Field trials in apple orchards with different covering methods to reduce plant protection treatments and yield losses due to pests and diseases

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Abstract

According to the principles of organic farming, only natural products and naturally obtained materials may be used for plant protection. Complicated and costly registration procedures make it difficult to approve new active ingredients, while the use of some traditional active ingredients, such as copper, is expected to be further reduced in the future. In short, only a few effective crop protection products are available for organic farming. In contrast, an increase in pests and diseases is observed due to climate change and globalization. As stated in the EU Regulation on Organic Farming, plant health should be preserved by preventative measures, among these also mechanical and physical methods, which undoubtedly include net and foil cover systems. Studies conducted over many years at the RC-Laimburg, working group organic farming, showed that interesting results in the fields of insect control, disease regulation, reduction of drift, and yield regulation can be achieved. However, at the moment not all questions regarding side effects, workload, profitability, landscape and - above all carbon foot print - in comparison to other techniques can be clearly answered.

Keywords: Apple, Codling moth, Apple scab, *Gloeosporium* fruit rot, *Marssonina* leaf blotch, crop regulation, rain cover, single row netting

Introduction

South Tyrol is the largest contiguous apple growing region in Europe. With approx. 2000 ha of organic apple (rising strongly) and yields per hectare of 50 tons and more, South Tyrol is also the most important producer of organic apples in Europe. The climate is ideal for apple growing. The farms are family farms with optimal training, high motivation and great clout. Most of the active ingredients allowed in organic farming, are available on the market in Italy. Despite these optimal conditions, crop protection is still a major challenge. The control of scab on steep slopes in rainy years, sooty mold on late varieties, storage rots on sensitive varieties, codling moth near villages, vectors of apple proliferation, woolly aphids, and the immigration of the brown marmorated stink bug and several more, are all hazards that can be life-threatening for an organic farm. On many cultivated crops (vegetables, table grapes, etc.), netting and covering represent an essential and very efficient complement to crop protection. In apple cultivation, there is little experience with covering structures. The aim of the field trials herein reported was to gain experience with these cover systems. However, implementation in practice in South Tyrol depends not only on the practicability of the cover system, but also on the acceptance by the society and, in particular, by the tourism industry, which plays a key role in South Tyrol's economics.

Material and Methods

The field trials were carried out from 2009 to 2017 in several apple orchards located at the Research Center Laimburg, Vadena, South Tyrol, Italy (coordinates 46°22'59"N 11°17'18"E, 222 m a.s.l., Ø annual rainfall 815 mm, Ø T 11.5°C, predominant soil texture: silty loamy sand). A detailed description of the experimental orchards is provided in Table 1. The trials

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aimed at evaluating whether covering structures could contribute to reducing damage caused by pests, in particular codling moth (*Cydia pomonella*), and diseases, primarily apple scab (*Venturia inaequalis*), *Marssonina* leaf blotch (*Marssonina coronaria*), *Gloeosporium* fruit rot (*Gloeosporium spp*.) sooty mold and Alternaria. In agronomics, the focus was on crop regulation. The assessed data were compared across treatments using Student t-Test or 1-way ANOVAs, followed by Tukey's test ($P<0.05$) for post-hoc comparisons of means. All analyses were performed using the software IBM SPSS Statistics 24.

Table 1: Description of the experimental orchards, in which the efficacy of different covering and netting systems for the control of Codling moth, Apple scab, *Gloeosporium* fruit rot, *Marssonina* leaf blotch and on crop regulation was evaluated.

plot	years	Variety / rootstock	plant. year	plant. distance	orchard management	covering system	topic
1	2011 - 2017	Fuji / M9	2003	3,4 x 1	certified organic	single row[1]	codling moth
110	2010 - 2017	Nicoter / M9	2006	3,0 x 0,8	IPM	plot system[2]	codling moth
53	2011 - 2017	Braeburn / M9	2006	3,2 x 0,8	IPM	single row / plot system	codling moth
103	2015	Fuji / M9	1998	3,2 x 0,9	IPM	Keep in touch®[3]	disease
41	2016 - 2017	Fuji / M9	2003	3,0 x 0,8	IPM	Keep in touch®	disease
82	2015	Cripps Pink / M9	2001	3,0 x 0,9	IPM	Keep in touch®	disease
93	2016 - 2017	Cripps Pink / M9	2012	3,0 x 0,9	IPM	Keep in touch®	disease
1	2010	Gold Rush / M9	2010	3,4 x 1,2	certified organic	single row	crop regulation
64	2011	Golden Reinders / M9	2011	3,2 x 0,9	IPM	single row	crop regulation
1	2014	Pinova / M9	2014	3,4 x 1	certified organic	single row	crop regulation

[1]single row: the single row was covered with a hail net (3x8mm)

[2]plot system: a plot was covered with a hailnet on the top and on the border (3x8mm)

[3] Keep in touch®: www.keepintouchsystem.eu

Results

Table 2: Percentage of fruits affected by codling moth at harvest in the different treatments (different netting systems and control treatment) and trials.

Treatment	Variety	Cydia pomonella - % affected fruits at harvest							
		2010	2011	2012	2013	2014	2015	2016	2017
Hail net - roof system	Braeburn	4,9	5,4	5,7	3,7	6,0	7,9	22,8	38,7
Hail net - single row, downside open	Braeburn	2,3	2,8	3,4	2,2	5,5	3,6	8,5	4,0
Hail - net single row, downside closed	Braeburn	1,4	1,6	1,2	1,5	0,8	2,6	17,3	15,4
Untreated control	Braeburn	27,4	25,9	29,4	27,8	33,8	30,1	65,6	72,5
Hail net - roof system	Nicoter	1,5	12,5	18,3	-	1,4	2,3	2,0	2,6
Untreated control	Nicoter	2,1	13,4	32,9	-	2,9	10,0	13,0	12,9
Hail net - single row	Fuji	0,6	2,5	3,4	2,7	13,4	4,6	35,6	1,1
Control (CpGV)	Fuji	1,7	14,8	2,9	9,4	50,6	9,8	72,0	1,9

Since 2009, at the RC-Laimburg, trials on the efficacy of various netting systems (roof system or single row, either open at the bottom or closed at the bottom) in reducing codling moth damage have been carried out (Kelderer et al., 2010). Except for applications of CpGV (*Cydia pomonella* Granulosis Virus) in the control plots of the Fuji variety (Table 1), no other treatments against codling moth were applied in the experimental plots. No statistical analysis was performed, because randomization of experimental plots was difficult to achieve.

All netting systems considerably reduced the codling moth infestation level in comparison to the control, with the single row netting being more efficient than the roof system (Table 2). In fact, especially under conditions of high pest pressure (plot Braeburn), fruit damage at harvest was considerably higher in the roof system than in the single row netting.

Table 3: Percentage of leaves and fruits affected by apple scab, leaves affected by *Marssonina* leaf blotch, number of predatory mites per leaf, and percentage of fruits affected by russeting at the end of the primary infection period in the different treatments and trials.

Year	Fuji / M9	scab % affect. leaves June	scab % affect. fruits June	marssonina % affect. leaves June	pred. mites per leaf June	russeting % affect. fruits harvest
2015	Polt. disperss, 75 g Cu /ha /treatment	1,0 a	0,3 a	-	0,5 a	17,1 a
	Keep In Touch® opened 05.04.	2,4 a	0,3 a	-	1,1 a	17,4 a
	untreated control	12,0 b	3,6 a	-	0,8 a	20,5 a
2016	Keep In Touch® opened 31.03.	0,0 a	0,6 a	0,8 a	0,4 b	1,3 a
	untreated control	1,6 a	16,7 b	1,0 a	0,2 a	0,2 a
2017	Keep In Touch® opened 10.04.	0,0 a	0,0 a	0,0 a	-	-
	untreated control	0,0 a	0,0 a	0,0 a	-	-

The effect of the rain cover system Keep in Touch® against scab and *Marssonina* leaf blotch infections was tested in comparison to an untreated control in 3 trials during the primary infection period. All experiments were carried out on the variety Fuji. In 2015, the rain cover was compared also to a treatment based on applications of reduced amounts of copper (75 g / ha metallic copper per treatment). In 2016 and 2017, the rain cover was not open until full flowering to avoid excessive thinning. Up to this moment, possible infections were controlled with preventative copper treatments.

The fungal infections in the 3 trial years were not very strong (Table 3). Scab infestation levels exceeding 10% in the untreated control were only observed in 2015 on leaves and in 2016 on fruits. In 2015, the copper treatments and Keep in Touch® achieved efficiencies of respectively 91.4 and 79.6% in reducing scab damage on leaves, and of 92.9% in reducing scab damage on fruits. In 2016, Keep in Touch® showed respectively 100 and 97% efficacy in reducing scab incidence on fruits and leaves. In 2017, no symptoms of apple scab were observed in any treatment. *Marssonina* leaf blotch infections were recorded only in 2016, but the percentage of affected leaves was negligible in all treatments. With regard to fruit russeting, no statistically differences were found between covered and untreated control plots, and no negative effects of the rain cover system on predatory mites emerged in our trials.

Table 4: Percentage of leaves and/or fruits affected by apple scab, *Marssonina* leaf blotch, sooty mold, Alternaria and phytotoxicity at harvest in the different treatments and trials.

year	variety	treatments	scab % affected leaves	scab % affected fruits	marssonina % affected leaves	sooty mold % affected fruits	alternaria % affected leaves	alternaria % affected fruits	phytotox % affected fruits
2015	Cripps Pink	Polt. disperss (150 g Cu /ha / treatment)	21,5 a	8,2 a	-	-	97,0 b	0,7 a	40,0 a
		Keep In Touch® opened 05.08.	8,8 a	21,3 ab	-	-	76,3 a	0,3 a	0,6 a
		untreated control	23,3 a	33,6 b	-	-	100,0 b	1,5 a	0,9 a
2016	Fuji	Keep In Touch® opened 05.04.	8,4 a	0,9 a	-	0,6 a	-	-	-
		untreated control	67,6 b	12,4 b	-	4,7 a	-	-	-
2017	Fuji	Keep In Touch® opened 10.04.	2,4 a	0,0 a	1,4 a	0,8 a	-	-	-
		untreated control	25,5 b	0,5 a	9,1 b	11,4 b	-	-	-

The effect of the rain cover system Keep in Touch® against apple scab, *Marssonina* leaf blotch, sooty mold and Alternaria at harvest was evaluated on the varieties Fuji and Cripps Pink in 3 experiments (from 2015 to 2017).

In the experiment of 2015 on Cripps Pink, the copper-treated trees had less scab-affected fruits than the covered trees (opening of the covers on 05.08.), and fruits on covered trees were again less attacked than those on untreated control trees (Table 4). The leaves were full of Alternaria spots in all three treatments, while Alternaria incidence on fruits was negligible. Striking was the high percentage of fruits burned by copper, although only a very small application rate per treatment was used. In 2016 and 2017, Keep in Touch® was mounted on a Fuji orchard already in spring and opened during flowering. The scab infections up to that time were covered preventatively with copper. In both years, a statistically significant reduction of apple scab, *Marssonina* leaf blotch and sooty mold was observed on covered trees in comparison to the untreated control, when relevant infection occurred.

Table 5: Percentage of fruits affected by *Gloeosporium* fruit rot in the different treatments and trials after 6 months of cold storage (=storage), and after several additional days of storage at room temperature (=shelf life).

Year	% of fruits affected by Gleosporium rot						
	variety	End of Storage	End of Shelf life	Treatments	after Storage	after Shelf life	Total
2015	Pinova	08.03.2016	21.03.2016	Ulmasud (2 treatments)	12,8 a	10,2 a	23,1 a
				Keep in touch® opend at 05/08/2016	11,9 a	12,9 a	24,8 a
				untreated control	18,6 a	11,6 a	30,3 a
2016	Pinova	06.02.2017	24.02.2017	Ulmasud (8 treatments)	15,7 ab	28,8 ab	44,5 ab
				Keep in touch® opend at 07/07/2016	6,6 a	13,0 a	19,6 a
				untreated control	24,2 b	37,7 b	61,9 b
2016	Rosy Glow	01.03.2017	16.03.2017	Keep in touch® opend at 02/08/2016	2,2 a	1,55 a	3,7 a
				untreated control	21,3 b	6,425 a	27,8 b

The effect of the rain cover system Keep in Touch® on *Gloeosporium* fruit rot was evaluated in 3 experiments. Two trials were performed on the variety Pinova, and the cover system was tested in comparison to an untreated control and treatments with acid clay (15 kg/ha/treatment), the standard treatment in organic cultivation against *Gloeosporium* fruit rot. The number of applied treatments is reported in Table 2. The third trial, instead, was carried out on the variety Rosy Glow, and the cover system was evaluated in comparison to an untreated control. The evaluation on *Gloeosporium* fruit rot was made after a 6-month storage period in regular atmosphere at T 2°C and RH 90%, and repeated after storage for several days at 20°C to investigate possible effects on shelf life.

In 2015, the cover system could be opened only in August, and during the same period the first treatment with acid clay was carried out. For this reason, the efficiency of the two tested treatments after storage and Shelf life was low (23.8% for acid clay and 22.0% for Keep in Touch®; Table 5). In 2016, the cover system was opened in July and compared to 8 acid clay treatments from that time on up to harvest. The efficacy of the acid clay treatments was similar to that observed in the previous year, while Keep in Touch® achieved an efficiency of 68.7%. The trial conducted on the variety Rosy Glow confirmed the good efficacy of the cover system against *Gloeosporium* fruit rot (86.7% efficacy).

Table 6: Percent thinning effect obtained with different netting and cover systems in the trials conducted from 2010 to 2016 on different varieties.

Year	variety	typ of net/ opening time	thinning eff. in %	fr / 100 f.c.	g / fruit
2010	GoldRush	hailnet / before flowering	46,5	63,4 a	-
		hailnet / during flowering	25,1	88,9 b	-
		control	-	118,6 c	-
2011	Golden D.	hailnet / before flowering	35,4	84,7 a	181,3
		hailnet / during flowering	21,4	103,0 b	178,9
		control	-	131,0 c	146,7
2014	Kanzi	hailnet / before flowering	29,9	66,5 a	211,8
		hailnet / during flowering	5,0	90,2 b	194,9
		control	-	94,9 b	173,7
2015	Fuji	Keep in Touch® / before flowering	65,0	-	-
2016	Fuji	Keep in Touch® / during flowering	~ 60*	-	-

* estimation

Since 2010, the impact of different cover systems on fecundation and yield has been assessed at the RC-Laimburg. Some of these data have already been published as part of the ecofruit proceedings (Kelderer et al., 2014). As shown in Table 1, both the single row cover and the Keep in Touch® system have been tested in recent years.

A significant thinning effect, which varied significantly depending on the time at which the cover was opened, emerged for both systems (Table 6).

Discussion

Organic fruit growers have a very limited number of tools available for direct crop protection and in some countries, no tools are available at all. Despite honest efforts to promote functional biodiversity and robust varieties, outbreaks of pests and diseases often occur. This is especially true in permanent crops, where sometimes over the years high population levels may build up due to the high number of generations per year of certain pests, infested plant material that constitutes a continuous inoculum, and development of resistance to plant protection products.

Organic vegetable farming is moving more and more towards protected cultivation. The question arises whether organic apple cultivation should also follow this path. There are many unanswered questions concerning the effectiveness of cover systems against various pests and diseases. Other questions are if other pests could be indirectly promoted, or whether adverse effects on the fruit set of the trees and the quality of the fruits may appear. The rationality and profitability of management is another important topic, and, last but not least, the carbon foot print of such systems that can be created only with high amounts of plastic films. Protected cultivation of cherries certainly plays a pioneering role in fruit growing (Charlot et al., 2014). Organic cherry growing without covers has become practically impossible in most regions of Europe, because fruit cracking, *Monilinia* spp., cherry fruit flies and above all the cherry vinegar fly leave the organic fruit farmer no other choice. In apple cultivation, the netting of individual rows or whole plots by a roof system against codling moth has made the start. Research and practice showed that, under normal pest pressure, codling moth can be controlled with these systems (Romet et al., 2008, 2010; Kelderer et al., 2010). Only in very extreme situations a strong population may build up, which was so far controlled with mating disruption and additional insecticide sprays.

The single row netting offered the opportunity to regulate fruit set by opening the net before or during flowering (Kelderer et al., 2014). However, also a significant increase of woolly aphid, a key pest for the organic apple grower, was observed (data not published).

Relatively new is the rain cover system in apple cultivation. The three-year experiments at the RC-Laimburg showed promising effects of this system against apple scab, *Marssonina* leaf blotch, Sooty mold and *Gloeosporium* fruit rot, while for Alternaria control no conclusions can be drawn, because the infestation level was too low. In order to recommend this system in practice, further tests on different varieties in different locations in comparison to other systems must be carried out, because such a system may result in significant changes in cultural management, which currently have not yet been identified.

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