under BSS, RH values were systematic lower than under BPF and AWS. Only in 2013, RHmin under BSS was similar to that under BPF for most of the year. In relation to wind speed (WS) (Table 5), the average, maximum, and minimum wind speed values under the three environments differed ($P < 0.05$). On average, the WS reduction caused by BPF was 70.9 and 63.7% for average and maximum WS, respectively. Under BSS, the WS attenuation was about 38.6 and 15.2% for average and maximum values, respectively.

The different plastic covers had little effect on total number of shoots per plant, but they influenced the number of shoots with bunches (Table 6). On average, vines grown under BPF developed 29% more productive shoots compared to vineyards under BSS. Similarly, the environments differed in relation to bunch weight, 10 berries weight and longitudinal diameter, as well as stem weight and width. Plants grown under BPF increased the values of these variables by 63.8, 8.7, 5.3, 72.2, and 50.3%, respectively, compared to BSS.

The different plastic covers also influenced other yield-related variables. In Fig. 5, the percentage of fertile buds per shoot, the number of bunches per shoot, and yields (kg per shoot and per plant) are compared between vineyards cultivated under BPF and BSS. The plants grown under BPF had a significant increase of 9.6% in fertile buds per plant, 69.9% in yield per shoot, and 97% in yield per plant, on average, compared to the vineyard under BSS. On average, these differences correspond to 8.1% more fertile buds per plant,

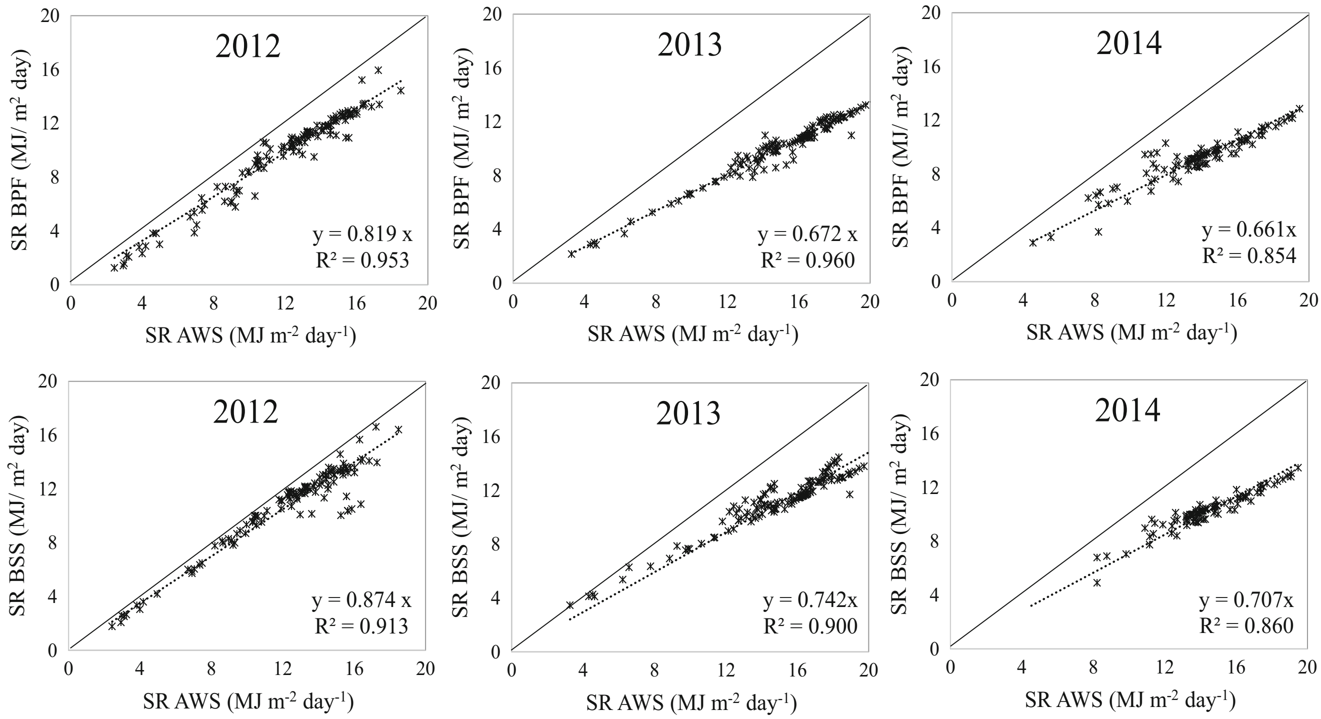

Fig. 1 Relationship between global solar radiation (SR) under the covered environments and the outside conditions, during the three growing periods, where *BPF* braided polypropylene film, *BSS* black shading screen 18%, and *AWS* automatic weather station

0.12 kg in yield per shoot, and 5.71 kg in yield per plant. Although the number of fertile buds per shoot was higher in plants under BPF compared to BSS, in 2013 and 2014, the number of bunches per shoot was similar in both covered vineyards. This means that although the number of fertile buds was higher under BPF, especially in 2014, many of the buds did not bear fruit. However, yield was much higher in BPF even with a similar number of bunches per shoot in both environments. This is because the number of shoots with bunch and bunch weight were higher under BPF (Table 6), increasing yield for vines under this environment.

Comparing leaf area in covered vineyards (Fig. 6), plants under BPF developed larger leaves compared to the vine under BSS. The final value of leaf area for the three experimental years was, on average, 6.10 m^2 per shoot and 3.96 m^2 per shoot for leaves developed under BPF and BSS, respectively. Therefore, leaf area was 54.04% higher under BPF cover. For this reason, variability of leaf sizes of plants grown under BPF was also higher, 0.20 to 7.45 m^2 per shoot, compared to BSS under which the leaf area values varied between 0.10 and 5.71 m^2 per shoot. This means a variation of 7.25 and 5.61 m^2 per shoot under BPF and BSS, respectively. Throughout the experimental years, leaf area did not increase similarly and steadily for both environments. Under BPF, the growth was more pronounced during the experimental years, with an average leaf growth rate of 11.51, 9.51, and 11.11% in

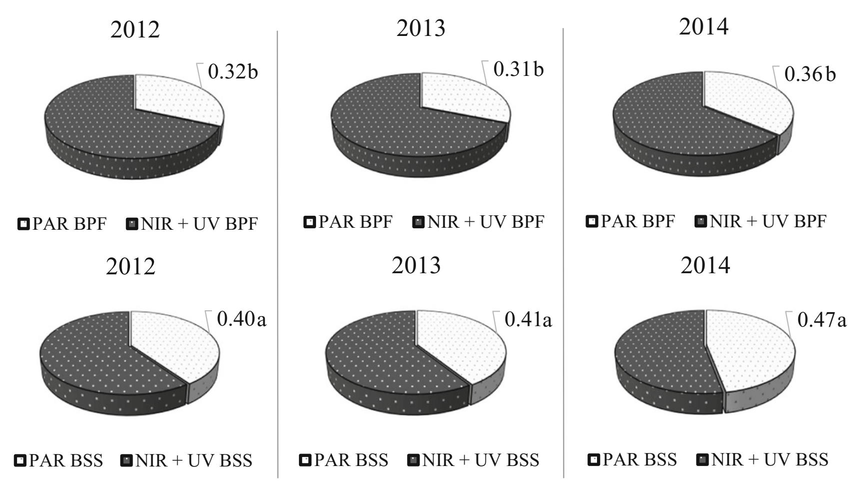

Fig. 2 Partition of global solar radiation (SR) in photosynthetic active radiation (PAR) and near infrared and ultraviolet radiation (NIR + UV), inside each environment (braided polypropylene film–*BPF*, black shading screen 18%–BSS), during the three experimental years. Averages followed by different letters in the same year, differ statistically from each other ($P < 0.05$)

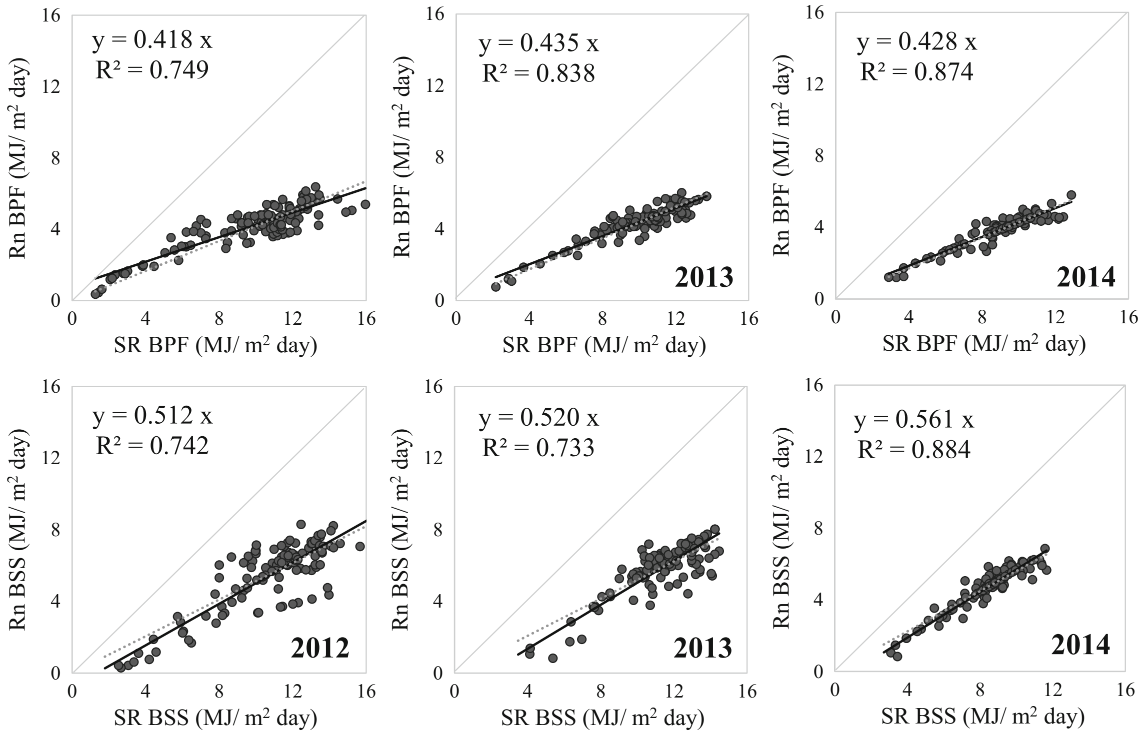

Fig. 3 Relationship between net radiation (Rn) and global solar radiation (SR) under the covered environments, during the three growing periods, where *BPF* braided polypropylene film, *BSS* black shading screen 18%

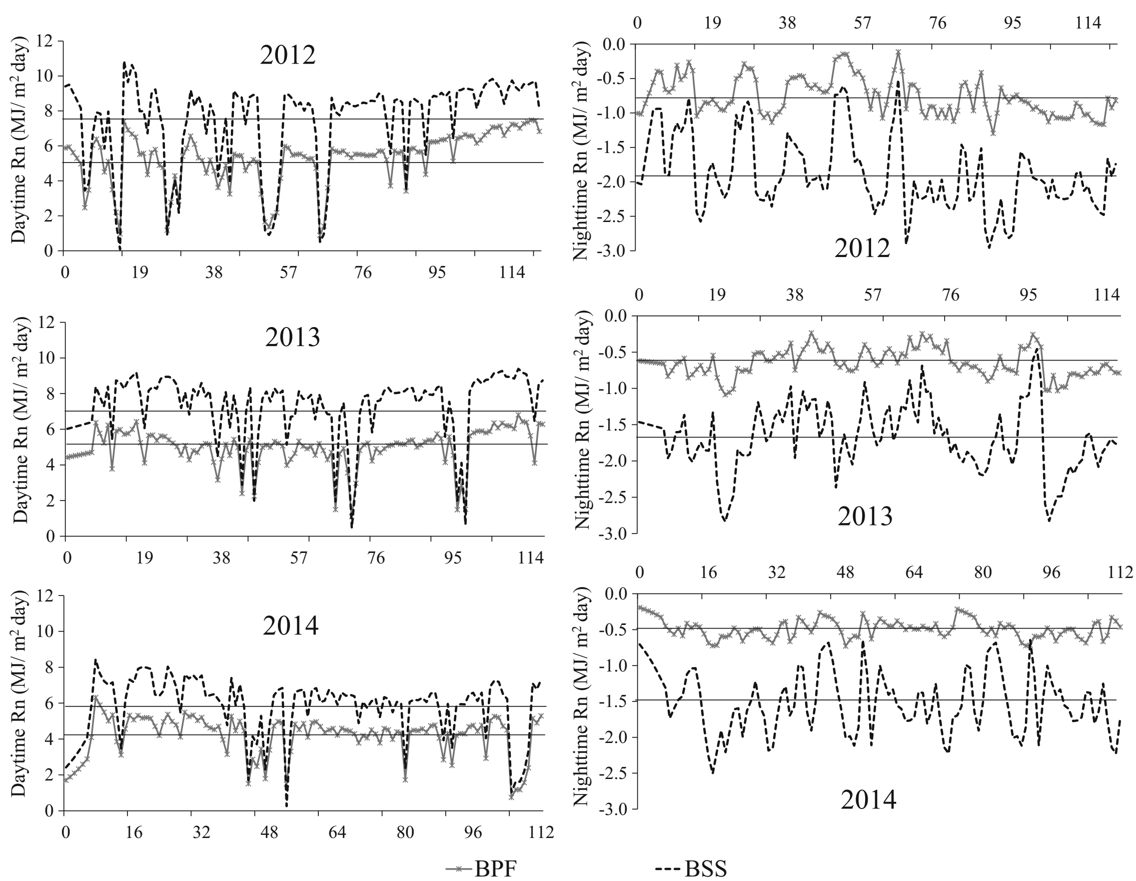

Fig. 4 Net radiation (daytime and nighttime Rn, MJ/ m^2 day) during the three experimental years under braided polypropylene film (BPF) and black shading screen 18% (BSS). The line (−) represents the Rn average value over each period

Table 3 Air temperature in each environment along the different experimental years: braided polypropylene film (BPF), black shading screen 18% (BSS), and automatic weather station (AWS)

Stage	DAP	T avg. (°C)			T max (°C)			T min (°C)		
		BPF	BSS	AWS	BPF	BSS	AWS	BPF	BSS	AWS
	2012									
0	5–16	21.1 a	21.1 a	21.1 a	27.8 ab	28.2 a	27.2 b	15.9 a	15.7 a	16.1 a
1	17–30	21.4 a	21.6 a	21.7 a	27.8 ab	28.2 a	27.3 b	17.1 a	17.1 a	17.4 a
5	31–37	21.2 a	21.4 a	21.5 a	28.4 ab	28.8 a	28.0 b	16.5 a	16.5 a	16.8 a
6	38–56	21.7 a	21.5 a	21.6 a	28.8 a	28.6 a	27.8 b	17.1 a	16.7 a	17.2 a
7	57–91	19.8 a	19.9 a	20.0 a	27.9 a	28.3 a	27.1 b	13.9 a	13.7 a	14.3 a
8	92–124	21.6 a	22.0 a	22.3 a	30.9 ab	31.6 a	30.6 b	14.7 b	14.8 ab	15.5 a
	2013									
0	4–13	21.5 a	21.6 a	21.9 a	28.8 a	29.0 a	28.4 a	16.3 a	16.1 a	16.5 a
1	14–24	22.9 a	23.1 a	23.1 a	31.1 ab	31.5 a	30.6 b	16.9 a	16.8 a	17.4 a
5	25–30	20.1 a	20.1 a	20.2 a	29.3 a	29.4 a	28.7 a	12.2 ab	11.9 b	12.7 a
6	31–51	22.5 a	22.6 a	22.8 a	30.7 a	30.6 a	30.2 a	16.9 a	16.8 a	17.3 a
7	52–90	21.9 a	22.0 a	22.5 a	29.3 a	29.4 a	29.0 a	17.1 a	16.9 a	17.1 a
8	91–126	19.7 a	20.0 a	20.1 a	28.9 a	29.3 a	28.6 a	12.7 a	12.6 a	12.3 a
	2014									
0	4–12	23.5 b	23.6 b	24.4 a	31.7 a	32.4 a	31.8 a	17.8 b	17.7 b	19.4 a
1	13–27	22.1 a	22.3 a	22.7 a	30.0 ab	30.7 a	29.9 b	16.0 b	16.1 b	17.2 a
5	28–35	21.7 a	21.8 a	22.1 a	31.0 ab	31.6 a	30.5 b	14.6 a	14.5 a	15.2 a
6	36–50	20.1 b	20.1 b	21.9 a	27.9 a	28.5 a	28.6 a	14.2 b	14.0 b	16.8 a
7	51–80	21.0 a	21.1 a	21.5 a	29.2 a	29.9 a	29.2 a	14.6 b	14.5 b	15.6 a
8	81–112	19.6 b	19.7 b	20.6 a	27.7 a	28.3 a	28.0 a	13.4 b	13.2 b	14.7 a

Phenological stages of vine development (Lorenz et al. 1995): *0* budding, *1* leaf development, *5* inflorescence emergence, *6* flowering, *7* fruit development, *8* fruit maturation. *DAP* days after pruning

For each main factor separately, averages followed by different letters in the same line differ statistically from each other by Kruskal-Wallis test ($P < 0.05$)

*PAR at AWS estimated from incoming solar radiation (Assis and Mendez 1989)

2012, 2013, and 2014, respectively. In the case of vineyard grown under BSS, for the same sequence of years, the average growth rate was 6.16, 6.83, and 7.54%.

Discussion

Under BPF and BSS, the average SR was lower than that at the AWS (Table 2), in all assessed periods, which was expected due to the solar radiation attenuation promoted by reflection and absorption of radiation by plastic covers (Sentelhas et al. 1997). This fact can also be observed by the angular coefficients in the equations presented in Fig. 1, whose values are consistent with results from Rana et al. (2004), Lulu and Pedro Júnior (2006), and Cardoso et al. (2008). These authors found SR availability reduction in vineyards covered with plastic polyethylene (150 and 200 μm) from 15 to 30% in relation to outside. Comparing BPF and BSS, SR and PAR differences compared to the external condition indicated that BSS allows higher SR and PAR incidence over the canopy, when compared with the BPF cover. The plastic films differ in terms of absorption, reflection, and transmissivity of short-and long-wave radiations according to their color, opacity, or transparency (Roberto et al. 2011). In addition, since BSS is composed of holes, it allowed higher SR and PAR transmissivity, which did not occur in BPF because it is a non-permeable plastic film.

From 2013 to 2014, there was a significant decrease of SR transmissivity under BPF (Fig. 1). According to Serrano et al. (2001), higher SR attenuation over time is caused by higher plastic degradation and dust accumulation, which was also observed by Chavarria et al. (2009) in vineyards under plastic covers. When exposed to natural weathering and agrochemicals commonly sprayed by growers, the plastic films are subjected to degradation of their mechanical and physical properties, causing discoloration, surface cracking, and stiffening (Vox and Schettini 2013), depending on their active principles, application method and frequency, ventilation, and greenhouse structure (Dilara and Briassoulis 2000). Ultra violet radiation (UV) absorbed by plastic films is the factors that

Table 4 Relative humidity obtained inside each environment and in each experimental year: braided polypropylene film (BPF), black shading screen 18% (BSS) and automatic weather station (AWS), and the differences between the covered environments and the outside conditions

Stage	DAP	RH avg. (%)			RH max (%)			RH min (%)		
		BPF	BSS	AWS	BPF	BSS	AWS	BPF	BSS	AWS
	2012									
0	5–16	81.0 a	77.5 a	82.0 a	98.6 a	96.4 b	98.6 a	53.7 b	50.4 c	56.8 a
1	17–30	77.5 a	73.6 a	78.1 a	95.7 a	93.5 b	95.5 a	51.4 b	48.2 c	54.2 a
5	31–37	73.5 a	72.6 a	73.1 a	92.1 a	89.9 b	91.3 ab	45.5 b	42.8 c	48.2 a
6	38–56	86.0 a	83.1 a	86.7 a	99.9 a	97.4 b	99.8 a	58.2 b	54.6 c	60.5 a
7	57–91	76.7 a	73.7 a	74.9 a	98.1 a	95.9 b	96.2 b	45.7 a	42.9 b	47.2 a
8	92–124	59.4 a	56.8 a	55.1 a	86.6 a	84.6 b	80.2 c	29.9 a	28.1 a	29.9 a
	2013									
0	4–13	80.1 a	78.3 a	78.2 a	98.1 a	97.1 a	97.1 a	51.0 a	48.7 b	51.4 a
1	14–24	73.1 a	71.5 a	71.4 a	96.7 a	95.4 a	95.5 a	40.5 ab	38.7 b	42.3 a
5	25–30	74.0 a	72.4 a	72.2 a	100.0 a	97.4 b	99.9 a	36.7 ab	35.0 b	37.1 a
6	31–51	76.8 a	74.7 a	74.4 a	97.1 a	94.4 b	95.5 ab	45.7 ab	43.7 b	45.9 a
7	52–90	82.0 a	80.3 a	79.8 a	98.4 a	97.2 a	97.7 a	52.6 a	50.2 b	52.7 a
8	91–126	67.6 a	66.2 a	64.5 a	94.1 a	91.3 b	90.9 b	36.5 a	34.9 a	36.5 a
	2014									
0	4–12	76.7 a	69.9 b	74.7 ab	98.6 a	92.1 c	96.1 b	45.5 a	42.7 b	47.0 a
1	13–27	73.1 a	66.6 b	71.4 ab	98.0 a	91.5 b	96.5 a	42.0 a	39.4 b	43.6 a
5	28–35	70.6 a	64.3 b	68.2 ab	98.3 a	91.7 b	96.7 a	35.9 a	33.6 b	36.7 a
6	36–50	77.4 a	70.5 b	79.7 a	97.3 a	90.8 b	96.0 a	47.2 b	44.3 c	54.1 a
7	51–80	72.0 a	65.5 b	68.7 ab	96.7 a	90.1 c	93.4 b	40.6 a	38.1 b	40.6 a
8	81–112	69.9 a	63.7 b	67.0 ab	94.1 a	85.5 c	90.1 b	40.7 a	38.2 b	42.2 a

Phenological stages of vine development (Lorenz et al. 1995): *0* budding, *1* leaf development, *5* inflorescence emergence, *6* flowering, *7* fruit development, *8* fruit maturation. *DAP* days after pruning

For each main factor separately, averages followed by different letters in the same line differ statistically from each other by Kruskal-Wallis test ($P < 0.05$)

most influences aging and photo-degradation processes, especially UV-B and UV-A radiation, which lead to bond cleavage and depolymerization and radical oxidation reactions (Sanchez-Lopez et al. 1991). The plastic covers used in the present experiment had anti-UV pigmentation in their composition. However, even with the addition of anti-UV pigments, which retard degradation (Castellano et al. 2008), plastic covers are susceptible to partial degradation over the years, causing a significant reduction of SR transmissivity. BPF degradation was higher during the experiment, compared to the BSS shade screen due to the parameters related to the film itself.

Even undergoing degradation and changes in its physical properties and despite SR transmissivity reduction over the years, PAR/SR ratio inside the covered environments increased (Fig. 2). From 2012 to 2014, this increase was 12.5 and 17.5% for BPF and BSS, respectively. Such processes of changes in the physical properties suffered by the plastic covers, along with the years, appear to have conferred greater selectivity to this material to photosynthetically active solar radiation. Rana et al. (2004) found opposite results. These authors observed PAR decrease over time in the vineyard canopy, with attenuation of 17% under light-colored shading screen and in 32% in areas covered with non-permeable and translucent plastic.

Net radiation (Rn) is the difference between incoming and outgoing radiation at short and long wavelengths (0.3–30 μm) (Rana et al. 2004). The use of shading screen (BSS) allowed greater SR transmissivity into the environment, resulting in higher radiation balance (short and long waves) in this environment, compared to BPF (Table 2 and Fig. 3). Radiometric properties of the cover material influenced directly the energy balance of covered environments (Vox et al. 2010). Thus, a higher radiation balance in BSS represents a larger amount of energy available in the vineyards covered with BSS compared to those with BPF.

The well-defined linear relationship between Rn and SR was observed and classified as excellent (Sentelhas and Nascimento 2003), allowing good estimation of Rn from SR (Fig. 3). However, for an accurate measurement, the coefficient of determination (R^2) should be close to 1. However, the R^2 values ranged from 0.73 to 0.88. Pezzopane and Pedro

Table 5 Wind speed obtained inside each environment and in each experimental year: braided polypropylene film (BPF), black shading screen 18% (BSS) and automatic weather station (AWS), and the differences between the covered environments with outside conditions

Stage	DAP	WS avg. (m s^{-1})			WS max (m s^{-1})		
		BPF	BSS	AWS	BPF	BSS	AWS
	2012						
0	5–16	0.36 c	0.63 b	0.95 a	0.94 c	1.33 b	1.79 a
1	17–30	0.31 c	0.62 b	0.96 a	0.89 c	1.40 b	1.85 a
5	31–37	0.31 c	0.71 b	1.01 a	0.69 c	1.41 b	1.81 a
6	38–56	0.30 c	0.60 b	0.92 a	0.81 c	1.35 b	1.76 a
7	57–91	0.30 c	0.53 b	0.97 a	0.81 c	1.40 b	1.68 a
8	92–124	0.40 c	0.58 b	1.06 a	0.93 c	1.49 b	1.73 a
	2013						
0	4–13	0.36 c	0.57 b	0.93 a	0.54 c	1.35 b	1.65 a
1	14–24	0.24 c	0.59 b	0.93 a	0.47 c	1.46 b	1.72 a
5	25–30	0.23 c	0.46 b	0.89 a	0.41 c	1.37 b	1.53 a
6	31–51	0.21 c	0.63 b	0.96 a	0.33 c	1.48 b	1.61 a
7	52–90	0.22 c	0.55 b	0.92 a	0.35 c	1.45 b	1.61 a
8	91–126	0.23 c	0.65 b	1.01 a	0.42 c	1.56 b	1.76 a
	2014						
0	4–12	0.29 c	0.57 b	0.95 a	0.80 c	1.45 b	1.60 a
1	13–27	0.27 c	0.61 b	0.93 a	0.59 c	1.48 b	1.67 a
5	28–35	0.24 c	0.55 b	0.92 a	0.44 c	1.34 b	1.59 a
6	36–50	0.24 c	0.49 b	0.88 a	0.56 c	1.28 b	1.40 a
7	51–80	0.24 c	0.61 b	0.96 a	0.51 c	1.41 b	1.66 a
8	81–112	0.23 c	0.53 b	0.90 a	0.46 c	1.33 b	1.54 a

Phenological stages of vine development (Lorenz et al. 1995): *0* budding, *1* leaf development, *5* inflorescence emergence, *6* flowering, *7* fruit development, *8* fruit maturation. *DAP* days after pruning. *DAP* days after pruning, *WS avg.* average wind speed, *WS max* maximum wind speed

For each main factor separately, averages followed by different letters in the same line differ statistically from each other by Kruskal-Wallis test ($P < 0.05$)

Junior (2003) obtained similar results when determining the relationship between Rn and SR for an uncovered *Niagara Rosada* vineyard, which ranged from 0.54 to 0.85. Increased Rn/SR under the two covered environments during the experimental years (Fig. 3) was probably caused by plastic aging, which caused changes in optical characteristics and, consequently, higher short-and long-wave retention in the environments. According to Vox and Schettini (2013), inside the plastic cover exposed to climatic agents and agrochemicals, the highest retention occurs for long-wave infrared radiation (LWIR), ranging from 7500 to 12.500 nm.

The analysis of the daytime Rn (Fig. 4) showed that higher SR transmissivity through BSS cover promoted a 43.8% increase in Rn under this environment compared to BPF, during all diurnal period. Rana et al. (2004) obtained similar results, however, with a smaller difference between environments (5.0%), by comparing light-colored shading screen with a plastic film of greater transparency than the BPF. Figure 4 also shows that, under BSS, nighttime Rn was more negative than under BPF in all evaluated days. As previously mentioned, the screen mesh allowed a higher sunlight flux density in the BSS environment. Likewise, in this environment, a larger amount of long-wave radiation was emitted by the canopy and by the soil surface and transmitted to the external environment through the screen. The BPF blocked part of the long wave loss, with more intensity than BSS, generating less negative net radiation. Besides that, the water condensation in the inner side of plastic cover also contributed to intercept long-wave radiation, reducing transmittance (Martins et al. 1999).

The partial energy retention by plastic covers increased air temperature under covered environments in comparison to outside condition. By limiting both convective and radiative thermic dispersions, plastic covers elevated the average air temperature (Novello et al. 2000). A phenomenon known as "the greenhouse effect," which depends on the radiometric properties of plastic covers (Scarascia-Mugnozza et al.

Table 6 Biometric variables of cv "BRS Morena" in each environment studied, in three periods, being braided polypropylene film (BPF), black shading screen 18% (BSS), and automatic weather station (AWS)

Biometric variables	2012		2013		2014	
	BPF	BSS	BPF	BSS	BPF	BSS
N° shoot per plant	41.2 a	28.0 b	42.0 a	39.0 a	39.2 a	39.7 a
N° shoot with bunch per plant	37.7 a	24.2 b	38.2 a	32.0 b	37.8 a	33.8 b
Bunch weight (g)	171.3 a	73.5 b	225.3 a	179.3 b	232.9 a	175.5 b
Stem weight (g)	5.9 a	2.6 b	7.0 a	4.5 b	6.3 a	4.7 b
Stem width (mm)	132 a	88 b	149 a	99 b	135 a	128 a
10 berries weight (g)	35.4 a	31.8 b	48.2 a	45.4 b	34.5 a	33.0 a
10 berries transversal diameter (mm)	166 a	160 a	172 a	173 a	164 a	162 a
10 berries longitudinal diameter (mm)	217 a	204 b	239 a	222 b	203 a	199 b

For each biometric variable and year separately, averages followed by different letters in the same line differ statistically from each other by Kruskal-Wallis test ($P < 0.05$)

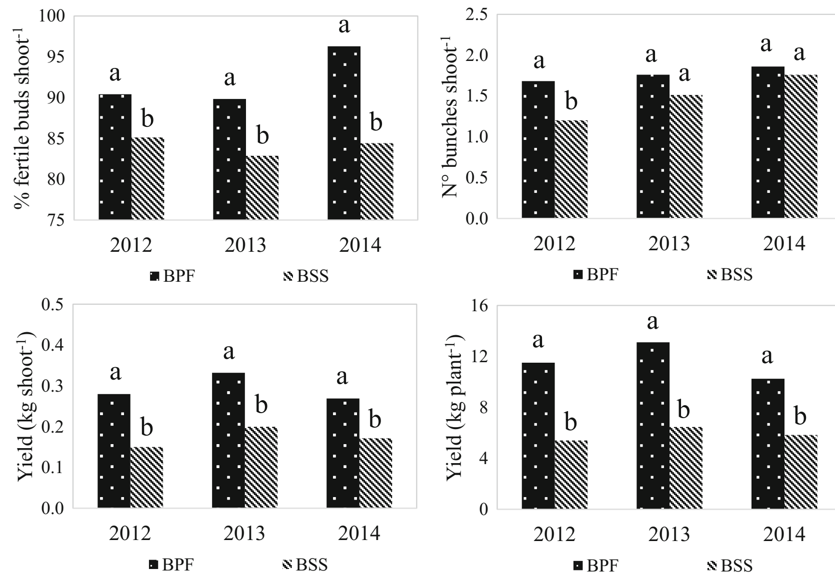

Fig. 5 Vineyards biometric variables along the growing seasons in Jales, SP, Brazil, with the plants cultivated under braided polypropylene film (BPF) and black shading screen 18% (BSS)

2011). In our study, this effect only occurred for Tmax in which the covered environments presented higher values compared to outside (Table 3), mainly in 2012. For average and minimum values (T avg. and T min), in most cases, the covered environments were similar to *T* of the outside environment. In some crop stages, the covered environments presented even lower averages as compared to outside. Even though BSS allowed higher SR transmissivity, the *T* differences between the environments were very small. Comparing both covered environments, Tavg, Tmax, and Tmin were similar to each other over the 3 years of study. Lulu and Pedro Júnior (2006) found similar results for Tmax in vineyards grown under plastic cover and for Tmin obtained by Comiran et al. (2012). Air circulation through the environments explain these results, which allowed free heat exchange and resulted in less sensitive heat accumulation near the sensor, reducing overheating. Opposite to what occurred in a vineyard protected by covers above the canopy and the sides,

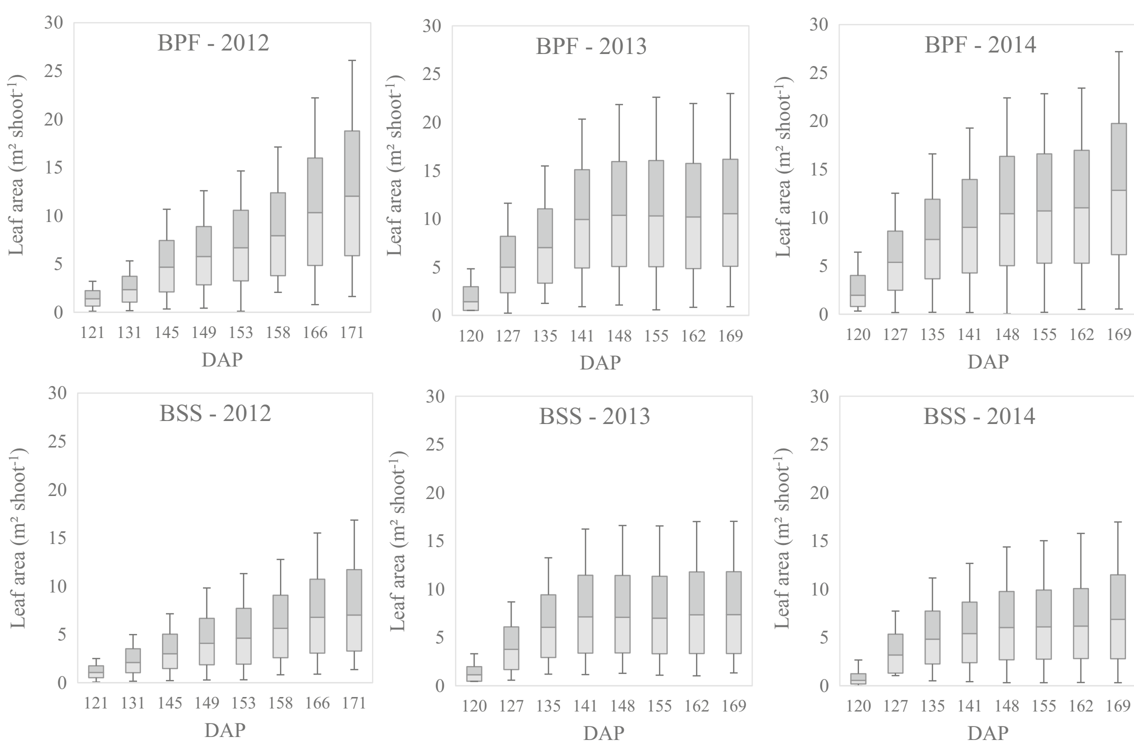

Fig. 6 Variation of vineyards leaf area along the growing seasons of 2012, 2013, and 2014 in Jales, SP, Brazil, with the plants cultivated under braided polypropylene film (BPF) and black shading screen 18% (BSS). *DAP* days after pruning

which retain a good portion of energy by limiting the convective and radiative thermal dispersions, increasing air temperature (Novello and de Palma 2008). Other authors, however, reported that, in covered environments with black shading screens or polyethylene plastic covers, the average temperature was higher than outside, with average differences ranging from 0.9 to 6 °C (Andrade Júnior et al. 2011; Comiran et al. 2012).

Similarly to what occurred with *T*, air circulation is one of the factors that directly influences RH variation in covered environments. Changes in radiative regime in covered vineyards modify air temperature and humidity at the grape cluster level (Rana et al. 2004). Because there was no plastic cover on the sides of the covered environments, the exchange of water vapor was allowed from the protected to the external environment and vice versa. Consequently, RH under BPF showed no differences ($P < 0.05$) to external condition (AWS) (Table 4). Several authors conducted experiments similar to those in this study and did not observe major differences in RH between covered environments and outside conditions (Cardoso et al. 2008; Chavarria et al. 2009; Pedro Júnior et al. 2011). Some authors observed opposite results in vineyards, which means lower RH under plastic covers than in the external condition, especially during daytime periods (Andrade Júnior et al. 2011) or higher RH in covered environments than in the open field (Novello et al. 2000). Thereby, RH was lower under BSS than in BPF, especially for RHmin and RHmax. The lower RH values under BSS usually occurs during daytime, in clear sky conditions, because RH is inversely proportional to *T*. Therefore, increasing *T* usually causes RH reduction under covered vineyards, even under well-ventilated conditions. Under BSS, Tmax was slightly higher than under other environments, therefore, lower RH was expected. The highest *T* was observed under BSS and the inverse relation between *T* and RH may have influenced the RH results. Andrade Júnior et al. (2011) also found the same pattern, observing that the lowest RH min values usually occurring when *T* reached maximum values.

Permeability and porosity of the plastic covers are basic parameters that influence air humidity, temperature, and wind speed under these environments (Castellano et al. 2008). Although plastic covers allowed air circulation through the vineyards sides, promoting small or negligible differences of *T* and RH between the covered environments, the plastic covers caused reduction of wind speed (WS) in vineyards at the canopy height (Table 5), since the canopy was close to the plastic covers (0.8 m above the covers). Other authors also obtained similar results. Cardoso et al. (2008) reported WS reduction of 88%, on average, by the plastic cover. Andrade Júnior et al. (2011), under an environment covered with black screen (50% of shading), reported an average WS reduction of 95.3%. Under BSS, WS reduction was lower than under BPF due to mesh openings of the shading screen that allowed wind to flow through the holes. In the case of BPF, the plastic acted as an effective physical barrier to air circulation. Consequently, the amount of water vapor under BPF tended to be higher than under BSS, which is represented by higher RH max. According to Cardoso et al. (2008), WS reduction inhibits the convective process originating from positive net radiation, causing partial retention of water vapor in the protected environment. Most humidity under plastic covers comes from the ground and is kept by the covers, which leads to a larger amount of water vapor in the system (Lima Filho et al. 2005).

According to Vox et al. (2010), radiometric properties of plastic covers influence the crop behavior. The analysis of biometric variables in Table 6 shows that BPF properties greatly influenced cv. *BRS Morena* quantitative traits, by increasing number of productive shoots, berry weight, and diameter. One hypothesis for the distinct berry sizes and weight between covered vineyards is RH differences between these environments. For Aljibury et al. (1975), an increase in RH tends to produce larger berries. Under BPF, RH was higher than BSS, especially for RHmin and RHmax (Table 4). Thus, the increased availability of water vapor in the air probably reduced plant transpiration under BPF. Consequently, the greater water preservation in cells of plant roots and tissues promoted the development of larger and, consequently, heavier berries compared to the BSS vineyard. On the other hand, Colombo et al. (2011) verified no differences of BRS Clara bunch weight between vines cultivated under black shading screen and under plastic film.

Solar radiation is fundamental for bud differentiation (Kishino and Caramori 2007). However, despite SR attenuation imposed by BPF, the percentage of fertile buds per shoot was not reduced in this environment. In contrast, vineyards cultivated under BPF improved significantly ($P < 0.05$) the percentage of fertile buds per shoot compared to BSS, and, consequently, the number of bunches per plant (yield) (Fig. 5). Colombo et al. (2011) and Yamamoto et al. (2012) found opposite results. These authors did not find difference in the percentage of fertile buds and number of bunches comparing vineyards under plastic cover and black shading screen.

The vineyard canopy under BPF developed larger leaf areas compared to BSS (Fig. 6), probably due to the higher shading intensity imposed by the plastic film compared to the shading screen (Table 2). In general, plants use mechanisms to avoid compromising energetic decrease by restricting SR (Taiz and Zeiger 2004). The plant tends to expand leaf area in environments with more restrictive SR in order to increase its efficiency to capture luminosity without compromising the photosynthetic activity or compromising as little as possible. Regarding the speed of leaf area expansion, leaves under BPF expanded more rapidly compared to BSS. In other words, over time, leaf area growth rate was higher in comparison to BSS, contrary to results found by Greer et al. (2010). For the authors, in vineyards of *Semillon* (*Vitis vinifera* L.), shade caused a delay of leaf development, compensated by the greater expansion of shaded leaves.

The higher reduction of SR transmissivity through BPF plastic cover compared to BSS did not restrict the photosynthetic process in plants and nor bud fertility. On the contrary, micrometeorological changes generated by BPF resulted in a better performance of cultivar *BRS Morena* in comparison to vineyards of the same cultivar grown under BSS, with a much higher yield (per shoot and plant). Comparing vineyards covered with plastic film similar to BPF and uncovered vineyards, Chavarria et al. (2009) also observed higher yield per plant in vineyards under plastic film. This may have occurred because BPF allows a higher proportion of SR to reach indirectly the vineyard canopy, due to the partial blockage caused by the plastic cover. Therefore, much of the SR that reaches the canopy comes in the form of diffuse radiation. By irradiating multi-directionally, diffuse radiation has better penetration into plant canopy, increasing radiation use efficiency (Healey et al. 1998) and reducing shade zones in vineyards (Falleri and Magnani 1991). Furthermore, plants have compensation in environments that are more shaded, leading to reduced light compensation points and respiration rates in the dark (Vanden Heuvel et al. 2004). Thus, shaded leaves may exhibit increased photon absorption to maximize carbon assimilation and nutrient use efficiency under conditions of limited energy supply through anatomical, morphological, and biochemical adaptations (Henry and Aarssen 1997).

Conclusions

The braided polypropylene film promoted greater global solar radiation and photosynthetically active radiation attenuation on the vineyard canopy in comparison to black screen (18% of shading), which increased over the years due to plastic cover aging and dust and soot deposition over time. The proportion of photosynthetically active radiation compared to global solar radiation was also lower under braided polypropylene film in comparison to black screen.

The same pattern for solar radiation was observed for diurnal net radiation, in all periods evaluated, which means that a larger amount of energy was available in the vineyards covered with black screen. However, at night, polypropylene film retained long-wave radiation more efficiently, which was also favored by steam-water condensation in the inner side of the plastic cover, generating net radiation values less negative when compared to the black screen.

In general, air temperature under both covered environments was similar to that in the outside condition. The plastic covers reduced air circulation in the vineyards, but the braided polypropylene film provided a larger reduction, resulting in higher water vapor accumulation in this environment, when compared to black screen and outside conditions.

These microclimate changes promoted by braided polypropylene film provides better conditions for growth and development of vineyards, resulting in higher fruit yields compared to those under the black screen. This type of plastic cover has proved to be particularly suitable for BRS Morena cultivar, improving yield. However, its effectiveness may vary depending on the use of distinct cultivars and climatic conditions.

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