Bragantia
ISSN: 0006-8705
ISSN: 1678-4499
Instituto Agronômico de Campinas

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Bragantia, vol. 77, no. 1, January-March, 2018, pp. 181-192
Instituto Agronômico de Campinas

DOI: 10.1590/1678-4499.2016459

DOI: http://dx.doi.org/10.1590/1678-4499.2016459

AGROMETEOROLOGY - Article

Microclimate alterations caused by agricultural hail net coverage and effects on apple tree yield in subtropical climate of Southern Brazil

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ABSTRACT: The use of hail net coverage on plants is an effective measure to mitigate damage caused by hailstorms. In southern Brazil, areas with apple orchards under hail net coverage have increased in recent years. However, little is known about the possible effects on the microclimate and, consequently, on plant growth, crop yield and fruit quality. The hypothesis of this study was that hail net promotes microclimate and yield changes in apple orchards. The objective was to characterize the microclimate and production of apple trees cultivated under hail nets and to consequently generate numeric parameters that can be used in the management of apple orchards and in crop modeling. The study was conducted in commercial orchards growing under hail net and open sky. Continuous measurements of photosynthetically active radiation (PAR), air temperature and humidity, wind speed and rainfall were performed. Production was assessed based on the number and weight of fruits per plant. The hail nets reduced PAR by 32.8% and the wind speed by 30%. In contrast, coverage did not alter the air temperature, humidity or rainfall. The yield of apples tends to be higher under hail net and this is more pronounced when one hailstorm event occur. These results are important for researchers, and apple farmers to establish criteria for decision making regarding the implementation of hail net coverage and to develop appropriate management systems for protecting orchards to ensure and improve fruit production. Overall, the effects of long-term micrometeorological factors are essential to perform modeling of agricultural production.

Key words: *Malus domestica* Borkh, solar radiation, air temperature, humidity, wind.

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Received: Nov. 2, 2016 – Accepted: Mar. 23, 2017

INTRODUCTION

The increased occurrence of extreme weather events due to climate change has heightened the demand for measures that can mitigate losses in agriculture. Under scenarios of moderate climate change, damage caused by hailstorms tends to increase (Botzen et al. 2010). In agriculture, hail is considered an extreme event of great destructive potential, for example, a single hailstorm event in an orchard could result in the total loss of fruit production and would damage the trees (Garnaud 1998).

Apple (*Malus domestica* Borkh) trees grow in temperate regions or at high elevations. Although the climatic characteristics of such regions may result in increased production and fruit quality, these areas are affected by frequent hailstorms, causing damage to orchards and adversely affecting growers. In Rio Grande do Sul State, Brazil, the highest incidence of hailstorms occurs in regions of higher elevation and continentality, with four or more events per year (Berlato et al. 2000).

In those cultivation areas, covering plants with hail nets is considered the safest and most effective method of protecting against hailstorms, and the utilization of these nets is increasing. Since the 1950s, several systems with hail nets have been developed, and their use has proven to be effective as an alternative control of hail. Indeed, there has been an intensification of hail net use in horticulture since 2000 in Brazil (Amarante et al. 2011; Leite et al. 2002), Australia (Middleton and McWaters 2002), Italy (Corollaro et al. 2015), Argentina (Dussi et al. 2005), Spain (Iglesias and Alegre 2006), Germany (Solomakhin and Blanke 2007), South Africa (Gindaba and Wand 2007), Slovenia (Jakopic et al. 2007), and Israel (Tanny 2009). However, information on the effects of hail protection nets on the orchard microclimate is inconsistent and varies with site conditions, the screens used and orchard management. Therefore, apple producers in Brazil have been cautious about investing in the use of hail nets for large areas due to the uncertainty of their effects and the high costs of installation.

In addition, hail nets can promote micrometeorological alterations that interfere with plant-environment interactions. The interception of solar radiation by such coverage, for example, tends to alter the balance of energy and radiation on plants and, therefore, interferes with the orchard's microclimate, most likely affecting photosynthesis, yield, and fruit quality (Kittas et al. 2012; Tanny et al. 2009). Microclimate changes in greenhouses tend to modify the water requirement of plants as well as the development of pathogens. The reduced solar radiation due to the use of hail nets can decrease evapotranspiration rates and increase water availability for the crop (Conceição and Marin 2009). On the other hand, the lower radiation inside the canopy reduces the evaporation of free water from the leaves or fruit and increases the risk of fungal diseases (Paula et al. 2012). Given these findings, the management of irrigation and phytosanitary control for plants cultivated under a screen will need to be adapted compared to that used for crops under open sky.

Micrometeorological elements are essential for the growth and development of apple trees, than more research is needed regarding techniques for improving coverage systems and plant management under hail nets and to ensure crop production and crop modelling. Tanny (2003), in a review about microclimate and evapotranpiration of crop covered by agricultural screens, concluded that this system is highly complex because involves various physical, chemical and physiological process at a wide range of scale. In this away he recommended more field measurements in exploring spatial variation in system properties that would be useful in validating and adjusting future agricultural models.

From an extensive bibliographical review about the use of anti-hail nets in orchards, it has been verified that there are scientific results showing that microclimatic modifications occur in a greater or smaller scale in the canopy of plants and, consequently, these modifications can alter the yield of fruits (Leite et al. 2002; Stampar et al. 2002; Middleton and Mcwaters 2002; Dussi et al. 2005; Iglesias and Alegre 2006; Solomakhin and Blanke 2007; Amarante et al. 2011; Bosco et al. 2015). The reduction of solar radiation due to the presence of the hail net, for example, triggers modifications in the environment that will determine accumulation of photoassimilates by the plants influencing the yield. In addition, in hail events, the physical protection of the hail net above the plants will prevent the direct contact of the hail with the fruits, guaranteeing the yield in these conditions. Due to these scientific reasons, the hypothesis of this study was that hail net promotes microclimate and yield changes in apple orchards. The objective was to characterize the →

microclimate and production of apple trees cultivated under hail nets and to consequently generate numeric parameters that can be used in the management of apple orchards and in crop modeling.

MATERIAL AND METHODS

The experiment was conducted in commercial apple orchards in Vacaria municipality, Rio Grande do Sul State, Brazil (930 m elevation; lat 28°24'52,5" S, long 50°50'53,8"W) for three production cycles (2008/2009, 2009/2010 and 2010/2011). According to the Köppen classification, the climate is Cfb – subtropical, with mild summers (Alvares et al. 2013). In this region, the maximum, minimum, and average annual temperature ranges vary widely, and the amount of and number of days with precipitation are evenly distributed throughout the year (Pereira et al. 2009).

The apple cultivar evaluated was 'Royal Gala', which was established in 1999 on M9 rootstock. The orchard was planted at a high density, with 1.0 m spacing between plants and 3.5 m between rows. The plant rows were in a north-south direction, arranged as a pyramid-shaped tree, with tiers and branches spaced along the trunk (central-leader system). Part of the orchard was covered with a black hail net with a mesh of 4 × 7 mm. The hail net was installed on a fixed pitch structure and was open sided, with an opening of 20 cm between the lines for the eventual disposal of hail. The hail net was installed in 2000, one year after the seedlings were planted. The other part of orchard was left without the hail net protection and distanced 15 m. This area was established and managed in a manner identical to the area covered by the hail net, with using the same cultivar and management practices. The orchard management was conducted following the specific technical standards for the Integrated Production of Apple's Ministry of Agriculture, Livestock and Supply of Brazil (NTEPI 2006).

The micrometeorological conditions of the orchards were monitored from September 18, 2008 to April 30, 2011 under open sky and under the hail net in the different canopy strata, covering the entire profile of the plants. In both areas of the orchard, sensors were connected to an automatic data acquisition system with a Campbell AM 416 multiplexer (40 channels), a CR21X datalogger, and an associated storage unit (Campbell Scientific, Logan, Utah). Readings were obtained every 30 seconds and recorded every 30 minutes. The results were tabulated and evaluated in specific data sheets for each measurement variable.

Measurements for photosynthetically active radiation (PAR) were obtained using bars containing five amorphous silicon photovoltaic cells facing upward to measure the incident PAR. The sensors for the measured incident PAR were installed at ground level and at 0.8 m (lower stratum), 1.5 m (middle stratum), and 2.7 m (upper stratum) above the ground; measurements were collected by two bars at each position. Dry bulb and wet bulb air temperatures were measured using copper-constantan thermocouple psychrometers. These sensors were installed at 0.8, 1.5, and 2.7m above the ground; two psychrometers were used at each position and were installed on opposite sides of the canopy. The maximum and minimum daily air temperatures were measured according to the dry bulb temperature of the psychrometers.

Based on the measurements of the dry and wet bulb temperatures (expressed in degrees Celsius), the saturation vapor pressure of the air (hPa) was calculated using the Tetens equation, and the partial vapor pressure of the air (hPa) was calculated with the modified psychrometric equation and relative humidity (%). Additionally, the absolute humidity of the air ($g \cdot m^{-3}$) was calculated based on the air temperature.

Wind speed was measured using one electronic anemometer (Vector A100R, North Wales, United Kingdom) in each environment. These anemometers were installed on top of the canopy at 2.7 m above the ground in both treatments.

An electrical pulse pluviometer (Waterra ARG 100, West Midlands, United Kingdom) was installed at 2.7 m above ground under the hail net to measure rainfall. The rainfall under the open sky treatment was measured using the electrical pulse pluviometer of an automatic weather station (TE525WS, Texas Electronics, Campbell Scientific, Canada) that was installed at 215 m from the experimental area.

The net radiation (Rn) was measured in the upper stratum of the plants from the December 2009 to March 2010 using two net radiometers (NR-Lite-L, Kipp and Zonen and Q7.1, Campbell Scientific), the first installed under open sky and the second under the hail net. →

Calibration procedures for the net radiometers were performed to standardize the measurements before installing the devices in the upper stratum of the trees.

All the fruits from the 10 labeled plants in both treatments were harvested for determining yield components. The harvest was performed during the fruit ripening stage, taking into account the content of soluble solids (minimum of 12 °Brix) and the visual assessment of fruit color. The harvest of 'Royal Gala' fruits under hail net was performed on 3/4/2009, 2/18/2010, and 3/18/2011. In the open sky treatment, the fruits were harvested on 2/17/2009 and 2/4/2010; however, there was no harvest for the 2010/2011 cycle due to a total loss of fruits caused by one hailstorm event. After harvest, the fruits of each plant were counted and weighed to obtain the number and average weight of fruits per plant. The fruit yield ($t{\cdot}ha^{-1}$) was calculated, considering an area of 3.5 m^2 for each plant.

After the hailstorm event occurred in the apple orchard in November 2010, the severity of the damage to the fruit harvested from the upper and lower strata of the canopy in both environments was evaluated. Three levels of fruit damage severity were considered: mild = superficial lesions without epidermis rupture; moderate = lesions ruptured in less than 50% of the epidermis; and severe = lesions with rupture of more than 50% of the epidermis.

The averages of variables in each treatment were subjected to Bartlett, Kolmogorov-Smirnov and Durbin-Watson tests to verify the homogeneity of variance, normal distribution, and independence of the data, respectively (Schneider 1998). These conditions were confirmed for all data.

The mean values of PAR, air temperature, and air humidity were subjected to analyses of variance to quantify the effect of variation sources (environment and canopy stratum), as each cycle analysis was performed separately. When this analysis was significant (by the F-test), separation of the means was performed using Tukey's test. Statistical significance was tested at a 5% probability of error. For these analyses, 19 periods of 10-day averages were considered as replications in each environment and each stratum of the canopy (Pimentel-Gomes and Garcia 2002).

To quantify the effect of the environment with regard to wind speed, rainfall, global solar radiation and net radiation, linear regression by the F-test was used.

Number of fruits per plant, average fruit fresh weight, yield and severity were subjected to analyses of variance to quantify the effect of the cropping environment. When the effect of the treatment was significant (by the F-test), separation of the means was performed using Tukey's test. The statistical significance was tested at a 5% probability of error. Data for the severity of damaged fruit in % were transformed into arcsen $\sqrt{x/100}$ for statistical analysis in order to meet normality assumption.

RESULTS AND DISCUSSION

Of the global solar radiation (Rg) incident on the apple orchards analyzed in this study, 79% corresponded to the net radiation (Rn) available to the orchard under the open sky and 75% to the Rn of the orchard under the anti-hail net. The linear coefficient of the regression between Rn and Rg was more negative in the open sky environment than under anti-hail net (Figure 1a). This

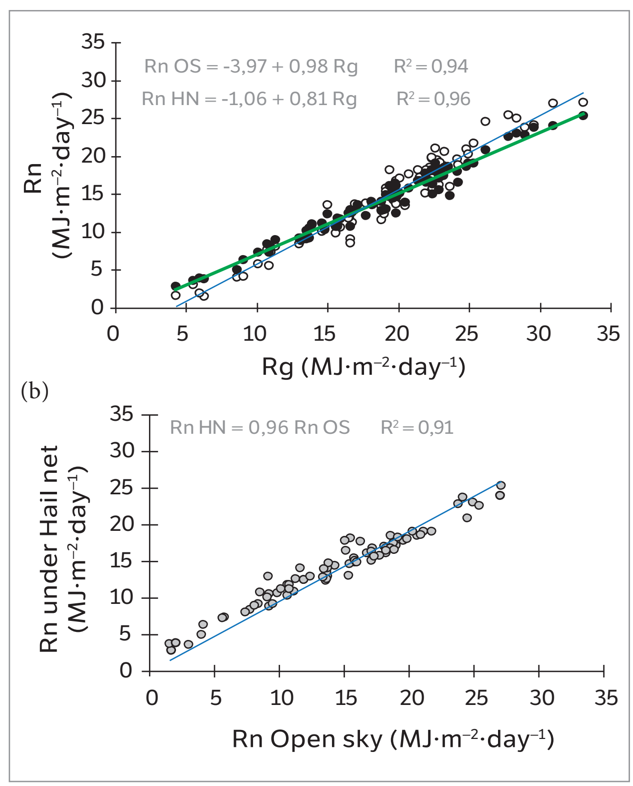

Figure 1. Relationship between (a) net radiation (Rn) and global solar radiation (Rg); and relationship between (b) Rn in apple orchard 'Royal Gala' under hail net (HN) and open sky (OS) in the period from December 2009 to March 2010. In (a) the black line represents the trend line of data under hail net, gray line trend line data in the open sky. Linear regressions were significant by the F-test ($p \leq 0.05$).

coefficient indicates that longwave radiation loss was lower under the anti-hail net than under the open sky. It was found that net radiation tended to be lower under the anti-hail net when Rg was high and increased under conditions of reduced availability of Rg. Although the trend indicated that Rn under the open sky was 4% higher than Rn under the hail net, it can be stated that under reduced availability of radiation (up to 15 $MJ \cdot m^{-2} \cdot day^{-1}$), the Rn in environment under the anti-hail net was higher (Figure 1b).

The hail net reduced the incident PAR on the apple tree canopy strata. An interaction occurred between the environment and the canopy stratum. In the upper stratum of the covered canopy, the incident PAR was reduced by 27.4%, 33.8%, and 37.3% in the 2008/2009, 2009/2010, and 2010/2011 cycles, respectively. In the other canopy strata, a reduction in the incident radiation was observed between the environments but only in the 2009/2010 and 2010/2011 cycles (Table 1). During these cycles, a large amount of cloudiness and rainfall interfered with the incoming solar radiation and, consequently, with the PAR intercepted by the hail net. Strata interactions occurred for the incident PAR at the middle, lower, and ground levels of the canopy. This interaction of solar radiation with the canopy varied due to the planting density and conduction system of plants, as also observed by Robinson et al. (2007) and Yang et al. (2016). The orchards in the current study were arranged as a central-leader system and a high plant density, which is common in apple production regions of Southern Brazil. In this system, the larger branches are in the lower stratum, thus avoiding excessive shading of the plants. Moreover, the wide spacing among rows of plants (3.5 m) allows for the distribution of incoming solar radiation to the lower strata of the canopy.

In the analyses of variance, the differences in maximum, average, and minimum air temperatures were not significant for the environment and canopy stratum factors (Table 2). In the 2008/2009 production cycle, increases of 0.3 °C in the average air temperature and 0.2 °C in the minimum air temperature were observed in the covered orchard (compared to the open sky orchard). In the 2009/2010 cycle, there was a reduction of 0.4 °C in the maximum air temperature under the hail net and increases of 0.9 °C in the average air temperature and 0.5 °C in the minimum air temperature. In the 2010/2011 cycle, the average air temperature under the hail net was 0.5 °C lower than under open sky, though the minimum air temperature was 0.4 °C higher (Table 2). Therefore, reductions in the incident PAR in the covered canopy did not result in large changes in air temperature. The air temperature under a plastic screen in São Paulo, Brazil, conducted in a small cultivated area of only 0.7 ha did not differ from that under open sky (Conceição and Marin 2009).

In the three production cycles, the partial vapor pressure and absolute humidity showed no interaction among the environments and stratum factors. The partial vapor pressure and absolute humidity were higher under the hail net than under open sky only in the 2010/2011 cycle (Table 3). This occurred because there was a lower incidence of solar radiation during this cycle compared to the previous cycles, and the environmental factor (coverage) showed a significant effect in this case.

There was an interaction among the environmental (coverage) and stratum factors with regard to the relative humidity in the 2008/2009 and 2010/2011 cycles. The relative humidity was 4% lower under the hail net than under open sky for the upper stratum in the 2008/2009 cycle. However, the relative humidity in the 2009/2010 →

Table 1. Incident Photosynthetic Active Radiation (PAR) on the upper (2.7 m), middle (1.5 m), lower (0.8 m), and ground level stratum of the canopy in 'Royal Gala' apple trees in open sky and under hail net protection, in the 2008/2009, 2009/2010 e 2010/2011 vegetative cycles.

PAR ($MJ \cdot m^{-2} \cdot day^{-1}$) – 2008/2009 cycle			PAR ($MJ \cdot m^{-2} \cdot day^{-1}$) – 2009/2010 cycle			PAR ($MJ \cdot m^{-2} \cdot day^{-1}$) – 2010/2011 cycle		
Stratum canopy	Open sky	Hail net	Stratum canopy	Open sky	Hail net	Stratum canopy	Open sky	Hail net
Upper	7.3 Aa	5.3 Ab	Upper	7.4 Aa	4.9 Ab	Upper	6.7 Aa	4.2 Ab
Middle	2.5 Ba	2.6 Ba	Middle	2.5 Ba	1.8 Bb	Middle	2.2 Ba	1.4 Bb
Lower	2.0 Ca	2.0 Ca	Lower	1.6 Ca	1.2Cb	Lower	1.6 BCa	1.1 BCb
Ground level	1.9 Ca	1.6 Ca	Ground level	1.3 Ca	0.8 Cb	Ground level	1.2 Ca	0.7 Cb

Uppercase letters in the column and lowercase letters in the line, when different, indicate statistically significant differences by Tukey's test ($p \leq 0.05$).

cycle was 3% higher under the hail net than the open sky. In the 2010/2011 cycle, the relative humidity in all strata was higher under the hail net than under open sky (Table 3). Under identical conditions, in the 2009/2010 vegetative cycle, Paula et al. (2012) found that the duration of leaf wetness in 'Royal Gala' apple trees - a parameter directly related to the air humidity and wind speed for all strata of the canopy - was higher under hail

Table 2. Maximum (Tmax), average (Tavg), and minimum (Tmin) air temperatures in different strata of apple orchard cv. 'Royal Gala' in open sky (OS) and under hail net protection (HN) in the 2008/2009, 2009/2010 and 2010/2011 vegetative cycles.

Stratum canopy	Tmax (°C)			Tavg (°C)			Tmin (°C)		
	OS	HN	Mean	OS	HN	Mean	OS	HN	Mean
2008/2009 cycle									
Upper	26.5	26.7	26.6	18.3	18.9	18.6	13.4	13.6	13.5
Middle	27.5	26.8	27.2	19.0	19.0	19.0	13.5	13.7	13.6
Lower	26.4	27.0	26.7	18.8	19.0	18.9	13.6	13.8	13.7
Mean	26.8	26.8		18.7	19.0		13.5	13.7	
2009/2010 cycle									
Upper	28.6	27.7	28.2	19.6	20.3	20.0	14.7	15.1	14.9
Middle	28.2	27.7	28.0	19.4	20.4	19.9	14.8	15.2	15.0
Lower	27.6	27.6	27.6	19.6	20.3	20.0	14.6	15.3	15.0
Mean	28.1	27.7		19.5	20.4		14.7	15.2	
2010/2011 cycle									
Upper	*	27.4	*	19.3	19.0	19.2	13.3	13.7	13.5
Middle	*	27.1	*	19.2	18.5	18.9	13.3	13.4	13.4
Lower	*	27.0	*	19.2	19.0	19.1	13.4	14.4	13.9
Mean	*	27.2		19.3	18.8		13.4	13.8	

Absence of letters in the columns and lines show that the differences were not significant for effect of the sources variation environment and canopy stratum (by the F-test). The asterisk (*) indicates not available data.

Table 3. Partial vapor pressure (*e*), absolute humidity (AH), and relative humidity (RH) in different strata of apple orchard 'Royal Gala' in open sky (OS) and under hail net protection (HN), in 2008/2009, 2009/2010, and 2010/2011 vegetative cycles.

Stratum canopy	e (mm Hg)			AH ($g{\cdot}m^{-3}$)			RH (%)		
	OS	HN	Mean	OS	HN	Mean	OS	HN	Mean
2008/2009 cycle									
Upper	14.6	14.0	14.3A	14.4	13.8	14.1A	89Aa	85Ab	-
Middle	14.0	14.0	14.0A	13.8	13.8	13.8A	85Ba	85Aa	-
Lower	13.9	14.2	14.1A	13.7	14.0	13.9A	85Ba	86Aa	-
Mean	14.2a	14.1a		14.0a	13.9a		-	-	
2009/2010 cycle									
Upper	15.6	15.1	15.4A	15.3	14.8	15.1A	88	90	89A
Middle	14.9	15.6	15.3A	14.7	15.4	15.1A	86	89	88A
Lower	15.5	15.8	15.7A	15.2	15.5	15.4A	88	90	89A
Mean	15.3a	15.5a		15.1a	15.2a		87b	90a	
2010/2011 cycle									
Upper	15.0	15.2	15.1A	14.8	15.0	14.9A	88Ab	94Aa	-
Middle	15.2	16.2	15.7A	14.9	16.0	15.5A	89Ab	92Aa	-
Lower	14.2	15.5	14.9A	14.0	15.5	14.8A	85Bb	93Aa	-
Mean	14.8b	15.6a		14.6b	15.5a		-	-	

Uppercase letters in the column and lowercase letters on the line, when different, indicate statistically significant differences among means by Tukey's test ($p \leq 0.05$). The hyphen (-) indicates that occurred interaction between stratum and environment.

nets than under open sky. Thus, a hail net can provide increased air humidity, depending on the conditions of solar radiation, air temperature, wind speed and rainfall.

In the orchard under the hail net, the wind speed at 2.7 m above the soil level was, on average, reduced by 30% compared to the orchard under open sky (Figure 2a, b,c). These effects were similar to those found in Australia, where a 50% reduction in wind speed under hail nets was reported (Middleton and Mcwaters 2002).

Rainfall interception by hail nets has not been reported in studies investigating micrometeorological changes in orchards. However, this factor is important because it is directly related to the crop water balance and the air humidity in the canopy. The results of this study demonstrate that the hail net did not promote changes in the incident rainfall on the upper stratum of the orchard (Figure 2d,e,f).

In terms of apple production, a higher number of fruits per plant and greater yield occurred under the hail net in the 2008/2009 cycle, though a smaller fruit weight compared to open sky was observed. In the 2009/2010 cycle, the yield components and fruit yield did not differ between the environments. An intense hailstorm occurred in the experimental area during the 2010/2011

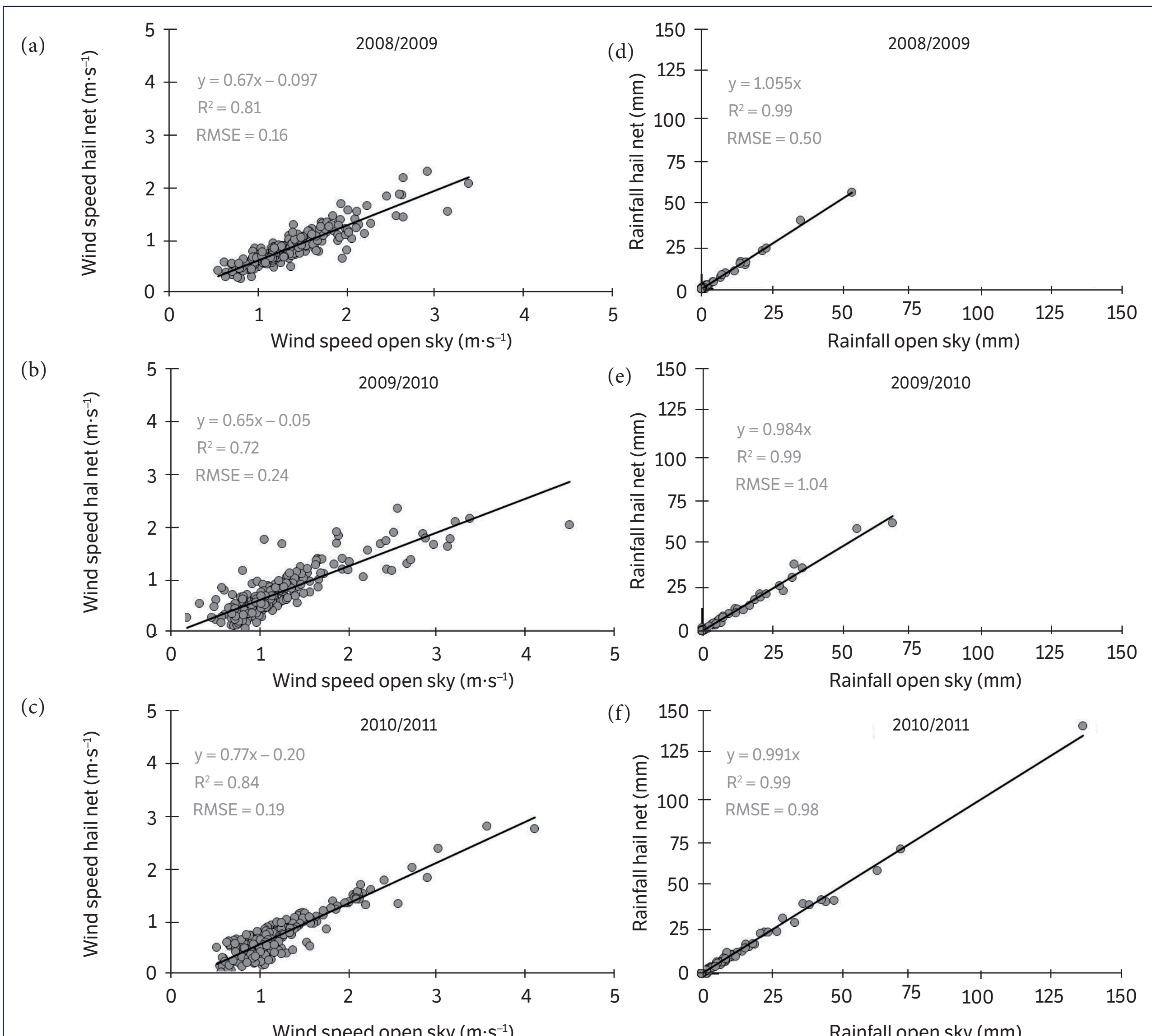

Figure 2. (a,b,c) Average wind speed and (d,e,f) rainfall in apple orchards of 'Royal Gala' apple trees in open sky and under hail net protection, in 2008/2009, 2009/2010 and 2010/2011 vegetative cycles. Linear regressions were significant by the F-test ($p \leq 0.05$).

cycle, which caused a total loss in fruit production in the open sky treatment. In contrast, production by the orchard under the anti-hail net was not affected by the hailstorm (Table 4).

In the severity analysis of 'Royal Gala' fruit, a higher percentage of fruit damage at the moderate and severe levels under open sky occurred, whereas almost all damage severity to the fruits under the anti-hail net was mild (Table 5). The severe level of damage was higher in the upper stratum of the trees under the open sky environment. Under the anti-hail net, the mild level of damage was found in a greater proportion in the lower stratum, and the damage to fruit under the hail net did not reduce production to destination in natura. However, in the orchard under the open sky, all the fruits were damaged and thus were only used by the fruit juice industry, reducing the production of the 2010/2011 cycle.

Table 4. Number of fruits per plant, average fresh weight of fruit and yield of 'Royal Gala' apple orchards under in open sky and under hail net protection, in 2008/2009, 2009/2010 and 2010/2011 vegetative cycles.

Environment	Number of fruits/plant	Fruit weight (g)	Yield ($t \cdot ha^{-1}$)
	2008/2009 cycle		
Open sky	150B	137.9A	59.3B
Hail net	231A	123.8B	90.0A
Mean	191	130.9	74.7
	2009/2010 cycle		
Open sky	66A	161.1A	30.9A
Hail net	84A	142.8A	36.2A
Mean	75	152.0	33.6
	2010/2011 cycle		
Open sky	-	-	-
Hail net	211	157.3	95.2
Mean	-	-	

Different uppercase letters in the column of each cycle indicate statistically significant differences by Tukey's test ($p \leq 0.05$). The hyphen (-) indicates no data due to the total loss of production in open sky, because of hail precipitation.

The hypothesis that covering apple orchards with hail net promotes microclimate changes was tested in the present study, particularly with regard to the incoming solar radiation and, consequently, the air temperature and humidity. The microclimate measurements showed a reduction in incident PAR in different strata of the plants, but the maximum, average, and minimum air temperatures and air humidity were little affected. In Slovenia, studies with a black hail net in apple orchards showed an average PAR reduction of 37.5% (Jakopic et al. 2007). In Germany, however, the reduction of PAR ranged between 12% and 23% under hail nets of different colors (Solomakhin and Blanke 2007). Another study in Southern Brazil utilizing white hail nets reported an average PAR reduction of 18.4% (Amarante et al. 2011). These results confirm the assertion that the effects of coverage on the microclimate of orchards are complex and vary according to the local meteorological conditions and to the characteristics of the hail net.

Reductions in air temperature were found in other studies using hail nets (Leite et al. 2002; Middleton and Mcwaters 2002; Solomakhin and Blanke 2007; Tanny et al. 2009). However, some of these results were obtained on only a few days during the cycle. In this work, data obtained continuously throughout three production cycles showed no differences in air temperature when comparing environments with or without hail net coverage. Furthermore, no trend air temperature being higher or lower under the hail net was found in the literature, indicating that the effect from hail net on air temperature is more complex than others meteorological elements. Tanny (2013), in a review about microclimate of crops covered by agricultural screen, explained that in theory the shading effect of screens reduces solar radiation and subsequently reduce air temperature, but studies show that this effect is not always really because the income air temperature is integrated with several energy transfer processes that occurs outcome.

→

Table 5. Severity of damage to fruit caused by 2010/2011 hailstorm in upper and lower strata in apple plant 'Royal Gala' under anti-hail net and open sky.

Environment	Mild (%)			Moderate (%)			Severe (%)		
	Upper	Lower	Mean	Upper	Lower	Mean	Upper	Lower	Mean
Open sky	10	28	19B	44	54	49A	46	18	32A
Hail net	41	64	53A	0	4	2B	0	0	0B
Mean	26a	46a		22a	29a		23a	9b	

Uppercase letters in the column and lowercase letters on the line, when different, indicate statistically significant differences among means by Tukey's test ($p \leq 0.05$).

The evaluations related to rainfall and wind speed under hail nets in the present study are unprecedented. Rain precipitation is directly related to crop water balance and to the air humidity in the canopy. The wind speed was reduced by 30% under the hail net, suggesting a reduction in wind gusts, an effect that can reduce the risk of mechanical damage to an orchard and reduce pesticides application (Middleton and Mcwaters 2002; Tanny 2013). Wind is responsible for renewing and homogenizing the air in contact with leaf surfaces, occurring to decrease in wind speed in an orchard covered with a hail net may be a lower atmospheric evaporative demand and, consequently, lower evapotranspiration, increase water use efficiency and favor pollinators activities. Whereas in the same place of this study, Paula et al. (2012) concluded that there was a longer duration of leaf wetness under the hail net than open sky. The prolong leaf wetness under the hail net, providing favorable conditions for the development of pathogens. Than a longer duration of leaf wetness under the hail net could be attributed to the decrease in air renewal in this environment compared to open sky. The alteration of wind speed was a potentially interesting finding which could have raised questions such as the link to fruit set (pollination success), overall fruit quality (e.g. disease pressure, wind damage), changes in leaf boundary layer and thus stomatal conductance and transpirations rates, soil water evaporation, and thus fundamentally different orchard energy balance and water balance.

The yield of apple fruits grown under the hail net and under open sky was mainly affected by the efficiency of hail net protection and little influenced by changes in the microclimate (PAR and wind speed). The factors that appear to control the fruit yield of apple are the quantity of light energy that is intercepted by an orchard system, the proportion of that energy that is converted into available carbohydrate for partitioning and the amount of assimilate allocated to fruits (Lakso 1994; Stephan et al. 2008; Yang et al. 2016). The average incoming PAR in Vacaria, Southern Brazil, in the three spring-summer periods ranged between 7.4 $MJ \cdot m^{-2} \cdot day^{-1}$ under open sky and 4.2 $MJ \cdot m^{-2} \cdot day^{-1}$ under the hail net. The interception of solar radiation by plants is considered critical for achieving the productive potential and fruit quality, and this radiation should be efficiently converted into dry matter through physiological processes to enhance fruit production (Cherbiy-Hoffmann et al. 2012; Iuchi 2006). Light interception and distribution are determined by a complex interplay of factors. Previous work has established that PAR interception and distribution in apple orchard system depends on orchard design factors such as alley width, row orientation, tree shape, tree spacing, tree height, leaf area index and length of the growing season (Lakso 1994; Palmer 1989; Wagenmakersa and Wertheimb 1991). Planting system are achieved by north-south row orientation, medium-high tree density, square tree layout, and dwarf trees with canopies of low leaf area density that spread over adjacent alleys (Grapadelli 2003; Hampson et al. 2002). Orchards with these characteristics are able to intercept a large amount of radiation and, consequently, exhibit high production because of the balance between vegetative and reproductive growth. In this study in Southern Brazil, the canopy management and layout employed for plants under hail nets appear to promote the optimization of tree canopy light interception and carbohydrate partitioning in support of potential fruit growth. In a complementary study to this, about the fruit quality assessments, was possible conclude that a reduction in solar radiation under a black hail net did not alter the quality of fruits but only caused a delay in the maturation process (Bosco et al. 2015).

The data presented in this study are from field research, representing the real influence of microclimate events on fruit yield cultivated under prevailing management at Southern Brazil. Variability in microclimate and production at the same place from year to year was observed. Thus, it was necessary to use high quality data sets for each condition to recognize the dynamics and interaction of the meteorological and biological processes of plants.

CONCLUSION

The hail nets reduced the incident radiation and the wind speed in apple orchard but did not alter the air temperature, humidity or rainfall. The reduce of the wind speed in 30% may increase the incidence of pathogens, decrease the evapotranspiration and improves pollinated, indicating different management for diseases and irrigation in plants cultivated under hail net than open sky. In this case it is essential to the development new research in phytopathology, agrometeorology and entomology to better guide the management of plants.

The use of hail protection nets in cropping systems with maximum efficiency interception of solar radiation is required to mitigate or prevent fruit loss and plants damage caused by hailstorms. The yield of apples tends to be higher under hail net and this is more pronounced when one hailstorm event occurs. It has been hypothesized that the damage caused to hailstorm on plants may affect production in the following years and their lifespan, than its necessary future research about this assumption.

These results are important for researchers, extension agents, and apple farmers to establish criteria for decision making regarding the implementation of hail net coverage and to develop appropriate management systems for protecting orchards to ensure and improve fruit production. Overall, the effects of long-term micrometeorological factors are essential to perform modeling of agricultural production and to account variations in the growth and development of plants, as well as in the physical and chemical qualities of fruits produced under a protective hail net.

ACKNOWLEDGMENTS

This research was supported by Brazilian Research and Technology Council (CNPq).

The authors thanks our colleagues Dr. Gilmar Ribeiro Nachtigall and Dr. Henrique Pessoa dos Santos for technical assistance and *Schio Agropecuária* for the commercial orchard used in this research.

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