WATER LEVELS AND SOIL MULCHES IN RELATION TO STRAWBERRY DISEASES AND YIELD IN A GREENHOUSE

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ABSTRACT: The occurrence of diseases and its influence on strawberry yield in a greenhouse as well as its association with water management are still not well known. So, the aim of this work was to evaluate the effect of different water levels and soil mulches on strawberry plant health and yield in a greenhouse. The experiment was carried out at Atibaia, State of São Paulo, Brazil, from April to December 1995. The experimental design was a 2 × 3 factorial, in randomized blocks, with five replications, and consisted of two soil mulches and three water levels. The soil mulches consisted of clear or black plastic. Trickle irrigation was applied whenever the soil water potential reached -10, -35 and -70 kPa at a depth of ten centimeters. Cultivar Campinas IAC 2712 was used. Plants grown at a soil water potential of -10 and -35 kPa, with clear plastic mulch provided the best yields. A linear function fitted well considering total yield data and irrigation depths. The equation was y = -233.54 + 1.56x (R^2 = 0.78). The irrigation level of -70 kPa and the use of black plastic favored a greater incidence of soil-borne diseases late in the harvest season.
Key words: *Fragaria* × *ananassa* Duch., water management, trickle irrigation, disease

IRRIGAÇÃO E COBERTURA DO SOLO EM RELAÇÃO À SANIDADE E PRODUTIVIDADE DO MORANGUEIRO SOB ESTUFA

RESUMO: A influência de doenças na produtividade do morangueiro cultivado em estufa, bem como sua associação com o manejo da irrigação é pouco conhecida. Desta forma, o presente trabalho teve por objetivo avaliar o efeito de diferentes níveis de água e coberturas do solo na sanidade e produtividade do morangueiro, sob ambiente protegido. O experimento foi realizado em Atibaia, estado de São Paulo, Brasil, de abril a dezembro de 1995. O delineamento utilizado foi o fatorial 2 × 3, em blocos ao acaso, com cinco repetições, sendo estudados duas coberturas do solo (plástico transparente e preto) e três níveis de água. A irrigação, por gotejamento, foi aplicada quando o potencial de água no solo alcançava -10, -35 e -70 kPa à profundidade de dez centímetros. A cultivar utilizada foi a Campinas IAC 2712. As plantas cultivadas nos potenciais de água de -10 e -35 kPa ou com o plástico transparente apresentaram as melhores produtividades. A equação estimada foi y = -233,54 + 1,56x (R^2 = 0,78). A irrigação a -70 kPa e o plástico preto favoreceram a maior incidência de patógenos do sistema radicular no período de outubro a dezembro.
Palavras-chave: *Fragaria* × *ananassa* Duch., manejo da água, irrigação localizada, doença

INTRODUCTION

The study of the influence of cultivation techniques in the strawberry crop has been an important matter in the last decades. The performance of different mulches on plant health and fruit yield is often inconstant (Passos, 1997) and their effect seems to be related to changes in the microclimate (Maas, 1998). Soil disinfestation or solarization has been used successfully (Voth & Bringhurst, 1990; Hartz et al., 1993; Himelrick et al., 1993), resulting in good control of weeds and some pathogens (Maas, 1998; Sugimura et al., 2001; Shalaby & Mohamed, 2005), with consequent strawberry yield increases (Hartz et al., 1993; Larson & Shaw, 1995; Umang & Harender, 2004).

In Brazil, sprinkler irrigation is used in most of the area cultivated with strawberries. However, this technique, as well as rainfall and dew, provides favorable conditions for the development and dissemination of fungi and bacteria (Rotem & Palti, 1969; Maas, 1998), and may result in yield reduction. Drip irrigation presents a number of advantages, contributing to avoiding the formation of a humid microclimate favorable to diseases (Howard et al., 1992; Madden et al., 1993; Tanaka et al., 2005; Tanaka, 2002). In addition, it allows automation, frequent irrigations, fertigation, and obtaining high yields (McNiesh et al., 1985; Voth & Bringhurst, 1990; Serrano et al., 1992; Passos, 1997; Pires, 1998; Rolbiecki et al., 2004). Irrigation management is also critical, because strawberry is sensitive either to water excess or deficit (Gehrmann, 1985; McNiesh et al., 1985; Serrano et al., 1992; Pires, 1998; Krüger et al., 1999; Kirnak et al., 2001; 2003). In the Atibaia region, one of the most important strawberry grower in Brazil, protected cultivation, together with drip irrigation, was introduced in the beginning of the 1990's, as an attempt to control anthracnose in strawberry flowers and young fruits (Passos, 1997).

The objective of the present work was to evaluate strawberry health and yield, under different water levels in the soil and raised bed mulches in a greenhouse.

MATERIAL AND METHODS

The experiment was carried out from 20 April (transplant date) to 22 December 1995, in Atibaia, State of São Paulo, Brazil (25º07'S and 46º50'W, 744 m above sea level), in a greenhouse. It was built of wood, 7 m of width and 50 m of length, covered with clear low-density polyethylene film, 100 µm thickness. The largest axis of the greenhouse was oriented in the northwest-southeast direction. The greenhouse height was 3.0 m at the center, and 2.15 m at the sides. The greenhouse sides were protected up to a 0.75 m height from the ground, and the remaining 1.4 m were maintained completely open during rainless days. In case of rain, the curtains were closed. The plots were installed in a parallel fashion with the largest side of the greenhouse. In order to prevent rain water from entering a plastic film was buried until 70 cm depth around the greenhouse.

The climate in the region is classified as Cfa, according to Köppen's classification, defined as subtropical, with a hot summer, without a pronounced dry season (Setzer, 1966). The soil (**Typic Eutrudox**) in the experiment was disinfested with methyl bromide in order to control invasive plants under the clear plastic, and especially to control pathogenic fungi, since the area had been cultivated with strawberry in previous years (Larson & Shaw, 1995). The use of pesticide does not represent approval by the authors. Solarization or other safe technique can be adopted due to the prohibition of methyl bromide.

Correction of soil acidity and pre-planting fertilization followed the recommendations by Raij et al. (1996). Post-planting fertilizations were performed based on leaf analyses results, according to interpretations by Ulrich et al. (1980). In order to monitor conditions in the environment, thermo-hygrographs were installed in the center of the greenhouse. Maximum, minimum and mean daily average air temperature were grouped into 10 or 11 days periods (Table 1). The experiment was implemented as a 2 × 3 factorial scheme (soil mulches and irrigation levels), in random blocks with five replicates, totaling 30 plots. The plants were grown in 1.2 m wide raised beds, at a spacing of 0.30 × 0.30 m. The plots consisted of 5.1 m long and 1.2 m wide raised beds. Each plot consisted of 68 plants. Black 30 µm thick and clear 50 µm thick low-density

Table 1 - Average maximum, minimum, and mean air temperature values, verified in thermo-hygrographs installed under protected crop conditions observed in the period from May 21 to December 22, 1995, in Atibaia, State of São Paulo, Brazil.

Period	Temperature ºC		
	Maximum	Minimum	Mean *
05/21 to 05/31	22.7	9.9	15.5
06/01 to 06/10	24.8	7.3	14.4
06/11 to 06/20	22.9	8.9	14.6
06/21 to 06/30	23.6	11.4	16.3
07/01 to 07/10	23.4	11.6	16.5
07/11 to 07/20	26.7	11.4	17.5
07/21 to 07/31	27.7	10.6	17.6
08/01 to 08/10	26.5	11.8	17.5
08/11 to 08/20	28.6	11.8	18.7
08/21 to 08/31	30.8	10.5	19.5
09/01 to 09/10	28.7	9.7	18.1
09/11 to 09/20	26.3	13.1	18.4
09/21 to 09/30	25.7	15.0	19.0
10/01 to 10/10	28.9	14.6	20.3
10/11 to 10/20	25.3	14.1	20.9
10/21 to 10/31	27.9	11.8	19.8
11/01 to 11/10	30.9	15.2	21.9
11/11 to 11/20	26.7	14.9	20.1
11/21 to 11/30	29.4	14.4	20.3
12/01 to 12/10	29.8	15.2	21.3
12/11 to 12/22	28.4	16.8	21.4

*Values estimated from the mean of readings obtained every two hours throughout the day.

polyethylene film (LDPF) were used as soil mulching. The soil mulches were installed on the 1st of June. Campinas IAC 2712 was chosen for study. It is an early-season cultivar that is highly productive and producer of sweet-flavored, juicy fruits.

During the plant establishment stage, until May 10, irrigations were performed by sprinkling, twice to six times a day. The drip irrigation system was installed on May 10 with drip emitters spaced at 0.3 m. Two drip lines were placed on each raised bed containing four plant rows; each line was placed between two plant rows, except the central row. Until the beginning of the water level treatments, irrigations were performed whenever the water potential in the soil reached -10 kPa in the tensiometer installed at a 10 cm depth. Starting on June 12 and 13, water levels were differentiated. Three water potential levels in the soil were used in order to determine irrigation time, corresponding to -10 (N_1), -35 (N_2), and -70 (N_3) kPa, measured in tensiometers installed at a 10 cm depth. Three tensiometer stations were installed for each soil mulch and irrigation level combination; two of them had tensiometers at depths of 10 and 20 cm, and a third station had five tensiometers installed at depths of 10, 20, 30, 40, and 50 cm. The tensiometers installed at depths between 20 and 50 cm were intended to monitor the wetting front in the soil profile, and to help adjust irrigation depth. The irrigation depth was estimated by means of the soil water retention curve and the soil water potential measured by tensiometers when irrigation was necessary.

To evaluate the incidence of diseases, plants showing visual symptoms were taken for pathogen identification in the laboratory. After being examined under the stereoscopic microscope, the plants were washed in running water and the crowns were cut in the longitudinal direction to allow observation of the occurrence of lesions and necroses. Part of this material was incubated in a humid chamber, and remained in it for 3 to 4 days, at laboratory room temperature. Isolation in culture medium was performed by removing small segments of lesioned tissues, which were submitted to surface asepsis with a 70% ethanol solution for one minute, and a 1% sodium hypochlorite solution for 1 to 2 minutes, depending on tissue thickness. Five segments per Petri dish were later placed equidistantly on the surface of a PDA medium (200 g potato, 20 g dextrose, 20 g agar, and 1 liter water), and incubation was carried out at 28°C, in the dark, for five to eight days.

Two evaluations were carried out in October to assess the occurrence of diseases. The number of plants showing wilting and/or stunting symptoms was counted per plot. In the same month, a sampling was performed to identify the pathogens. The intensity level of each fungus was estimated by the mean number of its structures detected in the sampled plants. At the end of the experiment the diseases were quantified by counting the number of plants showing wilting and/or stunting; plots showing more than 66%, between 33 and 66%, and less than 33% of plants with symptoms were considered as having high (H), medium (M), or low incidence (L), respectively.

The fruits were harvested at the “3/4 ripe” stage, and were classified as marketable and nonmarketable. Fruits containing rots, physical imperfections, or attacked by insects or birds were considered nonmarketable. After classification, the fruits were counted and weighed. Productivity data were put together in three seasons: from June to September (less favorable period to soil-borne diseases), from October to December (favorable period to soil-borne diseases) and from June to December (total harvest period). The data relative to the incidence of diseases and productivity were analyzed using analysis of variance and the F test. The split plot design was used for analysis of the incidence of diseases in October. Means were separated using Tukey’s multiple comparison test ($P < 0.05$).

Termohigrographs were installed under both the mulchings and in the different soil water potentials, with a replication. Sensors were installed at 5 cm of depth, between the central lines of plants in the plots. Maximum soil temperatures were determined daily. The irrigation depths, number and interval were similars in both soil mulches at a same irrigation level. So, each average irrigation depth was used separately for the related irrigation level in productivity regression analysis. The average irrigation depths were 580, 496 and 474 mm, respectively, for -10 kPa, -35 kPa and -70 kPa irrigation levels. According to the water management adopted in the experiment the number of irrigations for -10; -35 and -70 kPa were 188, 100 and 77.5 respectively. Approximately 75% of the irrigations occurred at intervals of 1 day, from 1 to 4 days and from 2 to 6 days for -10; -35 and -70 kPa irrigation levels, respectively.

RESULTS AND DISCUSSION

An attack of mites occurred in June, which was easily controlled. Except for the attack of this pest the plants remained without symptoms of diseases until the first half of September. In the second half of that month, some plants showed wilting and/or stunting, symptoms characteristic of the action of fungi that affect the crown and the root system (Paulus, 1990; Maas, 1998; Tanaka et al., 1998). The occurrence of these diseases could be associated with a number of factors; among them are climatic conditions favorable to the development of their causal agents, in especially the increase in maximum air temperature by the end of August, and the increase in minimum temperature beginning in the second half of September, with the consequent mean temperature increase (Table 1), as pointed out by Smith & Black (1987), Okayama (1989), and Maas (1998); and the presence of pathogens in the soil, due to a ineffective soil fumigation. In addition, it is also possible that the plants carried pathogens, whose symptoms only manifested lately in the presence of predisposing conditions (McInnes et al., 1992). The results obtained in both evaluations carried out in October are in Table 2.

The interactions between water levels and sampling seasons; water levels and soil mulches; and sampling seasons and soil mulches were not significant. There was an effect of water levels and soil mulches on the number of plants showing wilting and/or stunting symptoms (Table 2). The occurrence of diseases was lower when the clear plastic was used, when compared with the black plastic. With regard to irrigation levels, the number of diseased plants was lower at the levels of -10 and -35 kPa, when compared with the -70 kPa level. The occurrence of diseases in the second sampling season (27 October) was higher than that observed in the first sampling, probably due to a gradual accumulation of inoculum with time.

Table 2 - Evaluation of the mean number and percentage of diseased plants showing wilting and/or stunting symptoms, in a greenhouse with different soil mulches and irrigation levels, at two seasons (2 and 27 October) in strawberry at Atibaia, State of São Paulo, Brazil, in 1995.*

Items	Number and percentage of wilted and/or stunted plants per plot (3.6 m^2)			
	October 2nd		October 27th	
	Number	%	Number	%
Soil mulches				
Clear plastic	2.2 B	3.2	7.4 B	10.9
Black plastic	7.1 A	10.4	18.3 A	26.9
Irrigation levels (kPa)				
-10	2.7 B	4.0	6.8 B	10.0
-35	2.3 B	3.4	9.7 B	14.3
-70	8.9 A	13.1	22.1 A	32.5
Mean	4.6 b	6.8	12.9 a	19.0
CV plot = 55.3%	CV subplot = 29.3%			

*within each item, means followed by the same letter (upper case vertically and lower case horizontally) are not different (Tukey test, $P < 0.05$).

The higher incidence of diseased plants in the cultivation with black plastic (Table 2) could be associated to a higher soil temperature observed for this mulching, when compared with the clear plastic (Figure 1). The greater incidence of anthracnose (*Colletotrichum fragariae*) in black plastic was attributed to the higher soil temperature observed, when compared with other mulches evaluated (Camargo & Igue, 1973; Passos, 1997). In the same manner, soil temperature at the water level of -70 kPa was higher, when compared with the other levels (Figure 1). Another aspect that may have favored the occurrence of diseases at the driest water level (-70 kPa) was the larger interval between irrigations that occurred at that level, as compared to the others. A greater incidence of diseases in strawberry under less frequent irrigation conditions was also observed by Passos (1997).

The fungi identified in the samplings as well as their percentage of occurrence and level of intensity is in Table 3. The four most detected fungi were *Rhizoctonia* spp., *Verticillium dahliae*, *Fusarium* spp. and *Colletotrichum fragariae*, respectively presented in 83%, 58.3%, 58.3% and 50% of the sampled plants.

The intensity level of each disease was quantified by means of ratings according to its frequency in the plot, performed at the end of the experiment (Table 4). They agree with those observed in Table 2 for the month of October, showing a tendency for the development of diseases with black plastic and at the less humid water level (-70 kPa). These results disagree from those obtained by Laugale & Morocko (2000), who noticed that black plastic and black polypropylene limited the incidence of *Verticillium* wilt.

The average maximum temperatures values verified at the 5 cm depth, in periods next to the detection of wilting and stunting symptoms are in Figure 1.

Table 3 - Percentage of fungi occurrence and intensity level of fungi identified in strawberry samples showing wilting and/or stunting symptoms, collected from the protected cultivation on October 18, 1995, in Atibaia, State of São Paulo, Brazil.

Fungi identified	Occurrence (%)	Level of Intensity *
Rhizoctonia spp.	83.0	++
Verticillium dahliae	58.3	+++
Fusarium spp.	58.3	+
Colletotrichum fragariae	50.0	++
Pythium spp.	8.3	+
Phytophthora cactorum	8.3	+

* +++ fungus isolated and observed predominantly in most samples examined; ++ fungus isolated with medium frequency; + fungus isolated with low frequency.

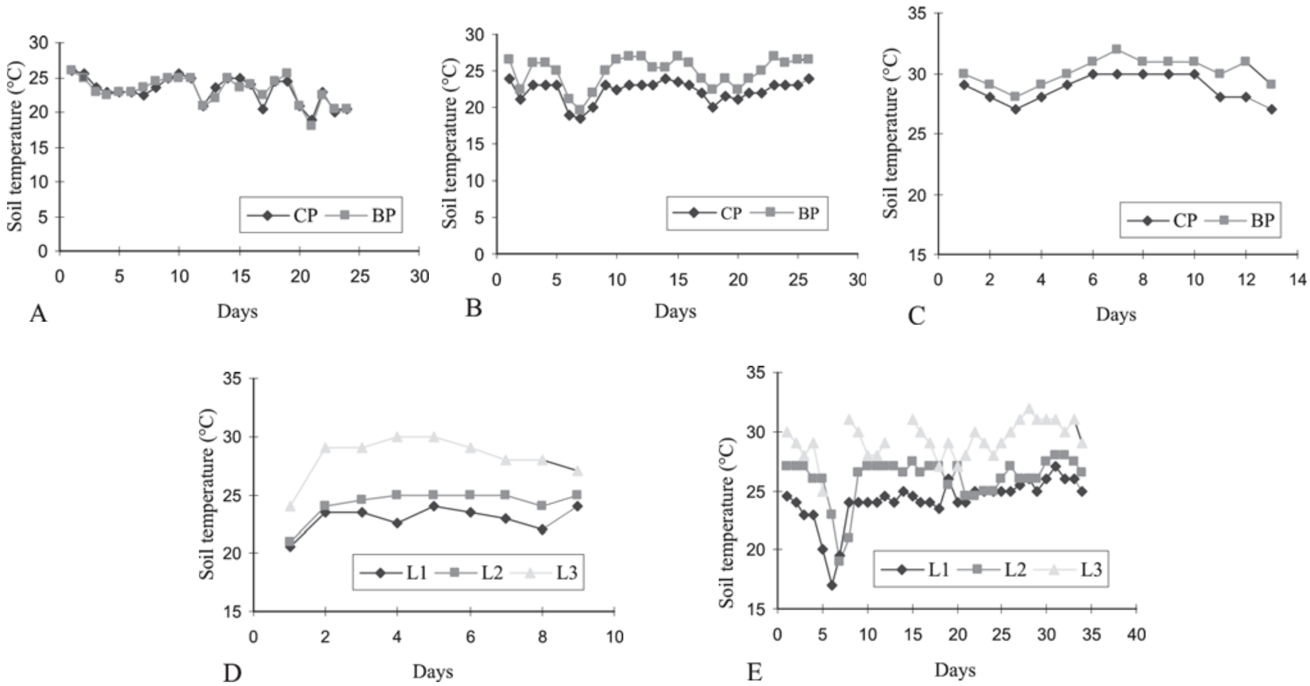

Figure 1 - Daily maximum soil temperature at 5 cm depth, under clear plastic (CP), black plastic (BP), irrigation level at -10 kPa (L1), irrigation level at -35 kPa (L2) and irrigation level at -70 kPa (L3). The Figures A, B and C refer to irrigation level at: L1 (from 1st to September 24), L2 (from 3rd to July 28), L3 (from August 21 to September 3rd), respectively. The Figures D and E refers to CP (from 1st to June 9) and BP (from 1st to August 30), respectively, in strawberry at Atibaia, State of São Paulo, Brazil, in 1995.

Table 4 - Means for incidence of diseased plants per plot (*), on December 22, 1995 in the protected cultivation, for different soil mulches and irrigation levels in Atibaia, State of São Paulo, Brazil.

Soil mulches	Irrigation levels (kPa)		
	-10	-35	-70
Clear plastic	L	L	M
Black plastic	M	M	H

*incidences high (H), medium (M), and low (L), represent more than 66%, from 33 to 66%, and less than 33% of plants showing disease symptoms, respectively.

Almost all the times they were above 20ºC favoring the development of *Colletotrichum fragariae*, *Phytophthora cactorum*, *Rhizoctonia* spp., *Verticillium dahliae*, *Fusarium* spp. and *Pythium* spp., especially the five first (Maas, 1998). Besides, temperature in the driest treatment (-70 kPa) was around 5ºC above that observed at the -10 kPa level and that black mulching was somehow more favorable to soil heating than the clear one. These conditions could have influenced the soil pathogens, since crown rot caused by *C. fragariae* is more severe above 25ºC and that water stress favors the incidence of crown rot caused by *P. cactorum* and the wilting caused by *Verticillium* spp. (Maas, 1998).

The marketable yield obtained from June to September, from October to December and from June to December are in Table 5. Nonmarketable fruit yield was practically nonexistent. The interaction between soil mulches and water levels was not significant in relation to total marketable yield in the three seasons.

There was a similar effect of soil mulching and irrigation levels on yield in the seasons of harvesting (Table 5), suggesting that the major effect was due to the treatments (mulching and irrigation) and not to the diseases. Their minor effect probably was due to the late occurrence in the harvest season. The most favorable soil mulching was provided by clear plastic. Total yield was higher at the water levels of -10 and -35 kPa, when compared with the yield obtained at the -70 kPa level, except from October to December. Total yield was favored in treatments at more humid irrigation levels, in a similar manner as observed by Passos (1997).

The results obtained in relation to the positive effect of the use of clear plastic on yield, when compared with black plastic (Table 5), are in agreement with those observed by Voth & Bringhurst (1990) in California, for several strawberry cultivars. Similar results as those presented in Table 5, with regard to the effect of irrigation levels on total yield, were observed in Spain, by Serrano et al. (1992). The total fruit yield

Table 5 - Mean marketable yield values per plant, under protected cultivation with different soil mulches and irrigation levels, from June to September (less favorable period to soil-borne diseases), from October to December (favorable period to soil-borne diseases) and from June to December 1995 in Atibaia, State of São Paulo, Brazil. *

Items	Yield		
	June to September	October to December	June to December
	-------------------	g per plant	-------------------
Soil mulches			
Clear plastic	463.5 a	191.0 a	654.5 a
Black plastic	376.4 b	116.9 b	493.3 b
Irrigation levels (kPa)			
-10	470.1 a	192.3 a	662.4 a
-35	429.4 a	163.2 ab	592.6 a
-70	360.4 b	106.3 b	466.7 b
CV (%)	14.0	36.7	18.9

*within each item means followed by the same letter are not different by Tukey test ($P < 0.05$).

per plant values was higher in this experiment (Table 5), ranging from 466.7 to 662.4 g per plant, when compared with those achieved by Passos (1997), using the same cultivar under protected cultivation (250 to 289 g per plant). A linear function fitted well the total yield data in relation to total irrigation depth. From June to December the equation was $y = -233.54 + 1.56x$ ($R^2 = 0.78$). Therefore, 78% of the total variation in the yield can be explained by a linear relationship between it and the irrigation depth.

CONCLUSIONS

The irrigation levels of -10 and -35 kPa and the clear plastic favored total marketable fruit yield. The -70 kPa irrigation level and the use of black plastic as soil mulch provided greater incidence of soil-borne diseases caused mainly by *Rhizoctonia* spp., *Colletotrichum fragariae*, *Verticillium dahliae*, *Fusarium* spp., *Pythium* spp. and *Phytophthora cactorum* late in the harvest season.

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