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Drip fungigation in early blight control of tomato

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ABSTRACT. The aim was to verify if the fungigation via drip irrigation is an alternative to the conventional method of spraying on tomato for controlling early blight. Tomato plants (variety Santa Clara) were grown in pots inside a greenhouse. Fifty days after transplanting, the plants were inoculated with *Alternaria solani* and treated with four different fungicides: azoxystrobin (8 g 100 L^{-1}), difeconazole (50 mL 100 L^{-1}), metiram+piraclostrobin (200 g 100 L^{-1}) and tebuconazole (100 mL 100 L^{-1}) using two applications methods: conventional spraying and fungigation dripping. The control plants did not receive fungicide application. To assess the severity of the disease, we used a rating scale expressed as the area under the disease progress curve (AUDPC) and production factors, such as number, weight and average diameter of the fruit and its productivity. The experimental design was completely randomized in factorial scheme 4 x 2 + 1 with eight replicates. Each plot had one plant in one pot. A 27% reduction in disease severity was observed when compared with the control plants, with no significant difference noted regarding the application method. The number of fruits did not statistically differ between the treatments. The average weight and diameter of the fruits were superior in the plants that had fungicide application compared to the control plant, reflecting an increase in productivity. Fungigation through water dripping is an alternative to the conventional method of spraying cultured tomatoes.

Keywords: chemigation, *Solanum lycropersicum*, *Alternaria solani*.

RESUMO. Fungigação por gotejamento no controle da pinta preta do tomateiro. O objetivo foi verificar se a fungigação via gotejamento é uma alternativa ao método convencinal de pulverização no controle da pinta-preta do tomate. Plantas de tomate (var Santa Clara) foram cultivadas em vasos instalados no interior de uma casa-de-vegetação. Aos 50 dias após o transplantio, foram inoculadas com *Alternaria solani* e tratadas com quatro diferentes fungicidas: azoxystrobina (8 g 100 L^{-1}), difeconazole (50 mL 100 L^{-1}), metiram+piraclostrobin (200 g 100 L^{-1}) e tebuconazole (100 mL 100 L^{-1}), em duas formas de aplicação: pulverização convencional e fungigação por gotejamento. Uma testemunha não recebeu aplicação de fungicidas. Avaliou-se a severidade da doença através de escala de notas expressa em área abaixo da curva de progresso da doença (AACPD) e fatores de produção, como número, peso e diâmetro médio dos frutos e produtividade. O delineamento experimental foi 4 x 2 + 1, com oito repetições. Cada parcela constou de uma planta em um vaso. Houve redução da severidade da doença de 27% em comparação com a testemunha. Não houve diferença significativa entre os métodos de aplicação. O número de frutos não diferiu estatisticamente entre os tratamentos. O peso médio e diâmetro dos frutos foram maiores nos tratamentos com fungicidas em comparação a testemunha, o que refletiu no aumento da produtividade. A fungigação por gotejamento é alternativa de aplicação de fungicida sistêmico por pulverização na cultura do tomate.

Palavras-chave: quimigação, *Solanum lycropersicum*, *Alternaria solani*.

Introduction

The tomatoes is one of the most important crop in the world (CANÇADO JÚNIOR et al., 2003), occupying an area of approximately 4.5 million hectares and producing 127 million tons. In Brazil, there are 55 thousand hectares of cultivated area with a production of 3.2 million tons (FILGUEIRA, 2003). However, diseases pose a serious limitation to production, increasing costs due to the need for their control.

The latest research and advances in irrigation systems and injection equipment allowed an expanding number of products applied by water irrigation. Thus, in modern irrigated agriculture, irrigation systems are being used not only to apply water but also fertilizers, insecticides, herbicides, fungicides, etc. Fungigation is the application of

fungicides by water irrigation. In regions with highly technological irrigated agriculture, fungigation is a common practice to control fungal diseases, and it has been demonstrated, in most cases, to be efficient and safe (PINTO, 1994; PAPADOPOULOS, 1999).

The early blight causes severe epidemics in tomato plants grown in warm and humid regions. Under favorable conditions to the disease progress, many secondary cycles of the pathogen may occur during the crop cycle (CHAERANI; VOORRIPS, 2006) leading to epidemics.

In localized irrigation systems, fungigation is restricted to systemic fungicide application and to controlling soil pathogens. In controlling diseases that affect the aerial parts by use of fungigation, Katz et al. (2006) had success with the grey mold fungus (*Botrytis cinerea*) on the ornamental plant Lisianthus. Browne et al. (2002) observed that the white mold (*Sclerotium rolfsii*) in potatoes could be controlled by applying metam sodium.

The aim of this study is to verify if the fungigation via drip irrigation is an alternative to the conventional method of spraying on tomato for controlling early blight.

Material and methods

The study was carried out on the campus of the Irrigation Technological Center (Centro Técnico de Irrigação (CTI)) of the Agronomy Department at the State University of Maringá, Maringá, Paraná State (23°25' S, 51°57' W and 542 m height). The region's Köppen climate classification is *Cfa*, with an annual average temperature of 22.6°C and a total annual precipitation of 1,500 mm.

The experiment was conducted in a greenhouse with an arc frame that is 20 m long and 7.5 m wide and with the lateral and frontal facades wrapped with anti-aphid nets. The covering was a low-density polyethylene plastic sheeting with a thickness of 150 microns and an anti-UV treatment.

Tomato seeds of the Santa Clara variety were sown in Styrofoam trays with 128 cells filled with commercial substrate for seedlings Plantmax®, which were kept inside the greenhouse. In this stage, the seedlings were receiving daily irrigation to keep the substrate moist. Thirty days after sowing, when two pairs of true leaves were present, the seedlings were transplanted to pots. They were filled with a mixture of solarized soil and sand in a proportion of 30 and 70%, respectively. The fertilization (NPK) was performed according to chemical analysis.

The pots were placed directly on the ground, forming six lines with 1.0 m spacing between the lines and 0.40 m spacing between the pots. Each line was composed of 20 pots, giving a total of 120 pots. The tomato treatments included fruit thinning, pruning and pest control, and were performed as needed.

Dripping tubes with an emitter inserted in the mainline tube were used, where these were non-compensated, with a diameter of 16 mm and 2 L h^{-1} flow. The water used for irrigation was derived from a reservoir supplied by an artesian well, using a localized irrigation drip system. The uniformity coefficient was 96.6%, which was considered to be excellent for localized irrigation systems.

Irrigation management was performed using an evaporation mini-tank (FARIAS et al., 1994; FERNANDES et al., 2003) with dimensions of 0.6 m diameter and 0.25 m height and with a built-in galvanized iron plate. It was installed in the center of the greenhouse on a wooden platform at a height of 0.15 m from the ground. The tank's coefficient (Kp) was considered equal to 1 (PRADOS, 1986). For the different phases of the culture development, the Kc used were initial: Kc = 0.5; growing: Kc = 0.8; flowering: Kc = 1.0; harvest: Kc = 0.8 (DOORENBOS; KASSAM, 2000). The amount of water applied was determined by multiplying the tank evaporation and the crop coefficient.

The *A. solani* isolate sample was obtained at the Agricultural Biotechnological Laboratory of the State University of Maringá. The fungus was grown on a Petri dish using a PDA medium (Potato-Dextrose Agar) and was kept in the dark, inside a BOD incubator chamber at 25°C. When the colony was 15 days old, a spore suspension was prepared at a concentration of 10^4 spores mL^{-1}. The inoculation of the disease was performed 50 days after the transplantation, at the beginning of the flowering period, and was repeated 20 days later. The spore suspension was sprayed over the tomato plants, and the environment was kept under high humidity levels for 24 hours, spraying water on the environment. The treatments consisted of fungicide application via drip irrigation and conventional spraying. The active ingredients of the fungicides, with their commercial name, rate and application intervals are presented in Table 1. All fungicides used are systemic and registered for tomato culture (ZAMBOLIM, 2008). We followed the recommendations for the rate and the application intervals.

Table 1. Fungicide rate for 100 L of water and interval between applications.

Active principle	Trade name	Rate	Interval between applications (days)
Azoxystrobin	Amystar	8 g	7
Difeconazol	Score	50 mL	7
Metiram+Pyraclostrobin	Cabrio Top	200 g	7
Tebuconazol	Folicur	100 mL	14

The experimental design used was totally randomized in a factorial scheme of 4 x 2 + 1, with four fungicides, two application methods and one control with no treatment. Eight repetitions were performed, and each plot comprised one pot with a tomato plant. The ANOVA to the factorial scheme with an additional treatment was performed according to the procedure described by Yassin et al. (2002). The factorial was unfolding when significant. The controls were compared to the other treatments by the Dunnett test, the analysis of factorials (fungicides) was by the Scott-Knott test and the analysis of factorials (application methods) was by the F test. Results were considered significant at a level of 0.05.

For the application of the fungigation, 2-L PET plastic bottles were used. They were adapted with a saline solution drip device that allowed for flow regulation. The water flow using the PET bottles was the same as the drip irrigation, ensuring equal conditions in all of the treatments.

Conventional fungicide spraying was performed with a hand sprayer. The water volume used per plant during the spraying served as a basis for estimating the quantity of the product that should be added to the irrigation water in order to maintain the same rate of fungicides in both treatments.

Harvesting began as the fruits were in the maturation stage, presenting a light red color. Harvesting was always performed at the same time during the morning. After harvest, the fruits were weighed using an analytical scale (0.1 g precision). The equatorial diameter was measured using a caliper (0.05 mm) and was obtained through the average of the two opposed measures.

To quantify the disease, the severity of the disease was determined and performed in four weekly evaluations, beginning 90 days after the transplantation. In these evaluations, the disease was quantified in the lower third of the plant. This way, the severity was expressed as the area under the disease progress curve (AUDPC), calculated by the following equation:

$$AUDPC = \sum \frac{(Y_{i+1} + Y_i)}{2} \times (T_{i+1} - T_i) \quad (1)$$

where:

AUDPC= Area under the disease progress curve;

Y_i= rate for severity in the *i*-th observation;

T_i = time (days) in the moment of the *i*-th observation.

The rates for the severity of the disease were attributed by visual acuity according to the diagrammatic scale developed by Boff et al. (1991):

1- absence of symptoms;
2- traces of symptoms up to 4% severity;
3- between 4% and 8% severity;
4- between 8% and 16% severity;
5- between 16% and 32% severity;
6- over 32% severity.

Results and discussion

Severity of disease

The factorial contrast vs. the control plants was significant ($p < 0.05$). This means that the factorial treatments were superior to the control plant, providing, on average, a 27% reduction in disease (Table 2). The Dunnett test ($p < 0.05$) demonstrated that the treatment with fungicide to be better than for the control plants, which had an AUDPC value of 96.81. The interaction analyses between treatments and control, as well as the individual effects for each application method, were not statistically significant. Thus, for either of the fungicides, the application through fungigation or spraying had similar efficiency.

Table 2. Area under the disease progress curve (AUDPC) for plants treated with four fungicides applied by two methods.

Fungicida	Fungigation	Spraying	Average
Azoxystrobin	60.41⋆ a	63.26⋆	61.84
Difeconazol	71.44⋆ b	72.13⋆	71.81
Metiram+Pyraclostrobin	75.33⋆ b	72.80⋆	74.06
Tebuconazol	74.93⋆ b	78.51⋆	76.60
Average	70.50	71.45	70.98
Control	96.81		

⋆significantly different from control by Dunnett test ($p < 0.05$). Same letter in column did not differ by Scott Knott Test ($p < 0.05$).

The systemic fungicide application, whose principle characteristic is the capacity to translocate through the plant, allows it to act very efficiently on the aerial part of the plant, even when it is applied to the soil, close to the roots. These results corroborate those found by Katz et al. (2006), who verified the reduction of grey mold (*Botrytis cinerea*) on Lisianthus plants using a thiophanate methyl, thiophanate methyl + chlorothalonil and iprodione application through fungigation dripping and conventional spraying. In the same study, a comparison between the application methods demonstrated that they had similar efficiency. The

studies by Potter (1985) and Reese et al. (1985b) with tomatoes showed efficient results in disease control through fungigation.

The interaction effects between fungicides were significant when applied through fungigation. Tomato treated with azoxystrobin had a lower AUDPC when compared to the other fungicides (Table 2). Applied by spraying all fungicides provided a similar level of control.

Productivity

The factorial contrast vs. control was significant ($p < 0.05$). The factorial treatments were, on average, 48% more productive than the control plant (Table 3). Thus, as demonstrated in the present study, Töfoli and Domingues (2005) and Töfoli et al. (2003) verified an increase of 107% in the productivity of tomatoes due to a decrease in the severity of early blight. This, in turn, was due to the fungicide applications of metiram + pyraclostrobin, azoxystrobin, difeconazol and tebuconazol, among others.

Table 3. Productivity (g plant^{-1}) of plants treated with four fungicides applied by two methods.

Fungicides	Fungigation	Spraying	Average
Azoxystrobin	1852.3*	1854.5*	1853.4
Difeconazol	1829.4*	1875.8*	1990.2
Metiram+Pyraclostrobin	2100.0*	1880.4*	1854.2
Tebuconazol	1828.1*	1917.5*	1869.8
Average	1904.8	1880.9	1892.9
Control	1275.7		

*significantly different from control by Dunnett test ($p < 0.05$).

In the plants treated with fungicides, the productivity was in the range of 1,828.1 g plant^{-1} to 2,100.0 g plant^{-1}, versus 1,275.7 g plant^{-1} for the control treatment. The interaction effects were insignificant, as were the individual effects for fungicides and the application methods. Therefore, all four of the fungicides applied by both methods were similar in reference to productivity per plant. In the fungigation method, the average productivity was 1,904.8 g plant^{-1}, and the spraying method was 1,880.9 g plant^{-1}.

The efficiency of the fungigation application in disease control allowed the plants to have a greater productivity when compared to the control plant. In support of the results obtained in this study, it is possible to cite the research of Potter and Crawford (1985) and Reese et al. (1985a) who found a reduction in early blight (*A. solani*) occurrence and an increase in productivity of potato culture, by using mancozeb fungigation.

Number of fruits

There was no statistically significant difference in the number of fruits between the factorial contrast and control treatments for either the treatment interaction or individual effects. The greatest number of fruits was reached using metiram + pyraclostrobin through fungigation. This treatment resulted in, on average, 22.8 fruits per plant. The lowest quantity was obtained using difeconazol, which resulted in, on average, 18.7 fruits per plant, versus 20 fruits per plant under the control treatment (Table 4). However, none of the treatments differed in terms of the number of fruits.

Table 4. Number of fruits per plant treated with four fungicides applied by two methods.

Fungicides	Fungigation	Spraying	Average
Azoxystrobin	20.3	21.6	20.9
Difeconazol	18.7	18.8	18.7
Metiram+Pyraclostrobin	22.8	20.0	21.4
Tebuconazol	20.1	20.7	20.4
Average	20.5	20.3	20.4
Control	20.0		

Overall, the number of fruits per plant was more related to nutritional and environmental factors than the incidence of disease. This fact is confirmed by Santos et al. (2001), who verified that an increase in the number of fruits per plant occurred with the increased dose of the NPK fertilizer, from 2.0 tons ha^{-1} to 3.5 tons ha^{-1} and 5.0 tons ha^{-1}, due a higher level of fertilizer proportionate to the higher vegetative growth. Sandri et al. (2002) verified that tomato plants adjust the number of fruits by abortion of surplus flowers according to the culture density.

Mass of fruits

The factorial contrast vs. the control was significant for fruit mass ($p < 0.05$). The factorial treatments were, on average, 31% superior when compared to the control plants (Table 5). The fungicide applications, by either fungigation or spraying, resulted in fruit mass being between 85.2 and 100.3 g, which is superior to the 63.8 g value for the control plants, as determined by the Dunnett test ($p < 0.05$). The interaction effects of the fungicide vs. the application methods did not show a significant difference. The statistical analysis of the individual effects of the application methods (meaning the spraying application or the fungigation) did not result in a difference in fruit mass. On average, using the fungigation treatment, the fruit mass was 93.2 g. Using the spraying treatment, the average mass was 93 g. For the individual effects of the fungicides, there was a statistically significant difference at the 5% probability level. By using the Scott-Knott test, it was possible to verify that the difeconazol fungicide resulted in fruits with greater mass.

Table 5. Mass of fruits (g) of plants treated with four fungicides applied by two methods.

Fungicides	Fungigation	Spraying	Average
Azoxystrobin	90.9*	85.2*	88.1 b
Difeconazol	99.3*	100.3*	99.8 a
Metiram+Pyraclostrobin	92.1*	94.2*	93.2 b
Tebuconazol	91.2*	92.2*	91.7 b
Average	93.2	93.0	93.1
Control	63.8		

*significantly different from control by Dunnett test ($p < 0.05$). Same letters in column do not differ by Scott-Knott test ($p < 0.05$).

The production per plant is expressed as a function of the number of fruits per plant and the mass of the fruits. Since the number of fruits was not statistically different between the treatments, the differences of productivity are derived from the values for fruit mass. Thus, the fungicide treatments were more productive, not by a greater quantity of fruits, but by producing fruits with a greater mass.

Diameter of the fruits

The factorial contrast vs. the control was significant ($p < 0.05$). The fungicide treatments produced fruits with diameters, on average, 14% greater than the control plant (Table 6). The diameter of fruits in the fungicide treatment ranged from 51.70 to 55.03 mm, which, by the Dunnett test ($p < 0.05$), were superior to the value of 46.44 mm for the control plants. The interaction effects, as well the individual effect for the application methods, were not significant. Therefore, the two application methods, fungigation and spraying, were equivalent in relation to fruit diameter. The fungicide individual effect was significant, and the Scott-Knott test ($p < 0.05$) showed that the difeconazal fungicide allowed for the greatest average diameter in the fruits. The diameter of the fruit is highly related to the fruit's mass value. This explains the analysis results showing that these variables were equal.

Table 6. Average diameter of the fruits (mm) of plants treated with four fungicides applied by two methods.

Fungicides	Fungigation	Spraying	Average
Azoxystrobin	52.95*	51.70*	52.32 b
Difeconazol	54.80*	55.03*	54.93 a
Metiram+Pyraclostrobin	53.22*	53.68*	53.45 b
Tebuconazol	53.03*	53.23*	53.12 b
Average	53.46	53.42	53.44
Control	46.94		

*significantly different from control by Dunnett test ($p < 0.05$). Same letters in column do not differ by Scott-Knott test ($p < 0.05$).

Conclusion

The fungigation via drip irrigation could be an alternative to the conventional method of spraying in tomato culture. Azoxystrobin is the most indicated fungicide for fungigation applications.

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