BioControl (2005) 50: 179–194

Effect of cultural methods on leaf spot (*Mycosphaerella fragariae*) and gray mold (*Botrytis cinerea*) damage in strawberries

Andi SCHMID*, Claudia DANIEL and Franco WEIBEL
Research Institute of Organic Agriculture (FiBL), Ackerstrasse, CH-5070 Frick, Switzerland
**Author for correspondence; e-mail: andi.schmid@fibl.ch*

Received 8 April 2003; accepted in revised form 15 May 2004

Abstract. Damage of leaf spot, caused by *Mycosphaerella fragariae* and gray mold also called Botrytis fruit rot, caused by *Botrytis cinerea*, average fruit weight and yield were evaluated with regard to cultural methods over 2 years. Leaf spot damage decreased significantly by around 90% due to leaf sanitation (removal of dead and leaf spot infected leaves in early spring) and by 50% due to plantation in a one-row-system instead of a two-row-system. When all leaves including the healthy green ones were removed in early spring, average fruit weight decreased significantly by 10%. Fruit sanitation – the third treatment – did not influence any of the measured parameters. Neither leaf sanitation nor fruit sanitation (removal of damaged fruits during harvest) reduced *B. cinerea* damage significant. Only the combination of a one-row-system, leaf sanitation and fruit sanitation almost halved (not significantly) *B. cinerea* damage in the first crop year compared to a two-row-system without leaf and fruit sanitation. *B. cinerea* damage correlated significantly and positively with the biomass of plants by $R^2 = 0.47$. According to this study and the cited literature it is suggested for humid Central European conditions to apply a one-row-system combined with leaf sanitation in early spring and fruit sanitation during harvest if fruit density is high, to reduce the risk of damages in larger dimension caused by *M. fragariae* and *B. cinerea*.

Key words: average fruit weight, biomass, Biotica: *Fragaria* × *ananassa* Duch.(Rosaceae), *Botrytis cinerea* Pers., fruit sanitation, leaf sanitation, *Mycosphaerella fragariae* Tul., yield

Introduction

Leaf spot caused by *Mycosphaerella fragariae* Tul. is one of the most common diseases of strawberry (*Fragaria* × *ananassa* Duchesne) (Maas, 1998b). There is a wide range of susceptibility between strawberry cultivars (Delhomez et al., 1995). Three sources of primary inoculum exist: Conidia that survive the winter on lesions on living leaves, conidia produced from overwintering sclerotia, and ascospores. In the absence of perithecia and sclerotia, conidia are the sole source of inoculum. Conidia are produced abundantly in early summer on leaf spots on both the upper and the lower surfaces of leaves and on lesions on other plant parts. Conidia are disseminated primarily by splashing water (Maas, 1998b). Ascospores are disseminated over long-distances by the wind. Ascospores can be as important source of primary inoculum as conidia (Maas, 1998b). Young leaves (5–7 days old) are much more susceptible than older ones (12 to 15 or 19 to 21 days old) to infection by conidia. The optimal temperature for infection is 25 °C and the minimum duration of leaf wetness required to induce infection is 12 h (Carisse et al., 2000). The control of leaf spot mostly relies on the application of protective fungicides (Maas, 1998b). In organic agriculture the use of copper products is effective (Vukovits, 1980) but the aim is to reduce or avoid the copper use because of its accumulation in the soil and its negative influence on vegetation (Bergmann, 1993). Control of leaf spot by leaf sanitation was suggested by Scherer (1989) but there are no results of scientific trials available.

The fungus *Botrytis cinerea* Pers. causes Botrytis fruit rot (= gray mold or ash mold), and is one of the most destructive diseases of strawberry worldwide (Maas, 1998a). Botrytis fruit rot is managed conventionally by fungicides applied during blossom to protect the flowers and fruits. Up to now, in organic agriculture in Switzerland there are no botryticides permitted against fruit rot in strawberry. The establishment of latent infections of floral parts is one of the major reasons for rot of ripe fruits caused by *B. cinerea* (Bulger et al., 1987). Conidia are the main inoculum in epidemics of Botrytis fruit rot (Maas, 1998a). In Canada dead strawberry leaves are the principal inoculum source (Braun and Sutton, 1988), but mycelium or sclerotia occur also in weed residues and mulch materials or in mummified fruits (scerotia) (Jarvis, 1962). Key strategies for managing gray mold fruit rot of strawberry include suppression of conidial production and protection of flowers against infection by conidia (Sutton and Peng, 1993). According to Sutton and Peng (1993), destruction or inhibition of pathogen colonies in senescent and dead leaves is one possible approach to protect susceptible green leaves against infections. In a study by Mertely et al. (2000) the removal of senescent leaves (leaf sanitation) afforded protection against Botrytis fruit rot; in another study (Daumgaard et al., 2003), leaf sanitation afforded protection in only one out of three years and only in one of two cultivars. In two other studies (Daumgaard, 2000; Boff et al., 2002), leaf sanitation did not decrease Botrytis fruit rot significantly. Fruit rot is favoured by moderate temperatures (15–25 °C) and long periods of high relative humidity or surface wetness during the flowering period (Wilcox and Seem, 1994). Legard (2000) determined, that narrower spacings had higher damages of *B. cinerea* than wider spacings.

The cultivation of strawberry on raised bed covered with plastic films has increased significantly in Switzerland since 1998 (Anonymous, 1998–2002). Farmers report that strawberry plants cultivated in this manner have much more dead leaves in spring than in the traditional system without plastic mulch films.

In this study the effects of sanitation practices (the removal of dead leaves and rotten fruit) and planting density (one-row-system and two-row-system) on leaf spot, Botrytis fruit rot, average fruit weight, yield and biomass was evaluated.

Material and methods

The experiments were carried out in 2000 and 2001 at the Research Institute of Organic Agriculture at Frick (380 m of altitude, 900 mm annual rainfall, loamy clay soil) and in 2001 in the center of a commercial organic strawberry field at Brittnau (500 m of altitude, 1000 mm annual rainfall, sandy loam). The aim of the study in the first year (2000) was to detect if cultural methods have any influences on *M. fragariae* and *B. cinerea* damages. In the second year (2001) it was the aim to determine the effectiveness of the applied cultural methods on *M. fragariae* and *B. cinerea* damages. Treatments and experimental designs are described in Table 1. Horticultural practices at Frick and Brittnau are described in Table 2.

Data collection

Frick 2000 and 2001

In each plot, fruits were picked plotwise at three picking dates. To avoid edge effects in 2000, fruits of the edge rows and at the end of the rows were not picked; in 2001, all blossoms from edge plants were removed. Healthy fruit and fruit damaged by *B. cinerea* were counted separately, healthy fruit were weighted. Leaf spot severity was assessed by estimation of percentage of leaf area covered according Cive (1971). After harvest in 2001 all plants were cut off and the biomass was determined.

Brittnau 2001

In the first harvest, all green fruit infested by *B. cinerea* were picked (at this moment there were no ripe fruit present). Later the ripe fruit were picked in twice. Healthy fruits were counted and weighed, fruits

Table 1. Treatments and experimental design at Frick and Brittnau in 2000 and 2001

Site, date	Treatment	Row-system	Leaf sanitation	Fruit sanitation	Repetitions	Blocks	Plants/repetition
Frick, 2000	A≪full prevention≫	ors	+ls	+fs	2	–	168
	B ≪control≫	trs	−ls	−fs	2		168
Frick, 2001	A	ors	+ls	+fs	4	2	21
	B	trs	−ls	−fs	4	2	21
	C	ors	+ls	−fs	4	2	21
	D	trs	−ls	+fs	4	2	21
	E	ors	−ls	+fs	4	2	21
	F	trs	+ls	−fs	4	2	21
	G	ors	−ls	−fs	4	2	21
	H	trs	+ls	+fs	4	2	21
Brittnau, 2001	D	trs	−ls	+fs	5	–	22
	H	trs	+ls	+fs	5		22

ors = one-row-system; trs = two-row-system; + ls = with leaf sanitation; −ls = without leaf sanitation; + fs = with fruit sanitation; −fs = without fruit sanitation.

damaged by *B.cinerea* were counted separately. Between two treatments four edge plants were not picked to reduce influences from the neighboring treatment. After harvest all plants were cut above ground level and biomass was determined.

Statistical analysis

Data analysis was done by JMP 4.0.2 (SAS incorp.) statistic program.

Model of analysis of variance (ANOVA) at Frick 2000: Repetition, treatment.

Model of analysis of variance (ANOVA) at Frick 2001: Block, row-system, leaf sanitation, fruit sanitation, row-system∗leaf sanitation, row-system∗fruit sanitation, leaf sanitation∗fruit sanitation, row-system∗leaf sanitation∗fruit sanitation. *M. fragariae* and *B. cinerea* damage, fruit weight and yield in 2000 were included in the ANOVA and checked as co-variable. Correlation between biomass and *M. fragariae* and *B. cinerea* damage fruit weight and yield was determined.

Model of analysis of variance at Brittnau 2001: Repetition, treatment.

Table 2. Horticultural practices at Frick and Brittnau in 1999, 2000 and 2001

Date	Frick	Brittnau
1999		
May	Milling of the extensively managed meadow and sowing of a green manure blend of oat and vetch	
July	Mulching the green manure, spading and milling again	
August	Forming of the raised beds. Two-row system: Width 40 cm, height 20 cm. One-row system: Width 25 cm height 20 cm, installation of a drip irrigation in each raised bed, covering with a black water impermeable mulch film. Followed by measurement of nitrogen content in 0 to 30 cm depth (four equal subplots in each repetition).	Planting of potted green plants cv. 'Thuriga' in double rows on raised beds (≪two-row system≫). Preceding crop: Grass clover blend. Distance between each plant 20 cm, between the row on one raised bed 25 cm, between the centre of the raised beds 1.75 m.
August 12	Planting of potted green plants cv. 'Senga Sengana'. Two-row system: Distance between each plant 33 cm, between the middle of the raised beds 1.50 m, between the rows on the raised bed 25 cm (– > 4 plants/m^2). One-row system: Distance between each plant 33 cm, between the middle of the raised beds 75 cm (– >4 plants/m^2).	
August 30	Assessment of mineralised nitrogen (N_{min}) content in 0 – 30 cm depth (at 4 subplots in each repetition; n = 16). N_{min} level in each subplot was raised to 60 kg/ha by an organic liquid fertiliser (≪Biorga N-flüssig≫ also called ≪Vinasse≫, 7.2% N, 1.5% K_2O).	
August–October	Irrigation if needed, the irrigation duration in the two-row system was double because of double count of plants to irrigate on each raised bed compared with the one-row system.	

Table 2. Continued

Date	Frick	Brittnau
2000		
March (before plants began to sprout):	Assessment of mineralised nitrogen content in 0 to 30 cm depth (at 4 subplots in each repetition; n = 16), no fertilisation because most of the N_{min} levels were above 60 kg/ha. Treatment ≪full prevention≫ (with leaf and with fruit sanitation, one-row system): Removal of all dead and leaf spot attacked leaves and stems by hand (once). Control: All dead and leaf spot attacked leaves were left.	
May–June	During harvest removal of all rotted fruits. Control: After counting the rotted fruits they were redistributed between the plants in this treatment. Treatment ≪full prevention≫: After counting the rotted fruits they were disposed. In both treatments all fruit were picked, also small ones at the end of harvest.	Fruit harvested by the farmer (no trial).
July	After harvest in both treatments all crowns up to one and all leaves were removed. Followed by feeding of half a liters of compost each plant.	
2001		
March (before plants began to sprout)	Treatment ≪+ls≫ Removal of all senescent and leaf spot attacked leaves and stems by hand.	Removal of all dead and healthy green leaves and stems in treatment ≪+ls≫. In the control all leaves were remained.
April (before blossom)	To avoid the spread of infective material between the treatments, each of the subplots (with and without leaf sanitation) were covered with a double layer of fleece (≪Covertan-Pro≫, 17 g/m^2), pillowed by iron rods of 0.90 m height. Pollination in each subplot was conducted four times by brush (in each subplot with a separate brush). After blossoming the fleeces were removed. Followed by assessment of mineralised nitrogen content in 0–30 cm depth (four equal subplots in each repetition). Highest content in a subplot was 227 kg N_{min}/ha, lowest content was 32 kg N_{min}/ha.	

May 9 (blossom)	Fertilisation with ≪Biorga N-flüssig≫ to increase the N_{min} level in each subplot to 250 kg/ha. Three, two and one days before first pick all plots were sprinkled in the evening by overhead irrigation to increase infestations of *B. cinerea* and *M. fragariae* (otherwise it would not be sure to have enough infections for a trial).	
May–June	During harvest removal of all rotted fruits. Rotted fruits from treatment ≪without fruit sanitation≫ were repatriated in this treatment like in control in 2000.	During harvest rotten fruits were removed in both treatments.

Results

M. fragariae *damage*

In 2000 *M. fragariae* damage decreased from 13.5% in 'control' to 1.0% in treatment 'full prevention', however this difference was not significant ($p = 0.08$) (Table 3).

A correlation analysis revealed that *M. fragariae* damage in 2000 did not influence *M. fragariae* damage in 2001. In 2001 the infested leaf surface was significantly influenced by leaf sanitation (+ls [4.8%] < −ls [53.0%]), row-system (ors [19.2%] < trs [38.7%]) and block (I [23.0%] < II [34.8%]) (analysis of variance, $p \leq 0.05$) (Table 4).

No significant correlation was found between *M. fragariae* damage and biomass (Table 6).

At Brittnau leaf spot damage was not evaluated (no damage).

B. cinerea *damage*

At Frick in 2000 *B. cinerea* damage decreased from 10.4% in the 'control' treatment to 5.0% in treatment 'full prevention' (difference not significant, analysis of variance, $p = 0.23$) (Table 3).

Table 3. Influence of two treatments and repetions on *M. fragariae* and *B. cinerea,* damage, average fruit weight and yield of strawberries (cv. Senga Sengana) at Frick 2000

	M. fragariae June 30 (% infested leaf surface)	*B. cinerea* (% infested fruits)	Average fruit weight (g)	Yield/plant, only healthy fruits (g)
Treatment	ors + ls + fs ≪full prevention≫ (1.0 ± 0.0) a < trs −ls –fs ≪control≫ (13.5 ± 2.1) a	ors + ls + fs ≪full prevention≫ (5.0 ± 2.2) a < trs −ls −fs ≪control≫ (10.4 ± 0.7) a	ors + ls + fs ≪full prevention≫ (7.7 ± 0.7) a > trs –ls –fs ≪control≫ (7.0 ± 1.0) a	ors + ls + fs ≪full prevention≫ (651.6 ± 67.7) a > trs −ls −fs ≪control≫ (410.8 ± 1.4) a
Repetition	I (6.5 ± 7.8) a < II (8.0 ± 9.9) a	I (7.1 ± 5.3) a < II (8.2 ± 2.4) a	I (7.4 ± 0.3) a > II (7.2 ± 1.3) a	I (507.8 ± 135.8) a < II (554.6 ± 204.9) a

Means (≪ ± ≫ = standard deviation) within each field followed by the same letter are not significantly different (analysis of variance, $p > 0.05$).
ors = one-row-system; trs = two-row-system; + ls = with leaf sanitation; −ls = without leaf sanitation; + fs = with fruit sanitation; −fs = without fruit sanitation.

Table 4. Influence of several factors on *M. fragariae* and *B. cinerea*, damage, average fruit weight, yield and biomass on strawberries (cv. Senga Sengana) at Frick 2001

Factor	*M. fragariae* June 21 (% infested leaf surface)	*B. cinerea* (% infested fruits)	Average fruit weight (g)	Yield/plant, only healthy fruits (g)	Biomass/plant (g)
M. fragariae June 30 2000 (% infested leaf surface) [co-variable]	n.s.	–	–	–	–
B. cinerea 2000 (% infested fruits) [co-variable]	–	*	–	–	–
Average fruit weight (g) [co-variable]	–	–	n.s.	–	–
Yield / plant, only healthy fruits (g) [co-variable]	–	–	–	n.s.	–
Block	I (23.0 ± 27.0) a < II (34.8 ± 32.7) b	I (9.6 ± 5.3) a > II (7.4 ± 4.5) b	I (3.8 ± 0.6) a > II (3.2 ± 0.4) b	I (273.8 ± 60.9) a > II (230.1 ± 59.2) b	I (127.0 ± 17.7) a > II (97.3 ± 35.0) b
Row-system	ors (19.2 ± 21.6) a < trs (38.7 ± 34.7) b	ors (8.9 ± 4.3) a > trs (8.1 ± 5.7) b	ors (3.5 ± 0.5) a > trs (3.4 ± 0.7) a	ors (281.9 ± 59.1) a > trs (222.0 ± 53.2) a	ors (125.5 ± 27.2) a > trs (98.8 ± 29.8) b
Leaf sanitation[a]	+ls (4.8 ± 2.3) a < −ls (53.0 ± 25.1) b	+ls (7.6 ± 4.5) a < −ls (9.4 ± 5.4) a	+ls (3.8 ± 0.6) a > −ls (3.1 ± 0.4) b	+ls (284.9 ± 61.4) a > −ls (219.0 ± 46.3) b	+ls (110.4 ± 28.9) a < −ls (113.9 ± 34.1) a

Table 4. Continued

Factor	*M. fragariae* June 21 (% infested leaf surface)	*B. cinerea* (% infested fruits)	Average fruit weight (g)	Yield/plant, only healthy fruits (g)	Biomass/plant (g)
Fruit sanitation	+fs (29.3 ± 32.0) a > −fs (28.6 ± 29.2) a	+fs (8.2 ± 4.3) a < −fs (8.8 ± 5.7) a	+fs (3.5 ± 0.5) a = −fs (3.5 ± 0.7) a	+fs (251.4 ± 65.0) a < −fs (252.5 ± 63.3) a	+fs (115.8 ± 33.9) a > −fs (108.4 ± 28.8) a

* significance at a level of 0.05.
n.s. = Not significant; – = obsolete to test.
ors = one-row-system; trs = two-row-system; +ls = with leaf sanitation; −ls = without leaf sanitation; +fs = with fruit sanitation; −fs = without fruit sanitation.
[a] Removal of dead leaves and green leaves infested by *M. fragariae* before sprouting
Means (≪ ± ≫ = standard deviation) within each field followed by the same letter are not significantly different (analysis of variance, $p > 0.05$).

B. cinerea damage in 2000 influenced *B. cinerea* damage in 2001 significantly (Table 4). With this effect included as co-variable in the ANOVA-Model in 2001 *B. cinerea* damage was influenced by the row-system (ors [8.9%] > trs [8.1%]) and by the block (I [9.6.0%] > II [7.4%]). Neither leaf sanitation nor fruit sanitation did reduce *B. cinerea* damage significantly (analysis of variance, $p > 0.05$) (Table 4).

At Brittnau leaf sanitation significantly (analysis of variance, $p = 0.05$) increased *B. cinerea* damage on green fruits (8 days before the first pick) from 10.8 to 20.4%. In the following two picks and in the total of all three picks, however, there occur no significant differences (analysis of variance, $p > 0.05$) between the two treatments (Table 5).

At Frick plant biomass after harvest correlated significantly positive (at a *p*-level of 0.001) with *B. cinerea* damage ($R^2 = 0.47$) (Table 6).

Average fruit weight, yield per plant and plant biomass after harvest

At Frick in 2000 in treatment 'full prevention' the average fruit weight was slightly but not significantly (analysis of variance, $p > 0.05$) higher (10%) than in the 'control'. Treatment 'full prevention' increased yield by 59% (652 g/plant) compared to the 'control' with 411 g/plant in (difference not significant, analysis of variance, $p = 0.13$) (Table 3).

The average fruit weight and yield in 2000 did not significantly influence these values in 2001. There, the average fruit weight was significantly influenced by leaf sanitation (+ls [3.8 g] > −ls [3.1 g]) and block (I [3.8 g] > II [3.2 g]) (analysis of variance, $p \leq 0.05$). Also yield was significantly influenced by leaf sanitation (+ls [285 g] > −ls [219 g]) and block (I [274 g] > II [230 g]). Biomass was significantly influenced by row-system (ors [126 g] > trs [99 g]) and block (I [127 g] > II [97 g]) and (Table 4).

In contrast to Frick at Brittnau the average fruit weight decreased significantly (analysis of variance, $p \leq 0.05$) from 10.4 g in the treatment without leaf sanitation to 9.4 g in the treatment with leaf sanitation. Leaf sanitation decreased also yield from 155 g to 138 g (difference not significant, analysis of variance, $p = 0.19$) (Table 5).

At Frick plant biomass correlated significantly and positively with average fruit weight ($R^2 = 0.25$, at a *p*-level of 0.01) and yield ($R^2 = 0.45$, at a *p*-level of 0.001) (Table 6).

Discussion

In 2000 *M. fragariae* damage was markedly (but not statistically significantly, probably due to the chosen experimental layout) reduced in

Table 5. Effect of leaf sanitation on *B. cinerea* damage, fruit weight, yield and biomass in strawberry cv. Thuriga at Brittnau 2001

Parameter	*B. cinerea* (% infested fruits) June 14[a]	*B. cinerea* (% infested fruits) June 22	*B. cinerea* (% infested fruits) June 29	*B. cinerea* (% infested fruits) Total	Average fruit weight (g)	Yield/plant, only healthy fruits (g)	Biomass/plant (g)
Leaf sanitation[b]	+ls (20.4 ± 6.2) a > −ls (10.8 ± 2.3) b	+ls (13.8 ± 3.0) a = −ls (13.8 ± 2.0) a	+ls (10.7 ± 2.3) a > −ls (10.6 ± 1.7) a	+ls (44.9 ± 9.9) a > -ls (35.2 ± 3.6) a	+ls (9.4 ± 0.6) a < −ls (10.4 ± 1.2) b	+ls (137.8 ± 21.3) a > −ls (155.1 ± 23.7) a	+ls (304.0 ± 45.0) a > −ls (300.4 ± 60.2) a

+ls = with leaf sanitation; −ls = without leaf sanitation.
[a] Gathering of *B. cinerea* infested green fruits, at this moment there were no fruits ripe
Means within each field followed by the same letter are not significantly different (analysis of variance, $P < 0.05$).
[b] Removal of all dead and green leaves before sprouting.

Table 6. Correlation coefficients (R^2) between biomass and *M. fragariae*, *B. cinerea* damage, average fruit weight and yield in strawberries cv. Senga Sengana at Frick in 2001 ($n = 32$)

Parameter	*M. fragariae* June 21	*B.cinerea*	Average fruit weight	Yield/plant, only healthy fruits
Biomass/plant	0.07 n.s.	0.47^{***}	0.25^{**}	0.45^{***}

** Significance at a level of 0.01; *** significance at a level of 0.001; n.s. = not significant.

treatment 'full prevention' (combination of leaf sanitation, fruit sanitation and one-row-system) compared to the 'control' (combination of no leaf sanitation, no fruit sanitation and two-row-system) by 92%. A significant reduction of *M. fragariae* damage by 91% due to leaf sanitation alone was observed in 2001. Although after harvest in 2000 all leaves were removed, *M. fragariae* damage did occur in 2001 quite severely, consequently this method suggested by Scherer (1989), did not prevent the reoccurrence of leaf spot. According our study it is more effective to remove all dead and leaf spot infested leaves in early spring before plants begin to sprout. Whereas, according the results from Brittnau in 2001, it is possible that average fruit weight and yield decrease if all leaves (also the healthy green ones) are removed. Therefore leaf sanitation in spring should be done carefully, healthy green leaves should remain intact. According to our study *M. fragariae* damage was also influenced by the choice of the row-system, in the one-row-system leaf spot damage was significantly 50% lower than in the two-row-system.

In 2000 Botrytis fruit rot damage was almost halved (not significant) in treatment 'full prevention' compared to the 'control'. However, in the second year (2001) only block and row-system influenced *B. cinerea* damage slightly. According to two other studies (Daugaard, 2000; Boff et al., 2002) leaf sanitation did not decrease Botrytis fruit rot significantly. However, in the experiment of Daugaard, (2000) leaf sanitation occurred in the fall (post-harvest) while in ours leaf sanitation was done in the spring (pre-blossom). Boff et al. (2002) removed all senescing leaves from the strawberry plants twice per week, starting immediately after transplanting until first harvest. This practice did not reduce *B. cinerea* infection in comparison with the untreated control. This experiment was conducted with an annual waiting-bed production. In an earlier study, Boff et al. (2001) determined that in the annual waiting-bed production, the aerial concentration of *B. cinerea* conidia in untreated plots did not differ from the concentration in plots where all dead leaves had been removed nor from the concentration at 25–50 m distance from the strawberry plots. Boff et al. (2001) detected that in the annual cropping system with waiting-bed transplants, necrotic leaves are not a significant source of *B. cinerea* inoculum, unlike in other more common strawberry production systems. In a second study Daugaard et al. (2003) applied pre-blossom-leaf sanitation and in another treatment post-harvest-leaf sanitation. In this study leaf sanitation (pre-blossom as well as post-harvest) did only in one of 3 years and only in one of two cultivars decrease *B. cinerea* damages. Mertely et al. (2000) removed necrotic and senescent leaves in one treatment twice (first time after plant establishment and second time after 3 months) and in another treatment monthly beginning after plant establishment. Affected fruit were removed twice a week. In contrast to single leaf sanitation or single fruit sanitation the combined treatment with fruit sanitation and monthly leaf sanitation reduced Botrytis fruit rot significantly from 12.6 to 8.3%.

In our study, *B. cinerea* damage was not influenced by fruit sanitation during harvest. Probably due to the fact that the fruit density was low and crossinfection from a rotted fruit to a healthy fruit by mycelium was rare. As mentioned only in 2000 the combined treatment with fruit sanitation, leaf sanitation and one-row system decreased *B. cinerea* damage (not significantly).

In 2001 at Frick the correlation between biomass and *B. cinerea* damage (infested fruits) was significant and positive in contrast to damage caused by *M. fragariae*, where no correlation was observed. This fact may explain the higher *B. cinerea* damage in the one-row-system (high biomass) compared to the two-row-system (low biomass). The correlation between Botrytis fruit rot damage and biomass might be caused by less space between each plant causing a longer wetness period of leaves, flowers and fruit promoting *B. cinerea* damage again (Wilcox and Seem, 1994; Berrie et al., 1998; Maas, 1998a). Also Legard (2000) determined that narrower spacings had higher damage of *B. cinerea* than wider spacings.

At Frick average fruit weight was in all treatments explicitly below-average due to the chosen variety and because all fruits – also the small ones at the end of harvest – were picked. In 2000 at Frick average fruit weight and yield increased (not significantly) in treatment ‘full prevention’ to 10 and 59% respectively compared with the ‘control’. We suppose that this increase was due to less leaf spot attack and less competition for nutrients, water and light in this treatment with leaf sanitation and one-row-system. Also in 2001 yield was higher (not significantly) in the one-row-system than in the two-row-system and was positively influenced by leaf sanitation (significantly). At Brittnau the removal of all leaves (also the healthy green ones) in spring, decreased average fruit weight (significantly) and yield (not significantly).

At Frick it is conspicuous that all parameters (*B. cinerea* and *M. fragariae* damages, fruit weight and yield) were influenced by block. We suppose that different soil conditions in the experimental field were responsible.

Although the results of this study – especially about the reduction of *M. fragariae* damage with leaf sanitation – are promising, further research with different varieties at different sites are needed to confirm the effect of cultural methods to control *M. fragariae* and *B. cinerea* damage in strawberry.

Nevertheless, according to the results of our study and the cited literature we suggest for humid Central European conditions to apply a one-row-system combined with leaf sanitation in early spring and fruit sanitation during harvest if fruit density is high. Under these conditions it is possible to reduce the risk of damage caused by *M. fragariae* and *B. cinerea* and to maintain the productivity.

Acknowledgement

This research was supported by the Swiss Federal Office for Agriculture (BLW).

References

Anonymous, 1998–2002. Beeren-Anbaufläche. Jährlicher Report. Schweizerischer Obstverband, 6302 Zug, Switzerland.

Bergmann, W., 1993. *Kupferüberschuss: Ernährungsstörungen bei Kulturpflanzen. 3.* Gustav Fischer Verlag Jena, Stuttgart, Germany. pp. 246–249.

Berrie, A.M., D.C. Harris, X.M. Xu and C.M. Burgess, 1998. Progress towards integrated control of Botrytis and powdery mildew of strawberry in the UK. *IOBC/WPRS Bull.* 21(10): 95–102.

Boff, P., P. Kastelein, de J. Kraker, M. Gerlagh and J. Köhl, 2001. Epidemiology of grey mould in annual waiting-bed production of strawberry. *Eur. J. Plant Pathol.* 107: 615–624.

Boff, P., J. Köhl, M. Jansen, P.J.F.M. Horsten, C. Lombaers-van der Plas and M. Gerlagh, 2002. Biological control of gray mold with *Ulocladium atrum* in annual strawberry crops. *Plant Dis.* 86(3): 220–224.

Braun, P.G. and J.C. Sutton, 1988. Infection cycles and population dynamics of *Botrytis cinerea* in strawberry leaves. *Can. J. Plant Pathol.* 10: 133–141.

Bulger, M.A., M.A. Ellis and L.V. Madden, 1987. Influence of temperature and wetness duration on infection of strawberry flowers by *Botrytis cinerea* and disease Incidences of fruit originating from infected flowers. *Phytopathology* 77: 1225–1230.

Carisse, O., G. Bourgeois and J.A. Duthie, 2000. Influence of temperature and leaf wetness duration on infection of strawberry leaves by *Mycosphaerella fragariae*. *Phytopathology* 90: 1120–1125.

Clive, J., 1971. A manual of assessment keys for plant diseases. Canada Department of Agriculture. Publication No. 1458. Key No. 2.2.

Daugaard, H., 2000. Effect of cultural methods on the occurrence of grey mould (*Botrytis cinerea* Pers.) in strawberries. *Biol. Agricult. Horticult.* 18: 77–83.

Daugaard, H., L. Sørensen and B. Løschenkohl, 2003. Effect of plant spacing, nitrogen fertilization, post-harvest defoliation and finger harrowing in the control of *Botrytis cinerea* Pers. in strawberry. *Euro. J. Horticult. Sci.* 68(2): 77–82.

Delhomez, N., O. Carisse, M. Lareau and S. Khanizadeh, 1995. Susceptibility of strawberry cultivars and advanced selections to leaf spot caused by *Mycosphaerella fragariae*. *Hort Sci.* 30(3): 592–595.

Jarvis, W.R., 1962. The infection of strawberry and raspberry fruits by *Botrytis cinerea* Fr. *Ann. Appl. Biol.* 50: 569–575.

Maas, J.L., 1998a. *Botrytis Fruit Rot and Blossom Blight: Compendium of strawberry disease*. The American Phytopathological Society St. Paul, Minnesota, USA. pp. 28–31.

Maas, J.L., 1998b. *Leaf Spot: Compendium of Strawberry Diseases*. The American Phytopathological Society St. Paul, Minnesota, USA. pp. 21–24.

Mertely, J.C., C.K. Chandler, C.L. Xiao and D.E. Ledgard, 2000. Comparison of sanitation and fungicides for management of Botrytis fruit rot of strawberry. *Plant Dis.* 84: 1197–1202.

Scherer, W., 1989. *Weissfleckenkrankheit, Mycosphaerella fragariae. Schäden an Erdbeeren*. Margit Scherer Verlag, Augsburg (Germany). pp. 75–77.

Sutton, J.C. and G. Peng, 1993. Biocontrol of *Botrytis cinerea* in strawberry leaves. *Phytopathology* 83(6): 615–621.

Vukovits, G., 1980. *Weissfleckenkrankheit der Erdbeere: Obstkrankheiten – Erkennen, Ursachen und Bekämpfung, Beerenobst (4)*. Leopold Stocker Verlag, Graz (Austria). pp. 89–93.

Wilcox, W.F. and R.C. Seem, 1994. Relationship between strawberry gray mold damage, environmental variables, and fungicide applications during different periods of the fruiting season. *Phytopathology* 84(3): 264–270.