Cite as: Arnegger, T., Bohr, A., Buchleither, S. (2022) Final results after 5 years testing of different rain-roof-covering-systems in organic apple production. *Proceedings of the 20th International Conference on Organic Fruit-Growing*, online 2022.02.21-23. Ed. FOEKO e.V. 2022: 86-93

Final results after 5 years testing of different rain-roof-covering-systems in organic apple production

T. Arnegger[1], A. Bohr[1] and S. Buchleither[1]

Abstract

"Topaz" apples were cultivated under rain protected conditions for 5 years. Two different systems of coverage differing in plastic foil width were compared. Mainly observed parameters were fungicide input, yield and infestation with pests and diseases. In both covering systems a reduced incidence of apple scab, sooty blotch and storage rots was observed, even though fungicide input was substantially reduced. Yield and fruit quality was mostly comparable to the Control or tended to be better. Infestation with European red mite and apple rust mite occurred but remained manageable. A sharp increase in the population of woolly aphid led to severe damage and imposed yet unresolved problems.

Keywords: covering system, foil coverage, protected cultivation, fungicide reduction

Introduction

The regulation of fungal pathogens by keeping leaves and fruit as dry as possible is the main goal in the use of covering systems. This is primarily intended to enable far-reaching savings in the number of fungicidal crop protection applications. However, the positive effect of fungicidal renunciation is to be pondered with possibly negative effects including changes in quality or quantity of the harvested fruit, plant health, landscape appearance, input of work and material. From many possible aspects, this paper focuses on changes of infestation with pests and diseases associated with the tested coverage systems and achieved yield over the years.

Material and Methods

Testing System. In 2013 an organically managed apple orchard of 0.7 ha was planted with the variety "Topaz" on rootstock M9 at planting distance of 3.5 x 1.0 m. The trial was not designed in randomized plots but in three large blocks. On the one hand, this was decided for technical reasons concerning the cover installation, on the other hand it also allows to observe possible differences in microclimate under the foil cover. The block design does not permit statistical evaluation, however. To compensate for this, the number of observed values was on a high level.

Starting in the year of planting, for each block four rows of 114 trees each were covered with a rain roof system of the company VOEN. With one transparent plastic foil strip of 50 cm width firmly sewed on the upper side of the hail net on the ridge and three additional, movable foil flaps (each with a width of 60 cm) in the lower segment, the cover width measured about 2.30 m from the ridge to the eave. Thus, the trees were completely protected from precipitation even with laterally falling rain. This treatment is named "Foil large" in this paper. Though the plastic foil was transparent an let light trough, we measured a reduction of photosynthetically active radiation of around 30% under the covers.

In 2017, an additional roofing system of VOEN (named "Foil medium" hereafter) was integrated into the trial on four additional rows. This system also had a foil compartment firmly sewed to the hail net in the ridge area, but only two instead of three movable foil flaps

[1] Kompetenzzentrum Obstbau Bodensee (KOB), Schuhmacherhof 6, D-88213 Ravensburg, Germany, thomas.arnegger@kob-bavendorf.de

with a total width of 1.70 m from the ridge towards the eaves and thus a higher proportion of hail net in the lower segment. The intention was to allow a better exposure to light while providing a lower but possibly still sufficient protection against precipitation. (Background information to estimate possible perennial effects: In 2015 and 2016, these four rows had been covered with “Foil small”, a system analogue to the systems described above but with only one movable foil flap.)

For a Control treatment, four rows were covered with standard hail net. The covered treatments were irrigated by a drip irrigation system with the amount of water matched to rain fall measured by the regional weather station, so Control and covered treatments received a similar amount of water.

Both covering systems were unfolded annually at bud break to prevent infections caused by apple scab in this early period. After completion of the harvest, the covers were folded analogous to the hail nets and stored on the ridge wire over the winter.

Plant protection management. While a standard organic plant protection management based on the recommendations of the regional advisory service for organic fruit growing (BÖO) was applied in the Control over the entire trial period, the input of fungicidal applications in both covering systems was successively reduced over the years. At the beginning of the experiment in 2015, 60% of the usual fungicidal treatments were skipped. In the further course of the experiment up to 100% of the usual fungicidal treatments were saved, see table 1.

Table 1: Reduction in number of fungicidal applications in covered treatments “Foil large” and “Foil medium” over the years. Percentage compared to Control treatment.

2015	2016	2017	2018	2019
60%	92%	87%	93%	96%

Pests and diseases monitoring. The effect of the tested covering systems on the occurrence of pests and diseases was monitored continuously, see table 2 for an overview. All parameters were assessed in the middle two of the four rows of each treatment. Mainly monitored diseases were apple scab, sooty blotch and storage rots. Differences in the infestation by apple powdery mildew (*Podosphaera leucotricha* (Ell. and Ev.) Salm) and fruit tree canker (*Neonectria ditissima* (Tul. & C. Tul.) Samuels & Rossman) were not found between the experimental treatments. Both diseases did not occur to a relevant extent in any experimental year.

Due to the changed climatic conditions under the covering systems, an increase in the occurrence of sucking insects was expected. Dryness, increased temperatures and lower air circulation create greenhouse-like climatic conditions that are conducive to an increased occurrence of mites and aphids. Especially on the population of mite species, the almost complete renunciation of applications containing sulphur in the covered treatments could also have an elevating effect. During the entire experimental period, the occurrence of European red mite, Apple rust mite, predatory mites and Woolly Aphid was monitored.

Since Azadirachtin (product name “NeemAzal T/S”) was applied annually as a standard measure in all treatments to regulate the rosy apple aphid (*Dysaphis plantaginea* (Passerini)), the occurrence of this pest was well regulated and no differences between the treatments were detected.

Tab. 2: List of monitored pests and diseases including rating method.

Common name	Scientific name	Observation method
Apple scab	*Venturia inaequalis* (Cooke) Winter	Rated each year in August. N = 100 long shoots per treatment rated with 0 = no scab visible or 1 = scab lesion(s) visible.
Sooty blotch	Complex of different fungi	Rated each year just before harvest. N = 550 fruits per treatment rated on a scale from 0 to 5 based on percentage of infested fruit surface. 0 = no infestation, 1 = very small spots only in flower or stalk pit, 2 = up to 10% infested area, 3 = 11-25% infested area, 4 = 26-50% infested area, 5 = more than 50% infested area.
Storage rots	Divided into *Neofabraea spp*. (not further divided) and others (not further divided)	Storage time of around 5 months at 2°C. N = 550 fruits per picking (normally 2 pickings) and treatment. Infestation rated after 3 and again after 5 months.
European red mite	*Panonychus ulmi* (Koch)	Yearly examination of 100 typical points of egg deposition per treatment in February, Number of eggs per examined point rated in four classes (up to 10, 11-50, 51-100, more than 100 eggs)
Predatory mites	*Typhlodromus pyri* and others (not further divided)	Number of individuals found on upper and lower side of N = 25 leaves per treatment in June/July using reflecting microscopy.
Apple rust mite	*Aculus schlechtendali* (Nalepa)	Number of individuals found on one cm^2 on N = 25 leaves per treatment showing symptoms (copper-tainted leaf colour and rolled at the sides) using reflecting microscopy. Yearly examination in June/July before and around 7 days after application of rapeseed oil (product name "Micula").
Woolly aphid	*Eriosoma lanigerum* (Hausmann)	Visual observation of N = 220 trees per treatment yearly in June/July. A tree is considered as "Infested" if infested area(s) can easily be seen when slowly walking by.

Results

Apple scab. The variety "Topaz" used in the experiment is classified Vf (Rvi6) resistant against apple scab. Since 2013 at the latest, however, apple scab has been found in the Lake Constance region also on “Topaz”, especially in years with favourable infection conditions. However, the intensity of infestation normally still remains lower than for non-resistant apple varieties.

The results presented in figure 1 show an increased proportion of infested long shoots in two out of four years for the Control. In the years 2016 and 2019 with a relatively high overall infection pressure in our region, the standard organic plant protection management carried out in the Control treatment led to a rate of 9% and 40% of infected long shoots respectively. However, only individual leaves of these long shoots showed scab lesions, and an infestation on fruit was not observed in any experimental year. In contrast, the percentages of infested long shoots in both covered treatments were between 0% and 1% over the entire test period. Thus, even in years with increased infestation pressure, the foil roofs were able to achieve an almost complete regulation of apple scab even though the input of fungicidal plant protection was substantially reduced.

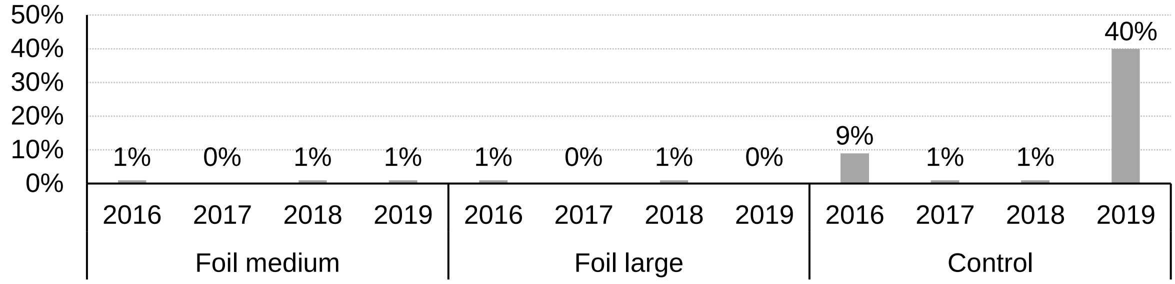
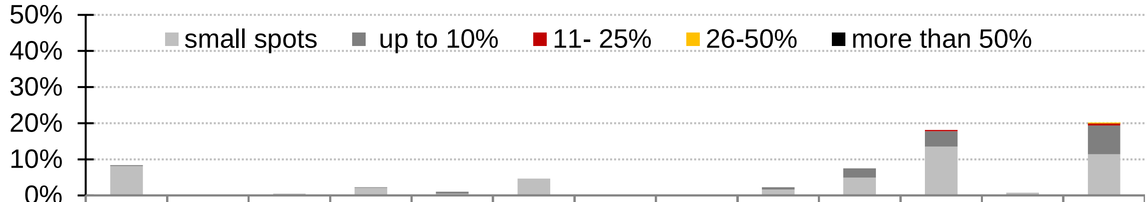


Fig. 1: Percentage of long shoots infested with apple scab, rated yearly in August. N = 100 shoots/treatment/year.

Sooty blotch. In the years 2015 to 2017, the Control treatment showed an annual increase in infestation with sooty blotch (figure 2). Apart from the annual weather conditions, this also reflects the increasing crown volume of the trees planted in 2013. With the exception of the particular dry year 2018, a substantial share of infested fruits was found annually in the Control. The intensity of infestation was largely at a low level, however. Only a small proportion of the examined fruit showed an intolerable degree of infestation with more than 10% of fruit surface covered by the disease.

In comparison, both covered treatments showed only a very small proportion of infested fruit in all five years of the experiment, despite the substantial renunciation of fungicidal plant protection measures.

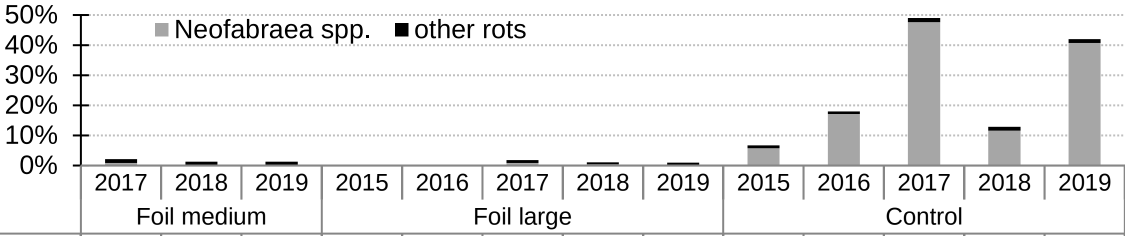


	Foil medium			Foil large					Control				
	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019
more than 50%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
26-50%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,3%
11- 25%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,3%	0,0%	0,5%
up to 10%	0,3%	0,0%	0,0%	0,2%	0,5%	0,0%	0,0%	0,0%	0,6%	2,6%	4,3%	0,0%	8,0%
small spots	8,1%	0,0%	0,5%	2,1%	0,5%	4,7%	0,0%	0,0%	1,7%	4,9%	13,5%	0,7%	11,4%

Fig. 2: Number of fruits infested with sooty blotch in percent, rated annually just before harvest. Percentage of infested fruit surface rated in classes 0-5 by visual estimation. N = 550 fruit/treatment/year.

Storage rots. In Lake Constance region, *Neofabraea spp*. is traditionally the most frequent storage rot. When recording the pathogens that occurred, the different *Neofabraea* species were not further subdivided. Other occurring pathogens such as *Botrytis cinerea*, *Penicillium expansum*, *Nectria galligena* or *Monilia fructigena* were grouped under the category "other rots" due to their low incidence. In the Control treatment, a varying level of incidence over the years of the experiment was observed.

Especially in 2017 and 2019, the percentage of fruit loss due to rots was intolerably high in the Control at around 49% and 42% respectively (figure 3), despite plant protection measures were applied as recommended. It must be taken into account that this level of infestation arose under conditions of cold storage at 2°C and could possibly have been significantly reduced by modern CA storage. Nevertheless, it is remarkable that both foil covers almost completely prevented the infestation by *Neofabraea spp.* over the entire test period.



	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019
	Foil medium			Foil large					Control				
other rots	1,3%	1,0%	1,0%	0,2%	0,0%	1,0%	0,7%	0,9%	0,9%	0,9%	1,4%	1,4%	1,3%
Neofabraea spp.	0,8%	0,3%	0,3%	0,0%	0,0%	0,8%	0,4%	0,1%	5,8%	17,1%	47,6%	11,5%	40,7%

Fig 3.: Percentage of fruits showing storage rots after 5 months of storage. Cumulated data for several pickings (usually 2). N = 550 fruit/treatment/picking/year.

European red mite. The treatment "Foil large" showed an increase in infestation with European red mite from the first year of the experiment on (figure 4). Winter eggs of the mite were found at over 60% of the examined points. From 2017 on, an annual paraffin oil treatment (product name "Para Sommer") was carried out in both covered treatments to control this unwanted development. In the years after, the incidence of winter eggs decreased substantially and fell to a level comparable to the Control. Interesting in this context is the parallel development of predatory mites as natural antagonists of the spider mite. The recording of their occurrence, which began in 2017, shows a steady increase in both covered treatments over the years 2017 to 2019. From 2017 on, the predator mite density has already been higher than in the Control. From 2018 on, substantially higher values were achieved than generally observed in commercial orchards. Values of > 4 predatory mites per leaf, as recorded from 2019 on, usually do not occur in practice and even 0.5 – 1 predatory mite/leaf is regarded sufficient to regulate spider mite population (Trautmann *et al*., 2014).

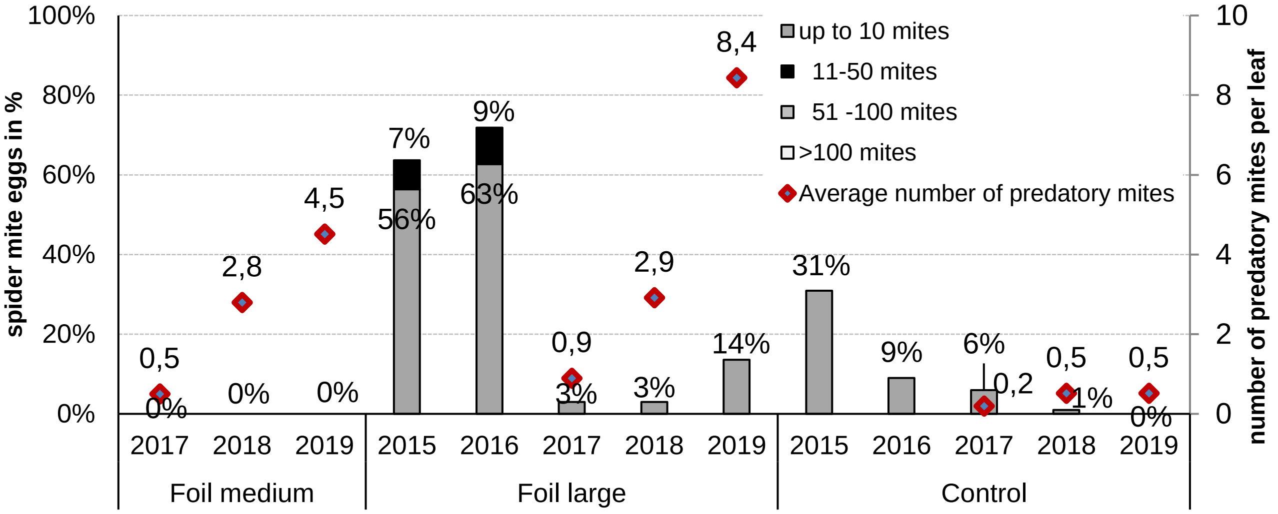


Fig. 4: Eggs of European red mite per point of observation, rated in classes and shown as percentage of N = 100 observation points per treatment/year (bars, left y-axis). Average number of predatory mites per leaf, N = 25 leaves per treatment/year (red point, right y-axis).

Woolly aphid. Infestation by the woolly aphid is a widespread problem, especially in organic apple cultivation, as there is currently no effective plant protection product available. Possible options for its regulation are limited to time-consuming measures such as brushing or indirect measures such as targeted promotion of beneficial organisms. As the variety "Topaz" used in the experiment is particularly susceptible to woolly aphid, an increase under the climatically favourable conditions of the covering systems was expected. Figure 5 shows clear differences in infestation between the covered treatments and the Control. From the first year after the installation of the foil roofs on, infestation levels rapidly increased in both covered treatments (figure 5). In the “Foil large” treatment, more than 60% of the trees were infested already in the second year. The infestation in “Foil medium” remained on a lower but still intolerable level.

From 2016 onwards, targeted measures were taken to regulate the increasing infestation: Earwigs were specifically introduced into the orchard and given day shelters in the form of bamboo canes and clay pots filled with wood wool. They were attached to every fifth tree. In addition, infested areas were brushed several times a year and glue rings were attached to the stem of every tree. Even with this bundle of time-consuming and cost-intensive measures, the infestation could not be reduced to a tolerable level until the end of the experiment. Apart from a slight infestation of 2% in 2018, no infestation by woolly aphid occurred in the Control covered with hail net only during the entire test period.

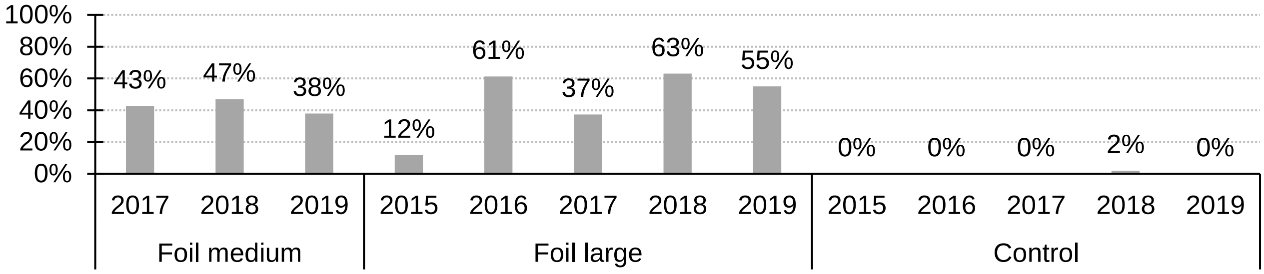
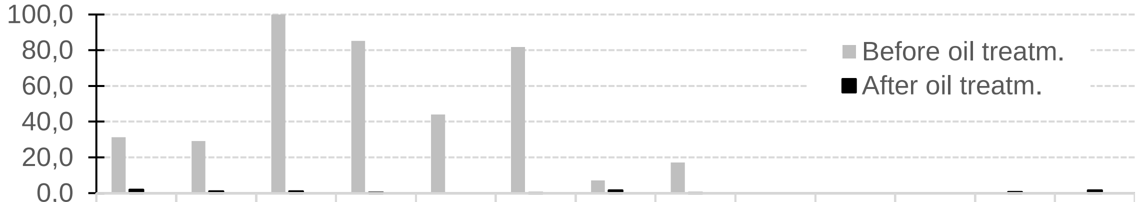


Fig. 5: Percentage of trees infested with woolly aphids. Visual examination, N = 220 trees per treatment/year.

Apple rust mite. Typically, the apple rust mite is not a problematic pest in organic apple cultivation as it occurs only rarely and does not cause any relevant damage in most cases. Under the changed climatic conditions and due to the extended renunciation of fungicide treatments, particularly sulphur, an increased occurrence of the apple rust mite in the covered treatments was detected annually in the period from mid-June to mid-July.



	Foil medium			Foil large					Control				
	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019
Before oil treatm.	31,3	29,2	100,0	85,2	44,0	81,7	7,1	17,1	0,0	0,0	0,0	0,5	0,5
After oil treatm.	2,0	1,1	1,1	0,4	0,0	0,2	1,5	0,2	0,0	0,0	0,0	0,6	1,6
No. of treatm.	2	1	1	1	1	2	1	1	0	0	0	0	0

Fig. 6: Infestation with apple rust mite before and one week after last treatment with rapeseed oil ("Micula"). Average number of individuals found on one examined cm^2 of leaf surface, N = 25 leaves.

In both covered treatments, values between 7.1 and 100 individuals per cm² of leaf surface were counted over the years (figure 6). However, this infestation was reduced to a level of 0 to 1.5 individuals per cm² of leaf surface with one or two applications of rapeseed oil (product name “Micula”) annually. All covered treatments received at least one application every year. If the incidence one week after the first application was still high, a second application was conducted. The Control never received an application.

Within this trial, no phytotoxic damage to the leaves caused by this application was observed. However, it should be noted that without the shading effect of the foil cover or when cultivating other, more oil-sensitive varieties, phytotoxic reactions like leaf necrosis or even leaf fall might be caused by an application of rapeseed oil during the summer months.

Influence on yield. The individual yield per tree was recorded annually on 20 reference trees per treatment. In usually two pickings, the respective number of fruits was counted and the total yield per tree was weighed. Subsequently, fruit size and coloration were measured by means of a sorting machine. When summing up the average tree yields (figure 7), it should be taken into account that treatment "Foil medium" was integrated into the experiment in 2017. As a result, two years of testing are missing in the total sum in this treatment. Apart from slight annual deviations all test treatments had largely comparable yields over the years. Relevant differences were only identified in 2017, when several strong frost events during the flowering period regionally led to high yield losses. In that year, the advantage of the two covering systems became apparent: At around 10 kg and 8 kg per tree, respectively, the yield in the covered treatments was substantially higher than the yield of around 2 kg generated in the Control. Even though a large part of the harvested fruits showed frost-related quality losses, the canopies favoured a higher fruit set in that year. Due to the lower proportion of fruits with fruit russeting, frost-related quality defects and sooty blotch symptoms, a higher proportion of marketable goods was generated in each of the covered treatments.

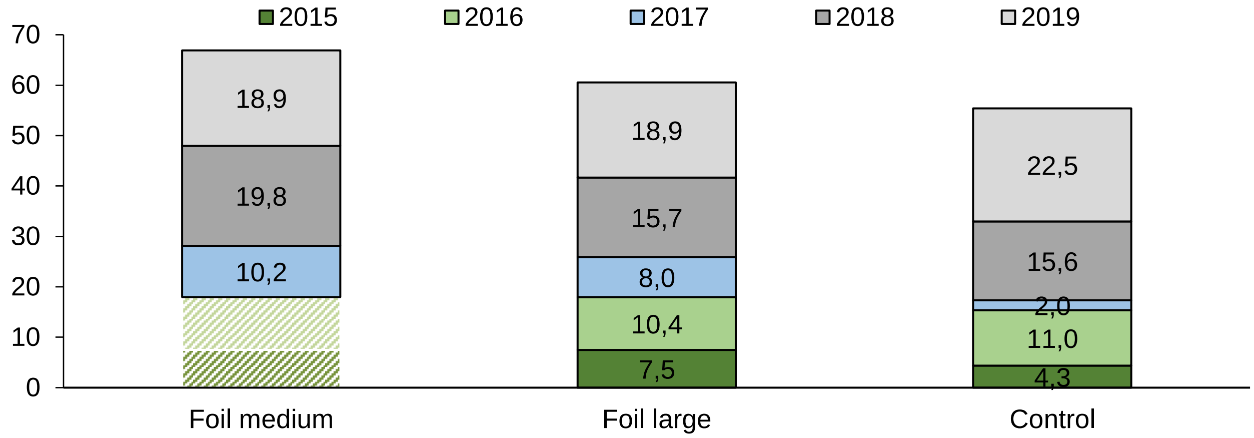


Fig. 7: Cumulative average total yield per tree in kg over the years 2015-2019. N = 20 reference trees per treatment. No values for "Foil medium" in 2015 and 2016, put up on the level of "Foil large" for illustration reasons.

Influence on coloration. Despite the reduction in photosynthetically active radiation of around 30% under the foil roofs, there were no relevant differences in coloration between the covered treatments and the Control.

Discussion

Over the entire test period, both covering-systems were able to allow an almost complete renunciation of fungicidal plant protection measures without negative effects on the infestation with fungal pathogens. In all years of the experiment, infestation by the most important diseases apple scab, sooty blotch and storage rots were completely prevented or at least kept on a level that appears tolerable from a marketing point of view. The standard organic plant protection management carried out in the Control treatment did not achieve a comparable regulatory success. In the overall analysis of fungal pathogens, the most economically relevant benefit of the covering systems was found in the regulation of storage rots. Both systems of coverage led to comparable good results in our trial, thus a reduction of the foil width seems to be possible.

Regarding yield and quality of harvested fruits, the covered systems showed reliable and promising results. The negative influence of frost during blossom was reduced and fruit coloration was hardly affected by the coverage.

Concerning pests, the expected promotion of sucking insects under the covered systems was confirmed. Both European red mite and apple rust mite increased substantially as a result of the coverage. This did not lead to further impairments, as the spider mite was regulated by one oil treatment annually and the sharp increase in predatory mites, and the apple rust mite was successfully regulated with one or at most two annual applications of a rapeseed oil product. However, the sharp increase in infestation by woolly aphids in the covered treatments was not satisfactorily regulated over the entire test period despite exhausting all possible measures. The damage to the trees caused by the woolly aphid was partly intolerable and also fruit loss was caused. A distinct increase in infestation with the woolly aphid was also observed in other field trials of KOB involving treatments covered with nets or foil roofs. Thus, from our results, the woolly aphid represents the largest and yet unresolved barrier for the future use of roofing systems in organic cultivation. For this reason, we are investigating the influence of aphid-tolerant Geneva rootstocks on woolly aphid population under rain roof in an ongoing experiment.

In addition to the plant cultivation aspects, the increased use of plastic must also be included in the overall view. Besides the amount of material used, its durability and recyclability also play a decisive role. The plastic foil used in our experiment only had a life span of a maximum of four years despite the greatest possible renunciation of net sulphur (which is known to lead to a rapid degradation of the foil). This must be described as insufficient, both from an economic point of view and for environmental reasons. Further developments will be necessary on the part of manufacturers of agricultural roofing systems in the future. Approaches involving an automated roof system or a combination with solar panels (agrivoltaics) appear promising. Both concepts will be investigated at KOB starting in 2022.

Acknowledgements

This trial was conducted at the Research and Educational Orchard for Organic Fruit Production at KOB and was funded by the Ministry of Food, Rural Affairs and Consumer Protection (MLR) of Baden-Württemberg, Germany.

References

Trautmann, M., Späth, S., Zeiser, A., Denzel, C. (2014). Situation der Raubmilben in Apfelanlagen des Bodenseegebietes, in: Obstbau: die Fachzeitschrift für den Obstbau-Profi 12/2014, pp. 642-645.