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ABSTRACT

The two biggest loss factors in the South African Avocado industry are caused by sunburn (32%) and wind damage (25%), according to an industry loss factor analysis in 2016. Growing avocado under shadenet was investigated to minimize these losses, as well as improve the quality of the fruit. Two shadenet structures were erected in two different geographic areas of South Africa. White net (30%) and black net (20%) was used separately on the respective sites. At both sites '3-29-5' ('Gem') on Dusa® was planted. Various horticultural aspects were compared between the shadenet and open field orchards over a period of three years. These included climatic parameters, tree measurements, tree yield, fruit quality and class distribution. The most significant findings were that wind damage was reduced (up to 27%) at both sites under the shadenet. As a result, more Class 1 fruit was harvested under the netted orchards. At the 30% white shadenet site the fruit size under the shadenet was one size bigger vs. the open field orchard. This trend was also observed under the 20% black shadenet. Furthermore, under the 20% black shadenet the trees showed more vegetative vigour and yielded a small first crop. However, the yield has improved with the trees maturing. Although the use of shadenet is a relatively new form of abiotic stress mitigation the netted structures seems to minimise the loss in fruit quality caused by wind damage.

Keywords: shadenet, wind damage, sunburn, fruit quality.

INTRODUCTION

The South African avocado industry export approximately 49.6% of the total avocado production to various markets around the world (SAAGA, 2019). According to an industry loss factor analysis in 2016, the two biggest loss factors in export fruit for the South African avocado industry are caused by sunburn (32%) and wind damage (25%). As export fruit offers a higher return for avocado growers, it is important that these losses are reduced. One manner in which this can be achieved is through the use of shadenets, which have been widely used in the apple, kiwi, citrus and other horticultural industries to reduce sunburn and wind damage (Stander and Cronje, 2016; Brink, *et.al*, 2015; Stamps, 2009).

However, the protective structure can alter the microclimate, which may have both beneficial and negative impacts on plant growth and yield. A key characteristic of any form of horizontal shadenet structure, regardless of intended purpose or objective, is that incoming solar radiation is reduced under the shade net (Cohen et al., 1997). This is largely dependent on the colour and percentage of the shadenet used. Whilst the reduction in solar radiation can reduce the incidence of sunburn, if the photosynthetically active radiation (PAR) is reduced below the photosynthetic light saturation level, then net assimilation of the crop can be reduced, which could impact dry matter accumulation (Jifon and Syvertsen, 2001). Relative humidity has also been shown to increase under protective structures and this can lead to increased incidence of pathogens and insect pests (Stander and Cronje 2016). It is therefore critical that crop responses to shadenet are evaluated to ensure that yield and quality is not adversely affected. The possibility of growing avocado under shadenet was therefore investigated with the aim of minimizing losses to sunburn and wind and hail damage, and improving the quality of the fruit, without impacting yield. Two different shadenet structures in two different geographical areas of South Africa were used to assess the impact of shadenets on Gem® on Dusa® avocado yield and quality. Both areas are prone to wind and hailstorms.

METHODOLOGY

Shadenet structures

Two shadenet structures were erected in two different geographical areas of South Africa. The Soekmekaar site (23°25'40.03" S, 30°01'11.85" E) is situated in the Limpopo province. This is a mountainous area with an altitude of 1 170 m.a.s.l. with a mild climate (Max: 25 – 30 ˚C; Min: 8 – 10 ˚C). The second shadenet site is situated at Everdon estate near Howick, KwaZulu-Natal province. The site (29°26'28.41" S, 30°16'16.34" E) is ±1060 m.a.s.l. with a similar mild climate as the first site. Both areas offer a late window marketing opportunity, and both are prone to hailstorms and wind. The shadenet structure at the Everdon site was established in 2013/2014 over 3-year-old Gem® trees and the Soekmekaar site during 2015. Gem® trees at Soekmekaar were planted in December 2015. Each shadenet site had an adjacent open field as the control. Table I provides details of these two sites. Gem® ('3-29-5') is a late season avocado cultivar which is harvested November/December and early January, when few black skin avocado cultivars are available in the South African market. This cultivar was planted on Dusa® at both sites, as a high value late season cultivar.

Three different hail purge systems at the Soekmekaar site are demonstrated by Figure I.

While awaiting a hailstorm at the Soekmekaar site, measurements were done under each of the different hail purge systems. It must be noted that it was not possible to randomize the different hail purge systems throughout the shadenet for financial reasons. Therefore, the results should be regarded as observations.

At both Soekmekaar (black shadenet) and Everdon (white shadenet) yield, class distribution (fruit quality) and count distribution were assessed at the end of each season from trees under the shadenet and in the open. In addition at the Soekmekaar site, environmental conditions inside the net and in the open were recorded, together with applied irrigation volumes. Tree measurements were also taken at this site, which included tree height, tree width and stem circumference. Photosynthesis measurements were also taken for two days in December 2018.

Leaf gas exchange was determined with an LI-6800 (LI-COR, Lincoln, Nebraska, USA) on 5 and 6 December 2018 at the Soekmekaar site on three sun exposed leaves and one shaded leaf on five trees under the shadenet and three trees in the open. Chamber CO_2 concentration was maintained at 400 µmol mol^{-1}, the flow rate was 400 µmol s^{-1}, PAR inside the chamber was maintained between 1500 – 2000 µmol m^{-2} s^{-1}. Measurements were typically recorded as soon as A stabilized, usually within two minutes of leaf insertion.

The auto program function of the LI-6800 was used to obtain photosynthetic light and CO_2 response (A/C_i) curves using mature sun-exposed leaves on the trees in the open and under the shadenet. Light and A/C_i curves were performed by altering the PAR (2000, 1500, 1000, 600, 400, 200, 100, 50, 0 µmol m^{-2} s^{-1}) and CO_2 concentration (400, 300, 200, 150, 100, 50, 0, 400, 600, 700, 1000, 2000 µmol mol^{-1}) within the chamber, respectively. For light response curves the CO_2 concentration was controlled at 400 µmol mol^{-1}, whilst PAR was set at 1500 µmol m^{-2} s^{-1} for A/C_i curves. T_{leaf} was controlled within 5°C of ambient by Peltier coolers, and RH within the chamber was maintained at more than 50%. Curve fitting and analysis was done using light response curves as described by Lobo et al. (2013) and by fitting the model described by Sharkey et al. (2007) for CO_2 response curves.

RESULTS AND DISCUSSION

Tree yield, class and count distribution at the Everdon site (white shadenet)

During a period of 3 years (2014 – 2017), the yield under the shadenet was between 2% to 5% higher than the yield in the open field. However, during the 2018 season yield in the open field was 11.6% higher than under the shadenet (Figure II). After the harvest in 2017, the trees under the shadenet were heavily pruned, as no pruning was done during the previous 3 years in this netted orchard. Growth of trees under the shadenet were denser in comparison to the open field trees. Therefore, a heavier pruning regime under the shadenet took place, with the aim to reduce the height of the trees and to cut two windows on the two sides of each tree, facing each other inside the row. This was to improve sunlight penetration into the overgrown trees, which will enable the trees to produce more fruit (Thorp, *et.*al.,2014). A pyramid structure, whereby the tree is slender at the top and bigger at the bottom of the tree had to be achieved. Bigger cuts therefore were made in the trees under the shadenet to allow more sunlight into the tree canopy. This could possibly explain why the open field outperformed the yield under the shadenet in 2018.

In addition, over a three-year period, the shadenet yielded between 6% and 15.5% more class 1 fruit in comparison to the open field (Figure III). However, during the 2018 season, the open field yielded 1% more class 1 fruit, which was non-significant.

The Gem® tree naturally bears fruit on the inside of the tree. As mentioned above, the open field trees were not as heavily pruned and therefore had no big windows in the tree canopy, as was the case with the trees grown under shadenet. Shadenet trees were more open after pruning, although the re-growth was excessive after the huge pruning cuts. Even though plant growth regulators are widely used in the avocado industry to reduce vegetative growth after pruning (Lovatt, 2014). However, this was not done on trees after the pruning exercise.

The fruit count distribution over four years (Figure IV) indicates that fruit size under the net was one to two sizes bigger than fruit from the open field. During the 2018 season, the open field orchard produced 14% more count 10 fruit than the shadenet.

However, the shadenet yielded 13.1% more count 12 fruit and 14% more count 14 fruit in comparison to the open field. It possible that following the heavy pruning dry matter was diverted to vegetative re-growth rather than in fruit growth.

Tree yield, class and count distribution at the Soekmekaar site (black shadenet)

The first harvest of Gem® fruit under black shadenet took place in 2017. The trees under shadenet yielded a small crop in comparison to the trees in the open field orchard (Table II). The following production season saw the shadenet improving on production with 1.7 tons less fruit than the open field orchard.

However, during 2017 trees under the shadenet yielded 10% more class 1 fruit than the open field and in 2018 17% more class 1 fruit were harvested from trees under the shadenet compared to fruit from the open field (Figure V). More class 1 fruit means more export fruit for the grower, which fetches a premium price.

Figure VI demonstrates the fruit count distribution. The fruit size under shadenet was one size bigger in comparison to the open field (Figure VI). During 2017 the shadenet had 16.3% more count 12 fruit than the open field and in 2018 there was 7.4% more count 10 fruit under the shadenet. The same trend was therefore observed under the black shadenet as for the white shadenet, with bigger fruit size found under the net. However, as this is only the second crop, no definite conclusions can be made, and more seasons of data are required.

Reducing wind damage at Soekmekaar site (black shadenet)

Wind speed was measured under the shadenet, as well as in the open field orchard with iLeaf weather stations. Table III indicates a difference of 8.4 km/h average wind speed between the open field and the shadenet, which resulted in a 35% decrease in windspeed under the shadenet. Average maximum windspeed was also reduced by 40% under the shadenet.

Furthermore, wind damage on the fruit grown under shadenet, was reduced by 45% in 2017 and 28% during 2018 (Figure VII). Therefore, the shadenet resulted in more class 1 fruit and reduced wind damage substantially. This will benefit the grower with premium prices.

Tree measurements at the Soekmekaar site (black shadenet)

Tree measurements were done of 40 index trees under each hail purge system under the shadenet and in the open field. Trees grown under shadenet were more vigorous in comparison to the open field trees (Table IV). It has been reported by Heath *et.al.*, (2006) that avocado leaf stomata close quickly in response to decreasing light. Therefore, if leaves are shaded by neighbouring trees or a 20% black net (provides 20% shade and 20% UV block) it could affect the productivity of the trees. This could possibly explain why the yield of the trees growing under shadenet was less in comparison to the open field orchard. It was therefore decided to perform photosynthesis measurements.

Photosynthesis measurements

Photosynthesis (A) and stomatal conductance (g_s) was significantly higher under the shadenet, whilst intrinsic water use efficiency (iWUE) was lower under the shadenet (Table V). Leaf temperature (T_{leaf}) was unaffected by the shadenet (Table V). Measurements were made from 9h30 to 13h30 and therefore would have captured the maximum rates of photosynthesis (Silber et al. 2013) and would be a fair reflection of photosynthesis for that day. The lower g_s of the trees in the open could mean that stomatal limitations to A were present in the open and could be related to the higher VPD_{leaf} in the open, as stomata typically close in response to increasing VPD_{leaf}. However, the higher iWUE in the open suggests that for trees in the open the water cost for carbon assimilation would be lower than under the shadenet. This, however, requires further investigation.

In order to try and explain the reduction in photosynthesis, parameters derived from A/Ci and light response curves were evaluated from trees grown under the shadenet and in the open (Table VI). Results indicate that there are also non-stomatal limitations to photosynthesis in the open, as both maximum velocity of Rubisco for carboxylation ($V_{c\ max}$) and maximum rate of electron transport (J_{max}) were reduced in the open. This suggests reduced Calvin cycle kinetics, which could be possibly due to the more extreme conditions in the open.

Whilst solar radiation is reduced under the shadenet, an analysis of solar radiation measured under the shadenet suggests that PAR was unlikely to be a limiting factor for A under the shadenet in the middle of the day. Yield was therefore unlikely to be reduced under the shadenet as a result of insufficient PAR for photosynthesis. A shift in the vegetative to reproductive in favour of vegetative growth could have occurred under the shadenets, as increased tree vigour has been reported in apple orchards under shadenet in South Africa.

DISCUSSION

The benefit of growing avocados under shadenetting as opposed to in the open field orchard was demonstrated at both sites. The shadenet produced between 10% - 17% more class 1 fruit in comparison to the open field orchard. This has an export benefit to growers which results in higher prices for fruit produced. Wind damage was reduced between 27% - 45% on the fruit, as the shadenet reduced the maximum windspeed by 40%. This resulted in more class 1 fruit under the shadenet. A trend of bigger fruit size under the shadenet as opposed to the open field fruit was observed at both sites. Under the black net there was an increase in A and gs, indicating the potential for greater dry matter accumulation. However, these are preliminary results and need to be investigated further. Understanding the partitioning of dry matter within the tree under shadenets will be important for understanding how to manage the tree to favour fruit production over vegetative growth.

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TABLES

Table I: Trial details for the Soekmekaar and Everdon shadenet trials.

Site	Type of net	Covered area	Cultivar	Spacing
Soekmekaar	20% black South African & Italian net with 3 hail purge systems in canopy of net	1.4 ha	Gem®	6m x 2m
Everdon	30% white net	1.5 ha	Gem®	7 m x 4 m

Table II: Yield of Gem® under shadenet vs. open field.

Yield (ton/ha)	**2017**	**2018**
Shadenet	0.7 ±1.1	10.8 ±5.4
Open field	1.2 ±1.5	12.5 ±5.8

Table III: Wind speed open field vs. shadenet.

Wind speed (May'16 – May'19)	**Difference open field vs net (km/h)**	**Difference open field vs net (%)**
Average wind speed	8.4 ±5.8	64.9 ±28.3
Average maximum wind speed	16.3 ±11.4	60.1 ±26.0

Table IV: Tree measurements 2016 – 2017 under different hail release and net systems.

			10-May-16		10-Oct-16		10-Jan-17			May-17	Oct-17		
	Blok	Treatment (n=40 trees)	Ave Height	Ave stem cir	Ave Height	Ave stem cir	Ave Height	Ave width	Ave stem cir	Ave stem cir	Ave stem cir	Ave height	Ave width
Net	A	SA button	103.4 ±2.8	5.6 ±0.3	117.5 ±3.5	8.43 ±0.2	162.6 ±4.9	160.5 ±5.2	12.6 ±0.3	18.6 ±0.4	20.47 ±0.5	196.5 ±5.0	192.1 ±6.1
	B	SA overlap	106.7 ±2.3	5.8 ±0.2	128.7 ±3.2	9.0 ±0.2	167.7 ±4.0	169.1 ±4.4	13.7 ±0.3	20.3 ±0.5	22.13 ±0.5	209.5 ±4.8	214.2 ±5.4
	C	Italian overlap	112.2 ±2.2	6.9 ±0.2	130.6 ±2.8	9.3 ±0.2	176.4 ±3.3	148.6 ±4.9	13.9 ±0.2	20.6 ±0.4	22.48 ±0.4	214.9 ±3.3	220 ±5.2
	D	SA funnel	104.4 ±2.0	6.6 ±0.2	123.9 ±3.4	8.43 ±0.3	165.1 ±5.0	162.0 ±6.3	12.9 ±0.4	18.6 ±0.6	21.74 ±0.7	217.1 ±5.5	199.8 ±6.6
	E	Italian funnel	91.92 ±2.6	6.2 ±0.2	116.1 ±3.3	8.20±0.2	162.6 ±4.1	174.2 ±4.2	13.6 ±0.3	19.8 ±0.5	21.9 ±0.6	196 ±4.7	207.4 ±5.0
Open field	Control	Open field	84 ± 2.3	6.1 ±0.2	94.4 ±3.0	7.6 ±0.2	131.8 ±3.2	139.6 ±3.6	12.4 ±0.4	18.0 ±0.6	20.85 ±0.6	168.1 ±3.6	175.1 ±3.4

Table V: Photosynthetic parameters of trees under the shadenet and in the open in 5 December 2015. A – photosynthesis, g_s – stomatal conductance, iWUE intrinsic water use efficiency, T_{leaf} – leaf temperature, VPD_{leaf} – vapour pressure deficit from the leaf to the air.

	Open	Shadenet
A (µmol CO_2 m^{-2} s^{-1})	14.33 ± 3.47 *	16.31 ± 3.84
g_s (mol m^{-2} s^{-1})	0.237 ± 0.107 *	0.373 ± 0.160
iWUE (µmol mol^{-1})ol	67.00 ± 16.44 *	50.20 ± 17.31
T_{leaf} (°C)	37.02 ±2.76	36.62 1.44
VPD_{leaf} (kPa)	3.59	3.31

* Indicates a significant difference between the open and shadenet (P<0.05)

Table VI: Parameters obtained from analysis of photosynthetically active radiation (PAR) and CO_2 response curves. Estimates of light response curve parameters include maximum light saturated net CO_2 assimilation rate (A_{max}), light compensation point (LCP), apparent quantum efficiency (AQE) and light saturation. Parameters estimated from photosynthetic CO_2 response (A/C_i) curves include maximum velocity of Rubisco for carboxylation ($V_{c\,max}$) and maximum rate of electron transport (J_{max})

PAR Response Curves		
	Open	**Shade**
A_{max} (µmol CO_2 m^{-2} s^{-1})	33.9	35.0
LCP (µmol PAR m^{-2} s^{-1})	28.9	29.2
AQE (mol mol^{-1})	0.146	0.142
Light saturation (µmol PAR m^{-2} s^{-1})	957	1000
CO_2 Response Curves		
$V_{c\,max}$ (µmol m^{-2} s^{-1})	116.18 ± 3.06*	140.95 ± 11.07
J_{max} (µmol m^{-2} s^{-1})	182.22 ± 2.16*	196.81 ± 2.16

FIGURES

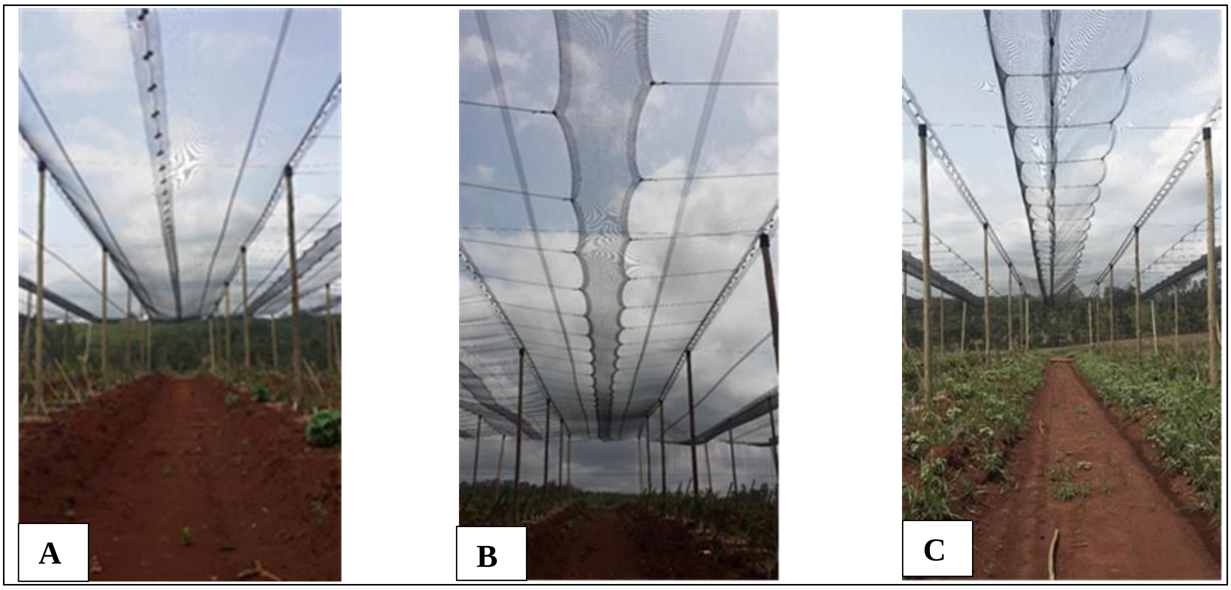

Figure I: Different hail purge systems: Button system (A), Overlap system (B) and Funnel system (C).

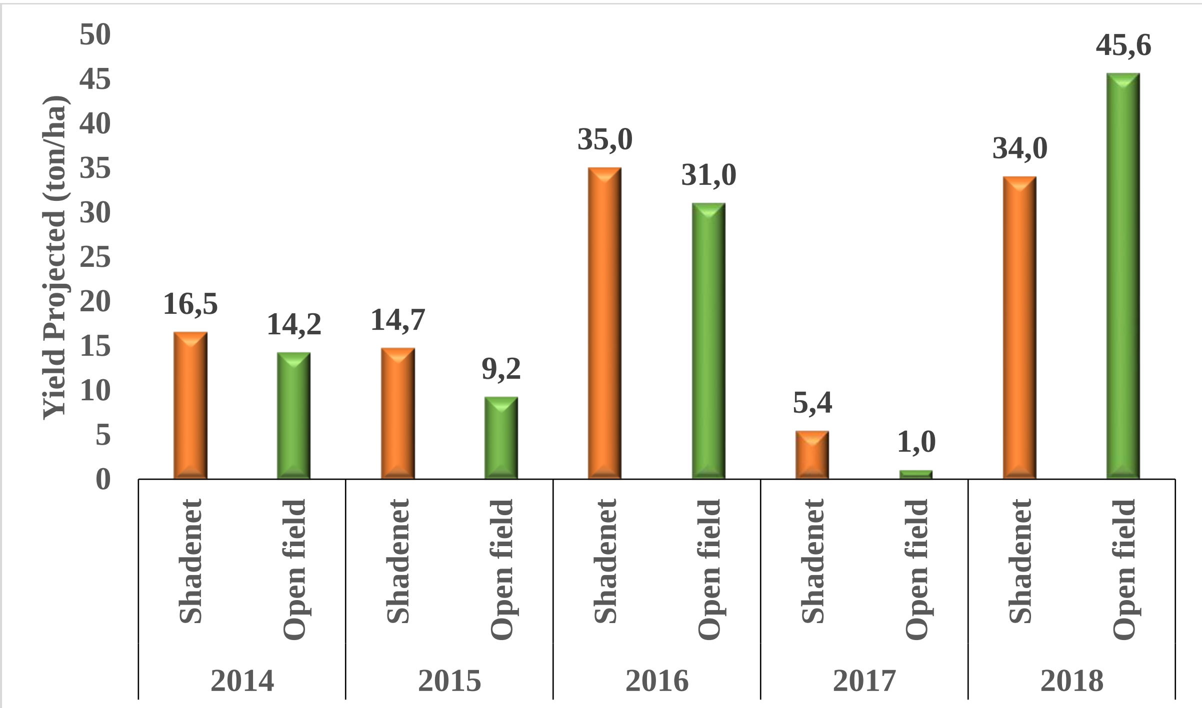

Figure II: Yield of Gem® under shadenet vs. open field 2014 – 2018 at Everdon.

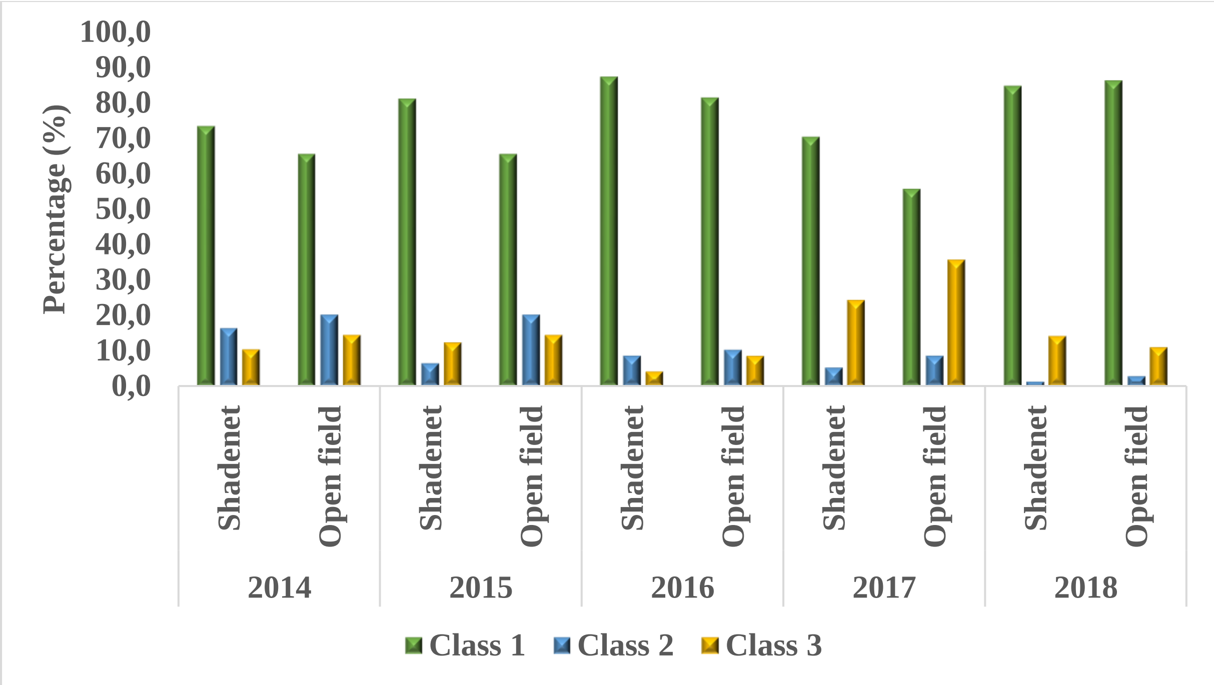

Figure III: Class distribution of fruit under shadenet vs. open field, 2014 – 2018 (Everdon).

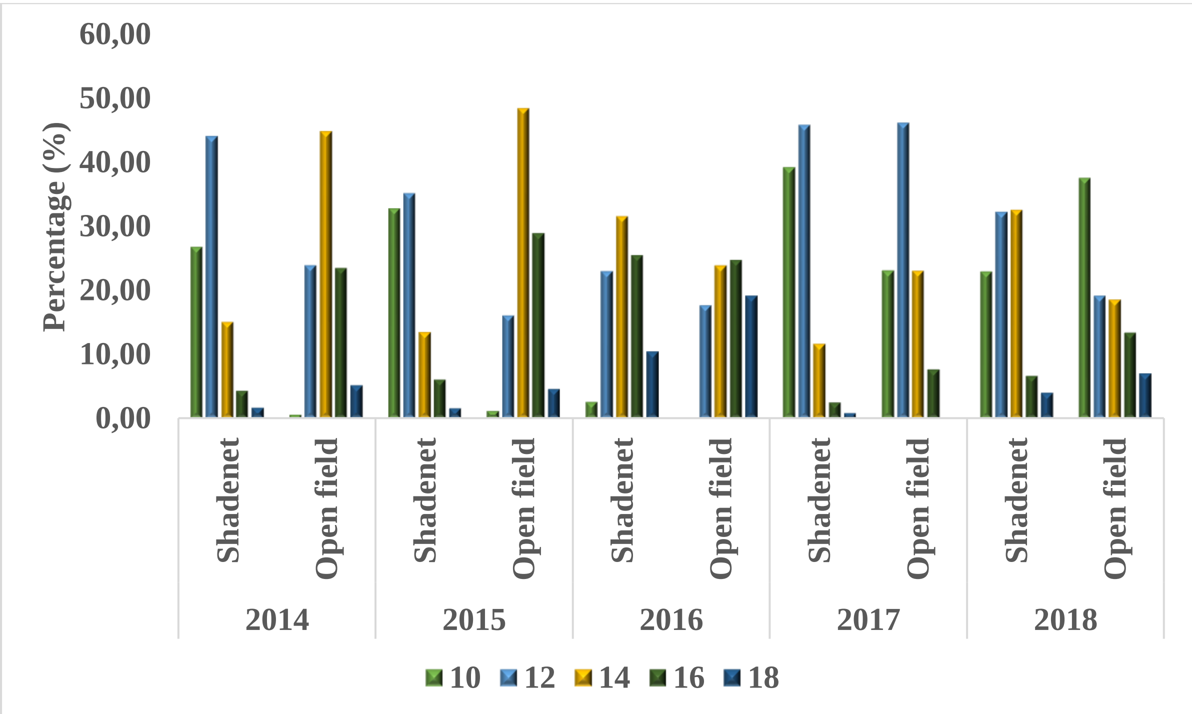

Figure IV: Count distribution of fruit under shadenet vs. open field, 2014 – 2018 (Everdon).

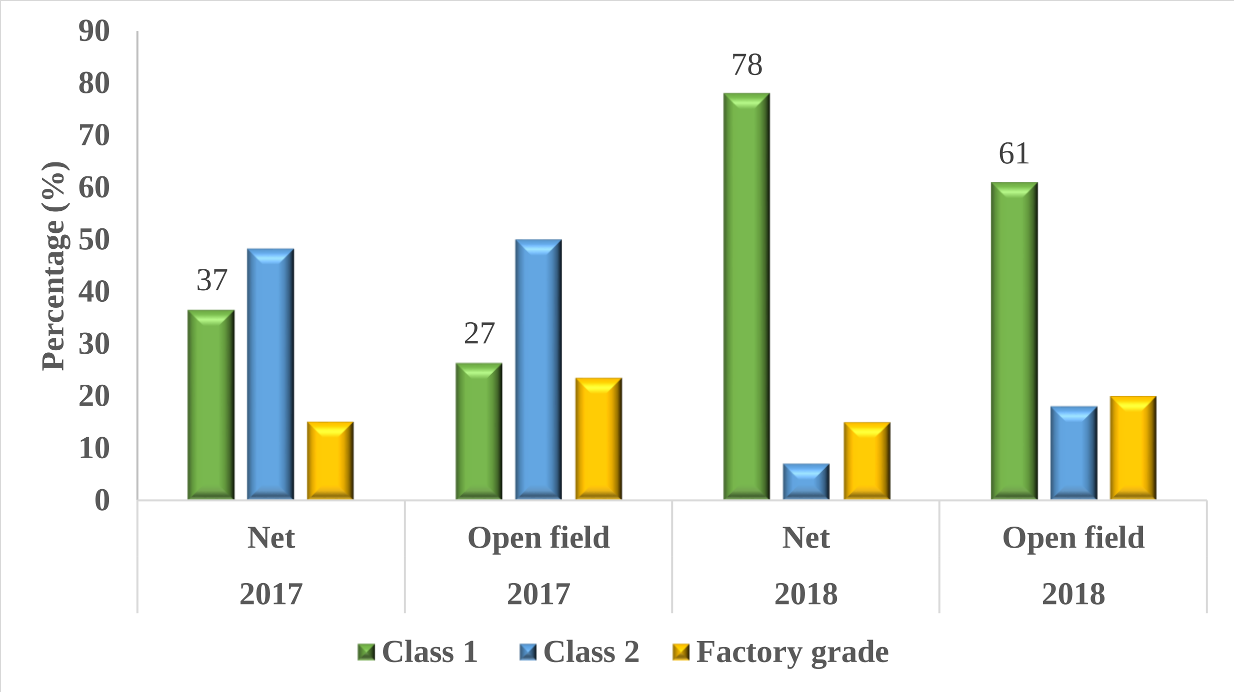

Figure V: Class distribution of fruit from under the shadenet and in the open field (Soekmekaar).

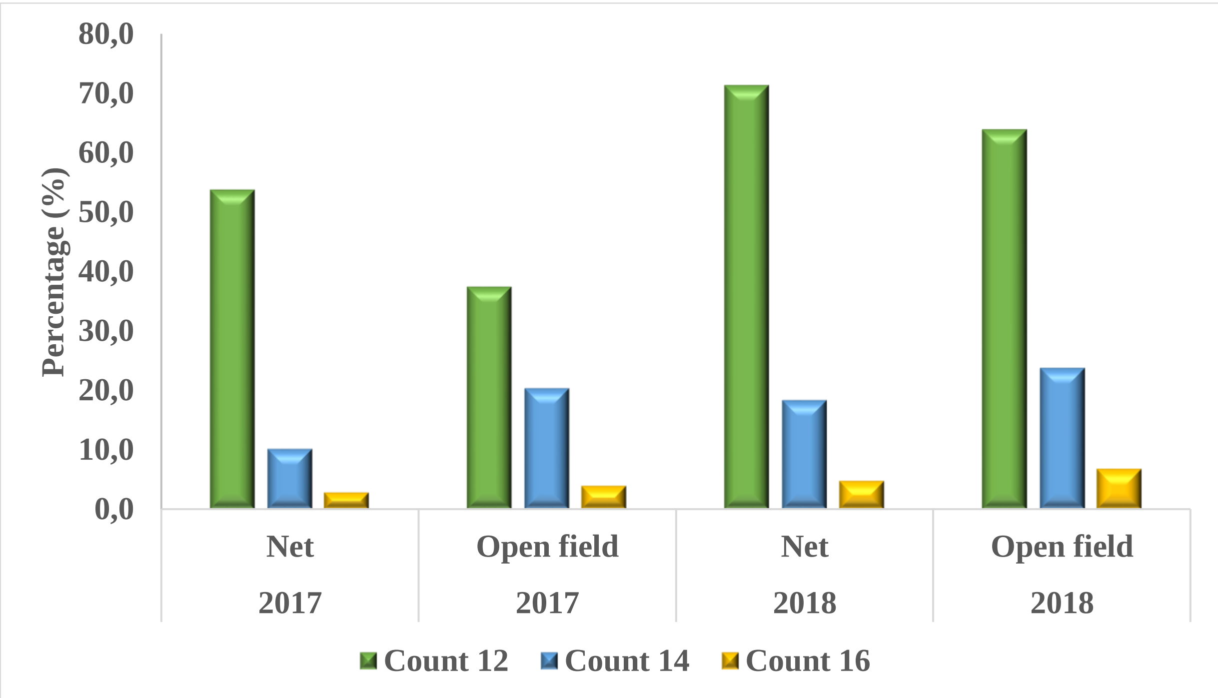

Figure VI: Fruit count distribution of shadenet vs. open field fruit (Soekmekaar).

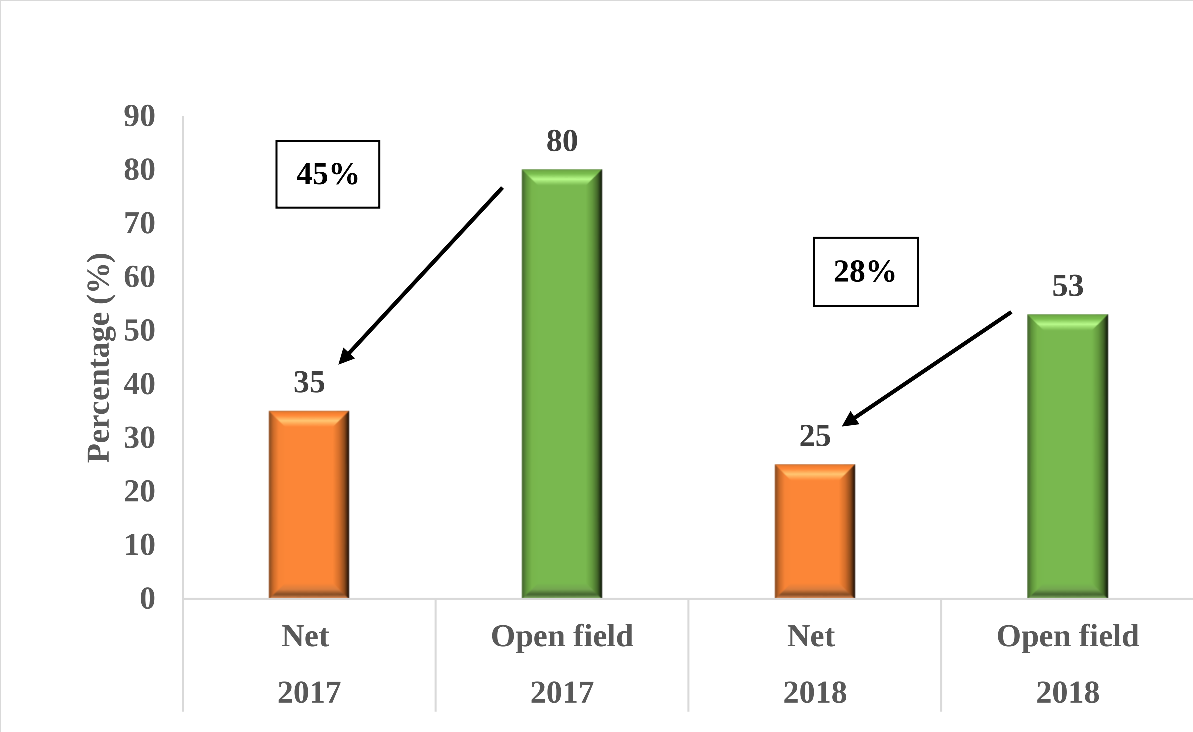

Figure VII: Wind damage on fruit under the shadenet vs. open field (Soekmekaar).