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The influence of differently coloured anti-hail nets and geomorphologic characteristics on microclimatic and light conditions in apple orchards

Vpliv različnih barv protitočnih mrež in geomorfoloških lastnosti na mikroklimatske in svetlobne razmere v nasadu jablan

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ABSTRACT

Geomorphologic characteristics like altitude and terrain slope have an important but often neglected impact on light conditions in orchards. The study concentrated on the impact of altitude and terrain slope in combination with various colours of anti-hail nets (red, grey, blue, green and black) on the light and microclimate conditions in apple orchards. The results exhibit a large reduction of the photosynthetically active radiation (PAR) under the nets, most prominently under blue and red nets (reduction between 38.7 and 45.6%), while the impact of coloured nets on other microclimatic parameters (average air temperature, relative air humidity, temperature of dew point, wet-bulb temperature, heat index, minimum air temperature, maximum air temperature) remain irrelevant. The only consistent difference is an average of 2% increase of maximum air temperature under the blue net in comparison to other treatments. The use of the net also significantly reduce the wind speed (on average by 56.3%) and air flow (on average by 63.4%), and changes the distribution of precipitation in the orchard, most prominently in cases of heavy rain and drizzle. Regarding the orchard's geomorphologic characteristics, a positive relationship exists between altitude and PAR.

Keywords: apple orchard, coloured anti-hail nets, light intensity, microclimate, terrain altitude, terrain slope

IZVLEČEK

Geomorfološke lastnosti, kot so nadmorska višina in naklon terena, imajo pomemben in pogosto spregledan vpliv na svetlobne razmere v nasadih. V raziskavi je bil preučevan vpliv nadmorske višine in naklona terena v kombinaciji z različnimi barvami protitočnih mrež (rdeča, siva, modra, zelena in črna) na svetlobne in mikroklimatske razmere v nasadu jablan. Rezultati kažejo veliko zmanjšanje fotosintetskega aktivnega sevanja (PAR) pod mrežami. Najbolj izrazito zmanjšanje PAR je pod modro in rdečo mrežo (med 38,7 in 45,6%). Vpliv barvnih mrež na druge mikroklimatske parametre (povprečna temperatura zraka, relativna zračna vlažnost, temperatura rosišča, temperaturna točka vodne kapljice, indeks toplote, minimalna temperatura zraka, maksimalna temperatura zraka) je neizrazit. Glede na ostala obravnavanja je ugotovljena le konsistentna in v povprečju za 2% višja maksimalna temperatura zraka pod modro mrežo. Uporaba mrež tudi bistveno zmanjša hitrost vetra (v povprečju za 56,3%) in pretok zraka (v povprečju za 63,4%) ter spremeni porazdelitev padavin v sadovnjaku, najizraziteje v primeru močnega dežja in rosenja. Glede na geomorfološke značilnosti sadovnjaka je ugotovljena pozitivna povezanost med nadmorsko višino in PAR.

Ključne riječi: nasad jablan, barvne protitočne mreže, intenzivnost svetlobe, mikroklima, nadmorska višina terena, naklon terena

INTRODUCTION

The use of anti-hail nets in apple tree orchards is a suitable possibility for protecting the apple trees and the yield against hail. In existing literature, different information regarding the influence of nets on microclimatic conditions in apple orchard can be found, some also contradictory. Since nets became a standard part of orchard equipment, there have been many questions regarding the practical use and impact of anti-hail nets of different colours. Is it only about environmental impression? How does the net's colour actually influence the conditions in the orchard and could the use of some types of nets also present risks for production?

It is generally accepted fact that anti-hail nets reduce photosynthetically active radiation (PAR). Conclusions about the influence of different colour of anti-hail nets on PAR vary greatly between different authors. These differences could be the result of different colour of the nets, different knitting patterns of anti-hail nets, differences in materials used and the spectral characteristics of the nets. According to Blanke (2007) in two coloured nets the measurement of PAR can be significantly influenced by the ratio of transparent and black fibres in the nets used. Most often the biggest PAR reduction has been reported under the black (Iglesias and Alegre (2006) (25%) and green-black net (Solomakhin et al., 2012) (20%). Red and blue nets reduced the PAR (with respect to the white net) in the same proportion (27%) (Bastias et al., 2012). When using the white nets 11–14% of PAR reduction is reported (Solomakhin and Blanke, 2011; Solomakhin et al., 2012), comparable to red-white, grey and green net (Blanke, 2009). According to reports from Agrintech (2017), the smallest PAR reduction is caused by using pearl (7%) and yellow net (4%).

Several authors have studied the influence of anti-hail nets (also of different colour) on the microclimatic conditions in the orchard and consequently on fruit quality. Some of them agree that anti-hail nets cause a reduction in average air temperature (Tavg) (Štampar et al., 2002; Elad et al., 2007; Solomakhin and Blanke, 2008, 2009; Ilić et al., 2012; Milivojević et al., 2016; Ilić et al., 2017). Tinyane et al. (2013) and Ben Yakir et al. (2012) report a higher Tavg under the yellow, pearl and red nets in comparison to black nets. Mashabela et al. (2015) report that Tavg under the yellow net is higher in comparison with the red, pearl and black nets.

According to Shahak et al. (2004), Iglesias and Alegre (2006), and Milanović et al. (2014) the presence of anti-hail net results in a lower maximum air temperature (Tmax), while Zadravec et al. (2009) have the opposite opinion. Minimum air temperature (Tmin) is the parameter which provides more uniform opinions among the researchers; apparently anti-hail net slightly increases Tmin in the orchard (Iglesias and Alegre, 2006; Zadravec et al., 2009; and Milanović et al., 2014).

Several authors agree that the use of anti-hail nets results in a higher relative air humidity (rh) (Shahak et al., 2004; Zadravec et al., 2009; Solomakhin and Blanke, 2011; Gaurav et al., 2016; Rambuda et al., 2017) and a longer persistence of a dew (Muntean, 2018). Again, there is a contradictory opinion which connects anti-hail nets to a lower rh and occasional absence of dew (Zadravec et al., 2009; Solomakhin and Blanke, 2009; Ilić et al., 2012, 2017). The colour of the net should also have an impact on rh; Mashabela et al. (2015) recorded lower rh under the yellow net in comparison with the red, pearl and black nets, whereas Ben Yakir et al. (2012) and Tinyane et al. (2013) report a lower rh under yellow, pearl and red nets in comparison with black nets.

Geomorphological characteristics of the orchard also contribute to some of the changes in microclimatic and light responses. Higher altitude reduces air temperature (Zang et al., 2007) and increases sunlight (Gale, 2004). Vršič and Lešnik (2005) report a reduction of mid-year temperatures of 0.5-0.6 °C for every 100 meters of altitude difference. Štampar et al. (2009) record a worse light exposure of trees on the northern hillside, which increases with growing terrain slope.

The available literature concerning microclimatic conditions under anti-hail nets is very modest on precipitation quantities and distribution, even though this parameter, as reported by Bosco et al. (2017), is directly connected to water balance and rh in treetops. Zadravec et al. (2009), who reported a smaller quantity of precipitation when using nets, believe that the change in precipitation measurements is the result of measuring accuracy of the instrument used. They predict that, in cases of very low precipitation, a portion of rain is "intercepted" by the net, where it also evaporates – therefore actually not falling on the plants and floor in the orchard under the net. Bosco et al. (2017) report no changes in precipitation quantities when covering the orchard with anti-hail nets.

The findings concerning the influence on anti-hail nets on microclimatic conditions in the orchard are not consistent, while all authors agree about strong reduction of the wind in the orchard under the net (Gordon, 2012; Milanović et al., 2014; McCaskill et al., 2016; Bosco et al., 2017; Ilić et al., 2017). According to Bosco et al. (2017), changes in wind speed can significantly influence the stomatal conductance, transpiration, energy and water balance, as well as pollination success. It is anticipated that information about the microclimate as well as the wind conditions are partly a consequence of different knitting pattern, materials used, the net's construction; all these parameters could cause differences in the results.

The collected data, directly connected to geomorphologic characteristics of the orchard, is going to more clearly define the less well researched effects of coloured anti-hail nets on light and microclimatic conditions in apple orchards, which are going to be influenced by ever greater climate change in the future.

MATERIALS AND METHODS

Trial orchard characteristics and trial design

The study of geomorphologic characteristics and influence of different colours of anti- hail nets on microclimatic parameters in apple orchards was carried out between 2015 and 2018 in an intensive apple orchard of the variety 'Braeburn Maririred'/M9 (46°23′ N, 15°26′ E, 385 MASL, Slovenia). The area where the orchard is located is known for its moderate continental climate, which is the result of diverse landscape and transitory position between the Alps and Pannonian Plain in Slovenia (Lešnik Štuhec, 2016).

The trial was conducted between the 8th and 10th growing seasons of the apple trees. The trees were planted in single rows with planting distances of 3.5 m × 1.0 m. The trees were planted with a north-south orientation. The trees were trained and pruned as slender spindle. The area under the trees (30 cm from the trees) was treated with herbicides. A drip irrigation system was installed and the trees were treated for pests and diseases according to the system of integrated crop production (standard commercial practice) (Ministry of Agriculture, Forestry and Food, 2019).

The trial was designed in accordance with the system of random blocks and included six treatments. The treatments represented the red, grey, blue, green and black nets and control / no net. Each treatment included 4 blocks. In each block 10 trees of similar growth and yield potential were chosen. The plot on which the whole trial was conducted encompassed 840 m^2 (6 treatments × 140 m^2).

Technical characteristics of the anti-hail system and coloured anti-hail nets

The anti-hail system in the trial was designed to fully cover the apple trees with a support and a 30% roofing slope. The supporting construction for the trial anti-hail nets was composed of impregnated wooden 4 m long pillars which were fixed at a depth of 0.7 m. The installation of the coloured anti-hail nets (with a binding clip weight tolerance of 70 kg/m^2 on a 1.5 m distance) on a height of 3.3 m above ground was conducted in April 2015. The anti-hail nets were in open position from the end of blooming (May) until the end of October.

The nets in the trial were created from highly compressed polyethylene fibres. All coloured nets used in the trial had the same mesh size (8 × 4 mm length and width, respectively) and thread thickness (320 μm). The anti-hail nets were constructed from double woven longitudinal and single transverse fibres. The longitudinal fibres, parallel to the tree rows, were intertwined twice for better mechanic durability and were coloured white in the grey net and black in the red, green, blue and black nets.

The latter's colour shades (red, blue, green and black) coincided with the individual colour types of the nets. The transverse fibre in the grey net was black. The nets were manufactured by Agrintech Srl, Eboli (SA), Italy.

Geomorphologic characteristics of the trial orchard

With the aid of an electronic tachymeters Leica 1201 and Leica GPS 1200+ (Leica Geosystems AG, Heerbrugg, Switzerland) it was determined two geomorphologic characteristics of the trial orchard on 06th September, 2016: altitude and terrain slope. To determine altitude, a starting point in the beginning of the row was selected and its altitude was determined with the GNSS (Global Navigation Satellite System), which was then used as the starting point for determining the altitudes of other points and slopes. To determine slopes, starting and terminal points were chosen in each tree row. Based on trigonometric approach, distances and altitude differences between the chosen points were determined (Breznikar,1996).

Measurements of PAR in the orchard

In the orchard, the measurements of PAR were carried out with the ceptometer AccuPAR LP-80 (Decagon Devices, Inc., Pullman, WA, USA) on a sunny day, on the first of July, 2015, in morning hours (from 8:19 to 8:42). At the time of the PAR measurements, the air temperature was 21.5 °C and rh was 70%. PAR measurements were repeated three times in each block, representing 12 measurements in a single treatment and 72 measurements in the whole trial.

The measurements of Tavg and rh

The T (average, Tmax, Tmin) and rh it was measured for 35 days from 14th June, 2017 to 18th July, 2017. Prior to beginning the measurements, thermometers and hygrometers (TH101E Analogue Thermometer/ Hygrometer, TFA Dostmann GmbH & Co. KG, Wertheim-Reicholzheim, Germany) which were used for measuring Tavg (in °C) and rh (in %) were installed on the supporting pillars. The instruments were placed 1.7 m above the soil surface in 24 locations in the trial, i.e., in each block of the individual treatment. The Tavg and rh data were manually recorded daily at 7:00, 14:00 and 21:00.

To measure Tmax and Tmin TFA Dostmann thermometers (TFA Dostmann GmbH & Co. KG, Wertheim-Reicholzheim, Germany) were placed on the supporting pillars of the anti-hail system on a height of 1.7 m from the ground. The data were manually recorded each day at 21:00.

The measurements of the wind parameters, heat index, the temperature of the dew point and the wet-bulb temperature

For the measurements of the wind speed (m/s), the air flow (m^3/h), the dew point (°C), the wet-bulb temperature (°C) and heat index (°C), the multifunctional transportable meter - Environment meter SP-9201 (Advancom Electronics Technologies, Puchong, Selangor, Malaysia) was used. The parameters recorded in two distinct situations (under the net and outside the net). Additionally, the intensity of the wind power was measured (>2.5 m/s – strong wind, 1.1–2.5 m/s – median wind, ≤ 1 m/s – weak wind). Prior to measuring, two points in the trial orchard were marked - under the net and outside of the net – at the height of 1.5 m from the ground. These two points represented places for the repeated measurements of the abovementioned parameters. The data were manually recorded daily at 7:00, 14:00 and 21:00, in a period of 35 days (from 14th June, 2017 to 18th July, 2017).

Measurements of precipitation distribution

The monitoring of differences in precipitation quantities (l/m^2) under and outside the net took place from 17th July, 2018 to 4th November, 2018. Before starting the measuring, measuring instruments were installed in four locations in the orchard: 1. outside the net, 2. under the net – on the edge of herbicide strip (30 cm from the trunk), 3. under the net – the driving lane (85 cm from the trunk), 4. under the net – in the middle between two rows (under the part where the anti-hail nets are tied together, ca. 175 cm from the trunk). These were used to monitor precipitation in cases of drizzle, medium and heavy rains. Data concerning precipitation quantities were manually recorded.

Statistical analysis

The information regarding microclimatic parameters and PAR measurements was processed with the programs Microsoft Excel 2016 and Statgraphics Centurion XV (Statpoint Technologies, Inc., Herndon, VA, USA). For the individual parameters, the basic statistic parameter ware calculated (arithmetic mean and standard deviation of dependant variable).

The mean values, measured under different coloured anti-hail nets (PAR, Tavg, Tmax, Tmin and rh) and precipitation quantities (measured in three locations under the net – independent of colour and on the location without the net) were compared to the Tukey test. The t – test was used to compare the mean values of the data measured in two situations – under the net (independent of colour) and outside the net (wind parameters, temperature of the dew point, wet-bulb temperature and heat index). All statistical methods used – based on the results of some of the studied parameters – confirmed the statistically characteristic differences ($P \leq 0.05$).

The parameter data measured under various coloured nets (Tavg, rh, Tmax, Tmin and PAR) were processed with the multivariate method – discriminant analysis, which was used to determine variables that influenced the differentiation between treatments the most.

RESULTS

Evaluation of light parameters in the orchard as a result of different colours of anti-hail nets

Anti-hail nets, independent of colour, significantly reduced PAR (Table 1) in comparison to the control / no net, where PAR reached an average value of 1 052 µmol/m^{2}s. The biggest reduction of PAR (compared with the control) was recorded under the red net (45.6%), while the smallest PAR reduction was recorded under the black net (24.8%). Blue, grey and green nets resulted in a statistically comparable PAR by reducing it by 36.3% compared to the control / no net.

Impact of geomorphologic characteristics on PAR and microclimatic condition

Considering the geomorphological characteristics of the orchard, the maximum altitude difference was 10.1 m between the trial blocks (T2-T9) expressing a fairly constant terrain slope, with the exception of the first block (T2-T3) (Table 2, Figure 1). Figure 1 shows the longitudinal profile of the trial orchard with an average slope of 14.5%.

The intensity of solar radiation partially depends on geomorphologic characteristics of the orchard, because PAR intensity was decreasing proportionately to the decrease of altitude. The impact of terrain slope on PAR was insignificant (Table 3).

Differences in altitude, which did not exceed 11 meters between different blocks, did not result in changes of Tavg and rh.

Evaluation of the microclimatic and light parameters

For this purpose, linear discriminant analysis (a multivariate statistical method) was used. With the analysis of the chosen parameters (Tavg, rh, Tmax, Tmin and PAR) there was a successful distribution of the samples with just one axis; the first discriminant function (DF 1 is 100%) has entirely contributed to the differentiation between the individual treatments and is connected with the variable PAR. As distinguished from Figure 2, it separates well all five coloured nets and the uncovered part of the orchards (control group).

The influence of anti-hail nets on Tavg and rh

In the whole period of the trial the microclimatic parameters (from 14th June, 2017 to 18th July, 2017) 27 “hot days” (Tmax ≥ 30 °C) and 8 “warm days” (Tmax ≥ 25 °C) were registered.

Table 1. Average photosynthetically active radiation (PAR) under different coloured anti-hail nets and the share of reduction of PAR in the orchard

Treatment / parameter	Red net	Grey net	Blue Net	Green net	Black net	No net / control
PAR (µmol/m²s)	572[e]	664[cd]	645[d]	703[c]	791[b]	1 052[a]
Reduction of PAR (%)	45.6	36.9	38.7	33.2	24.8	/

PAR - photosynthetically active radiation. Different letters (a, b, c, d, e) in the individual lines denote averages, which statistically differ among themselves (Tukey, 0.05)

Table 2. Geomorphologic characteristics of trial orchard

Point	Horizontal length	Height difference between points	Altitude	Distance from the starting point (start block 1)	Slope between points
	(m)	(m)	(m)	(m)	(%)
T1 – start of row			384.2	-12.201	
T1 – T2	12.20	0.829			6.8
T2 – start block 1			384.9	0.000	
block 1 (T2 – T3)	10.04	-0.364			-3.6
T3 – end block 1			384.6	10.044	
T3 – T4	10.06	-1.292			-12.8
T4 – start block 2			383.3	20.105	
block 2 (T4 – T5)	9.96	-1.706			-17.1
T5 – end block 2			381.6	30.068	
T5-T6	9.98	-1.761			-17.6
T6 – start block 3			379.9	40.051	
block 3 (T6 – T7)	9.98	-1.842			-18.5
T7 – end block 3			378.0	50.026	
T7-T8	9.98	-1.807			-18.1
T8 – start block 4			376.2	60.005	
block 4 (T8 – T9)	9.94	-1.396			-14.1
T9 – end block 4			374.8	69.94	
T9 – T10	7.26	-1.011			-13.9
T10 – end of row			373.8	77.199	

Table 3. Average PAR, Tavg and rh in relation to altitude and terrain slope in trial orchard

Treatment / parameter	Altitude / slope (384.9-384.6 m) / 3.6%	Altitude / slope (383.3-381.6 m) / 17.1%	Altitude / slope (379.9-378.0 m) / 18.5%	Altitude / slope (376.2-374.8 m) / 14.1%
PAR (μmol/m²s)	746[a]	745[a]	729[b]	720[c]
Tavg (°C)	23.30[a]	23.30[a]	23.31[a]	23.32[a]
rh (%)	29.73[a]	29.74[a]	29.75[a]	29.76[a]

PAR - photosynthetically active radiation, Tavg - average air temperature, rh - relative air humidity. Different letters (a, b, c) in the individual lines denote averages, which statistically differ among themselves (Tukey, 0.05)

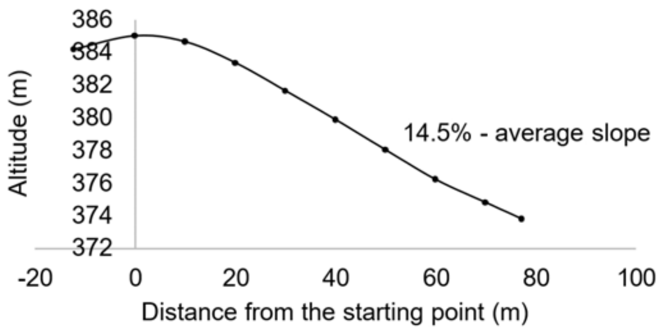

Figure 1. Longitudinal profile of trial orchard

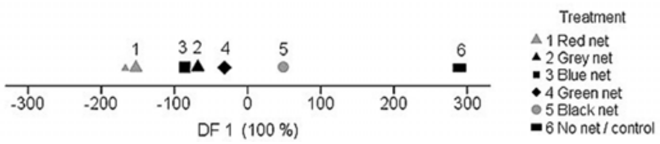

Figure 2. The linear discriminant analysis of the microclimatic parameters and photosynthetically active radiation (PAR) with regards to the colour of the anti-hail net

Based on the results of the microclimatic parameters (Tavg, rh, Tmin and Tmax), we can confirm that the anti-hail nets cause only small changes in the microclimate in the orchard (Table 4). When using anti-hail nets (independent of colour), no statistic differences in Tavg, rh and Tmin were confirmed, except with the blue net, where a statistically notably higher Tmax (by 4.7%) in comparison to the red net was noted. The use of the blue net resulted in a consistent, on average 2% higher Tmax in comparison with other treatments. The red net, however, reduces Tmax in average by 3.8% when compared to other nets and by 2.9% when compared to control (no net).

The influence of the anti-hail nets on the wind parameter

Table 5 shows that the presence of an anti-hail net distinctly reduced wind speed and air flow in the orchard (on average by 56.3 and 63.4%, respectively). The intensity of wind speed and flow in both situations (under and outside the net) differed based on the wind strength at the time of measuring. When the net was used, a statistically distinct reduction of wind speed and air flow (on average 61.1 and 68.5%, respectively) was noted with weak (≤ 1m/s) and medium (1.1–2.5 m/s) wind. With strong winds (> 2.5 m/s), a trend of reduced wind speed (on average 46.7%) and air flow (on average 53.3%) under the net in comparison to measurements outside the net was noted.

Evaluation of the heat index, temperature of the dew point and wet-bulb temperature

During the evaluation of the mentioned parameters in the research period (from 14th June, 2017 to 18th July, 2017) no significant differences between the treatments under and outside of the net were registered (Table 6). The data about the temperature of the dew point or the wet-bulb temperature under or outside of the net did not differ significantly and are in accordance with the data about rh, which also did not show significant differences in cases where anti-hail nets were used (Table 4).

Table 4. Average Tavg, rh, Tmax and Tmin in the period from 14th June to 18th July, 2017

Treatment / parameter	Red net	Grey net	Blue Net	Green net	Black net	No net / control
Tavg (°C)	25.1^{a}	25.1^{a}	25.1^{a}	25.2^{a}	25.2^{a}	25.1^{a}
rh (%)	57.6^{a}	57.1^{a}	57.4^{a}	57.2^{a}	57.3^{a}	57.1^{a}
Tmax (°C)	30.6^{b}	31.4^{ab}	32.1^{a}	31.9^{ab}	31.9^{ab}	31.5^{ab}
Tmin (°C)	15.4^{a}	15.5^{a}	15.6^{a}	15.6^{a}	15.4^{a}	15.5^{a}

Tavg - average air temperature, rh - relative air humidity, Tmax - maximum air temperature, Tmin - minimum air temperature. The different letters (a, b) in the individual lines denote averages, which statistically differ among themselves (Tukey, 0.05)

Table 5. Average wind speed and air flow, defined according to the wind power intensity (period from 14th June to 18th July, 2017)

Parameter / treatment	Wind speed at >2.5 (m/s)	Wind speed at 1.1–2.5 (m/s)	Wind speed at ≤ 1 (m/s)	Air flow at >2.5 (m^3/h)	Air flow at 1.1–2.5 (m^3/h)	Air flow at ≤ 1 (m^3/h)
Net	1.6^{a}	0.5^{b}	0.3^{b}	0.07^{a}	0.03^{b}	0.02^{b}
No net	3.0^{a}	1.8^{a}	0.6^{a}	0.15^{a}	0.13^{a}	0.05^{a}

The different letters (a, b) in the individual lines denote averages, which statistically differ between themselves (t-test, 0.05)

Table 6. Average temperature (°C) of the dew point, wet-bulb temperature and heat index at three different hours (period from 14th June to 18th July, 2017)

Parameter / treatment	Dew point 7:00	Dew point 14:00	Dew point 21:00	Wet bulb 7:00	Wet bulb 14:00	Wet bulb 21:00	Heat index 7:00	Heat index 14:00	Heat index 21:00
Net	16.31^{a}	17.60^{a}	17.08^{a}	19.47^{a}	21.90^{a}	19.58^{a}	26.17^{a}	31.99^{a}	24.84^{a}
No net	16.29^{a}	17.41^{a}	17.02^{a}	19.45^{a}	21.82^{a}	19.53^{a}	26.24^{a}	32.09^{a}	24.83^{a}

The letter (a) in the individual lines denote averages, which are statistically not different between themselves (t-test, 0.05)

The impact of anti-hail nets on precipitation quantity and distribution

The differences in precipitation quantities, measured during the period from 17th July, 2018 to 4th November, 2018, were quantitatively big regarding both the intensity and measuring location (Table 7). When anti-hail nets were used, the quantity of precipitation that reached the floor increased proportionately with the distance from the trunk. Regardless of precipitation intensity, the smallest quantity of precipitation was recorded under the net on the outer edge of the herbicide strip (30 cm from the trunk), where statistically distinctive lower quantities of precipitation were recorded in cases of heavy rain and drizzle (on average 27.6 in 26.9%, respectively) in comparison to other locations under the net. Precipitation quantity measured 30 cm from the trunk was significantly lower in cases of heavy rain, even when compared to the measurements outside of the net (on average lower by 21.2%). Independent of precipitation intensity, the measured precipitation quantity was lower in the driving lane (85 cm from the trunk) than in the middle of the row (175 cm from the trunk), on average by 3% and compared to the precipitation quantity measured on the outside edge of the herbicide area (30 cm from the trunk), bigger by 19.4%. Interesting is also a high quantity of precipitation recorded between two rows (175 cm from the trunk), more prominent in cases of heavy rain and drizzle. In cases of medium rain, the distribution of precipitation was more even and did not show a statistically important difference, neither under nor outside the net.

Table 7. Average precipitation under and outside anti-hail nets in the period from 17th July to 4th November, 2018

Parameter / treatment	Heavy rain (l/m^2)	Medium rain (l/m^2)	Drizzle (l/m^2)
Under net (herbicide strip – 30 cm from trunk)	6.38^b	4.20^a	2.23^b
Under net (driving lane – 85 cm from trunk)	8.55^a	4.49^a	3.03^a
Under net (between two rows – 175 cm from trunk)	9.10^a	4.56^a	3.07^a
Outside net	8.10^a	4.56^a	2.77^{ab}

The different letters (a, b) in the individual columns denote averages, which statistically differ among themselves (Tukey, 0.05)

DISCUSSION

Anti-hail nets are indispensable in fruit production. They do not only serve their original purpose - defence against hail which, in addition to damage of fruits, can also cause abiotic stress (Tartachnyk and Blanke, 2002) - but they also serve as a tool for reducing the negative indirect effect of changed climate conditions. We established that, in the case studying parameters in relation to net colour (PAR, Tavg, Tmin, Tmax, and rh), the biggest change between treatments is caused by the values of photosynthetically active radiation (PAR).

As expected considering the data accessible in literature (Jakopič et al., 2007; Blanke, 2009; Solomakhin et al., 2012; Agrintech, 2017) it was concluded that anti- hail nets of various colours undoubtedly impact the decrease of photosynthetically active radiation (PAR).The measurements of PAR under various nets did not prove a consistently stronger (negative) impact of black nets on light permeability, which was expected based on the data in existing literature. On the contrary, among all the coloured nets, the smallest PAR reduction was noted with black net. It could be explained by the impermeability of black net, which does not modify the light spectrum. According to Castellano et al. (2008) the shadowing factor in black net is almost directly proportional to the net permeability. The use of anti-hail nets (depending on colour) significantly reduced PAR, which, according to Elad et al. (2007) shows that anti-hail nets could be used to protect the yield (fruits) from excessive solar radiation. It is predicted that with increased climate change, the distinct reduction of PAR can reduce the risk of sunburn, drought and oxidation stress.

It is anticipated that PAR also depends on the geomorphologic characteristics of the orchard (altitude). The reduced solar radiation on lower terrain is the result of the extended travelling distance of solar radiation through the atmosphere, because the strength of solar radiation also depends on the density of the incoming energy (Rakovec and Vrhovec, 1998). It is expected that the interaction between PAR and anti-hail nets in lower fruit production parts (lower part of the orchard) can increase the risk some in physiological processes in apple trees, which (co)depend on the intensity of solar radiation.

The collected data concerning microclimate does not confirm important differences in Tavg, Tmin, Tmax and rh and are contradictory to reports of Solomakhin and Blanke (2009), Ilić et al. (2012), Milanović et al. (2014) and Milivojević et al. (2016), who describe changes in individual microclimatic micro-region when using nets. It is possible that in addition to the use of various colours and the method of weaving used in the anti-hail nets, the contradictory findings concerning microclimatic parameters could also be the result of different pedoclimatic characteristics of the orchard where trials were conducted. Research results are consistent with the findings of Oren-Shamir et al. (2001) and Bosco et al. (2017) who did not notice any clear changes in microclimatic conditions connected with the usage of nets. Despite this, it is anticipated that the higher Tmax under the blue net (32.1 °C) (on average 2% higher compared to other treatments) can impact certain changes in photosynthesis and consequently some physiological reactions of the apple trees (connected to natural fruit thinning), which can present a risk in apple production.

The share of the wind speed reduction is consistent with the findings of Middleton and McWaters (1996) and Milanović et al. (2014), who report up to 50% reduction in the wind speed under the anti-hail net. Due to the reduced wind effect under the anti- hail net (with simultaneously higher humidity under the anti-hail nets) Middleton and McWaters (1996) report a slower drying of the leaf surface, which can in practice enable a more term-planned and effective usage of protective means (Gordon, 2012; Billington and Bailey, 2015). Regarding the technological measures, it is reasonable to use this information when choosing the date for the application of protective means and reduction of third natural fruit drop. Wind reduction under anti-hail nets could in the future – and due to the prediction of more frequent and more intense wind – strongly impact temperature changes, rh, gas concentrations, photosynthesis and transpiration.

It is predicted that the unchanged dew conditions under anti-hail nets, which are contradictory to the reports of Zadravec et al. (2009) and Muntean (2018), can negate the fear of possible changes in the incubation period of apple scab and the risk of a later application of protective measures as well as reduce the working hours in orchards under nets. With increasing climate changes, anti-hail nets could, in theory, reduce the heat index (the feeling of heat) and indirectly improve work efficiency in the orchard.

It is concluded that the use of anti-hail nets has a significant impact on precipitation distribution, which is contradictory to the reports of Bosco et al. (2017). It is anticipated that in both situations (under and outside the net), the same amount of precipitation reaches the plants and floor and that the collected data is only a consequence of uneven precipitation distribution in a given environment. This might be the result of the 30% roofing slope of the net and, consequently, the redirection of raindrops toward the centre of the row, where the highest quantity of precipitations was recorded. The uneven distribution of rainfall under anti-hail nets can also partly be attributed to the rebounding of raindrops from the net and consequently changing the direction of raindrops to the floor's surface/measuring instrument. It has never been pointed out as a "signal for caution" when using weak rootstocks. With only light drizzle, it is possible that the raindrops are partially "captured" by the anti-hail net and that they evaporate from the net's surface, as believed by Zadravec et al. (2009).

CONCLUSIONS

The study revealed that anti-hail nets of different colours in association with various geomorphological characteristics have a strong impact on light condition in orchards. The presence of these nets does not exhibit high impact on other crucial microclimatic parameters such as Tavg, Tmin, rh, heat index, dew point and wet bulb temperature. An exception can be the blue net where constantly higher Tmax was recorded which, in some way, may represent a certain risk in apple production. The study also indicates that anti-hail nets significantly reduce wind velocity, but cause uneven distribution of precipitations. Considering the intensification of climatic changes, the reduction of wind velocity is highly desired, however, the uneaven distribution of precipitations will probably require additional actions associated with irrigation. When considering all major technical characteristics together with durability of different net types, the black anti-hail net obviously has several advantages and therefore remains the first choice for fruit growers.

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