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Efficacy of chloropicrin application by drip irrigation in controlling the soil-borne diseases of greenhouse pepper on commercial farms in Poland

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ABSTRACT

Three demonstration experiments were conducted on commercial greenhouse farms to assess the efficacy of chloropicrin (CP), applied by drip irrigation, in controlling Verticillium wilt and root rot disease complex of bell pepper, in comparison with dazomet at 40 g m^{-2}. Chloropicrin was applied through drip irrigation system at 20, 30 and 40 g m^{-2} of emulsified commercial formulation. The concentration of CP in water was constant, and the required doses were obtained by delivering different amounts of the irrigation water per area unit (from 12.5 to 33 mm). The highest mean efficacy in reducing the inoculum density of *Verticillium dahliae* in the soil at all locations was obtained after CP application at 30 and 40 g m^{-2}, about 85 and 86%, respectively. The number of viable microsclerotia recovered from the soil on the day of pepper planting was significantly correlated with the final incidence of Verticillium wilt disease ($r = 0.962$). The highest mean efficacy in controlling Verticillium wilt of pepper (86.4%) was obtained after soil treatment with CP at 40 g m^{-2}, and ranged from 80.2 to 95.6%. The yield was stronger correlated with root rot severity ($r = -0.849^{**}$) than with progression of Verticillium wilt, expressed by AUDPC ($r = -0.651^{**}$). The dominant soil-borne pathogen responsible for pepper root rot was *Colletotrichum coccodes*. All chemical treatments provided a significant reduction in root rot severity compared to the untreated control. On-thefarm evaluation revealed that soil fumigation with drip-applied chloropicrin presents a feasible option for pepper growers.

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1. Introduction

Bell pepper (*Capsicum annuum* L.) is an important greenhouse crop in Poland with the yearly production currently estimated at about 100,000 tons. Among soil-borne fungal pathogens, *Colletotrichum coccodes* (Wallr.) S.J. Hughes, *Fusarium solani* (Mart.) Ap. et Wr., *Pyrenochaeta lycopersici* Schneider et Gerlach, *Rhizoctonia solani* Kűhn, *Sclerotinia sclerotiorum* (Lib.) de Bary and *Verticillium dahliae* Kleb. are the most common causal agents of soil-borne pepper diseases in Poland (Ślusarski and Dobrzańska, 1999; Ślusarski, 2008). Over the past 20 years, Verticillium wilt of pepper has changed in Poland from being uncommon to a serious phytosanitary problem in the areas of concentrated pepper production in unheated plastic greenhouses (west of Radom and east of Krakow). The destructiveness of this disease is especially evident on farms with a long history of pepper growing in monoculture. In recent years, an increase in the incidence of Verticillium wilt of pepper has been reported from different parts of the world (Bhat et al., 2003; Douira et al., 1995; Sanogo and Carpenter, 2006; Tsror (Lahkim) et al., 1998).

During the process of methyl bromide phasing out, and shortly thereafter, a mixture of 1,3-dichloropropene (1,3-D) and chloropicrin (CP) was recognized in different countries as an effective alternative fumigant for controlling soil-borne diseases and nematodes (Ajwa et al., 2003; Ajwa and Trout, 2004; Cebolla et al., 2005; Duniway, 2002, 2004; Klose et al., 2007; Lacasa et al., 2002; Martin, 2003; Minuto et al., 2006; Spotti et al., 2011). Strong nematicidal properties of 1,3-D, used as a stand-alone fumigant, are well known, whereas chloropicrin is highly effective against plant pathogenic soil fungi, but for decades CP was used in mixtures with methyl bromide, rather than alone (Duniway, 2004; Wilhelm et al., 1974). However, both 1,3-D and CP have a limited herbicidal activity

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(Gilreath et al., 1997). There are also several reports demonstrating that the supplementary use of CP in a sequential application with metam sodium, dazomet (DZ), 1,3-D or 1,3-D + CP can improve yields and control of soil-borne pests in comparison with each fumigant applied alone (Ajwa et al., 2003; Ajwa and Trout, 2004; Gilreath et al., 2005; Kokalis-Burelle et al., 2005; Shem-Tov et al., 2006). Although the high efficacy of 1,3-D + CP mixture is well documented, this fumigant could not be used across the world due to the lack of registration in numerous countries. However, the latest decision of EC to phase-out 1,3-D (Commission Decision 2011/36/EU of 20 January 2011) precludes the use of this compound in the EU countries, except for emergency uses.

At present only metam sodium and dazoment are registered in EU countries. However, there are some stringent restriction on their use. Both chemicals can be used on the same field every three years and maximum permissible application rate of metam sodium has been reduced to 300 L per hectare (153 kg/ha), which corresponds to 86.3 kg/ha of MITC in case of open field applications. In greenhouses metam sodium can be applied by drip irrigation only, and the use of gas-tight plastic film is compulsory. Registration of DMDS (dimethyl disulfide) in some EU countries (France, Italy, Spain) is still pending. It is worth mentioning that European Chloropicrin Group (ECG) made a resubmission application for the inclusion of chloropicrin in Annex I in accordance with the provisions laid down in Chapter III of Commission Regulation (EC) No.33/2008. There is some hope that chloropicrin will again be included in Annex I to EC Regulation No 1107/2009. Also the choice of non-fumigant chemicals registered for controlling the soil-borne pests is generally limited in European countries, and in most cases restricted to two fungicides (fluazinam and propamocarb alone or in mixture with fosetyl-Al) and two nematicides (fosthiazate and oxamyl).

The results of numerous experiments indicate that CP applied alone by a shank injection method, in most cases at the rates from 124 to 690 kg ha^{-1}, can provide an effective control of different soil-borne fungi, including *Fusarium oxysporum* (Gullino et al., 2002), *Pyrenochaeta lycopersici* (Campbell et al., 1982), *Rhizoctonia solani* (Minuto et al., 2000), *Phytophthora cactorum* (De Cal et al., 2004) and *Verticillium* spp. (Harris, 1990;Wilhelm et al., 1974). Early studies of Stark (1948) revealed striking differences in the relative susceptibility to chloropicrin among 43 fungi species tested. Some saprotrophic fungi (*Aspergillus niger* v.Tieghem, *Chaetomium globosum* Kunze) were about 240 times more resistant than oomycetes such as *Phytophthora* sp. and *Pythium* sp.

In recent years, a new technology of the application of emulsified formulations of liquid alternative fumigants (1,3-D + CP and CP alone) by drip irrigation systems has been developed and extensively evaluated in different crops, especially in strawberries and tomatoes (Ajwa et al., 2002; Ajwa and Trout, 2004; Minuto et al., 2000). It was shown that the efficacy of CP in controlling weeds and nematodes can be higher when applied with the adequate volume of water through the drip irrigation system than when applied by shank injection (Ajwa and Trout, 2004; Fennimore et al., 2003). Drip fumigation has several advantages over shank injection, including a more uniform distribution of a chemical in the soil, reduced atmospheric emissions, lower application rates being used, reduced applicator exposure and lower cost of the treatment (Ajwa and Trout, 2004).

The aim of the present work was to evaluate the effects of chloropicrin, applied as a stand-alone fumigant through drip irrigation system, on Verticillium wilt, root rot severity and yield of bell pepper, grown in commercial greenhouses in naturally infected soil.

2. Material and methods

2.1. Experimental sites and trial design

Three demonstration experiments were conducted in 2009 on commercial greenhouse farms in the largest area of pepper cultivation in unheated plastic tunnels, located west of Radom (Central Poland), in three villages: Borowa Wola (Trial 1), Klwow (Trial 2) and Jelonek (Trial 3). Each farm had a long history of bell pepper cultivation in monoculture (more than 15 years), and problems with Verticillium disease in the past few years. In the plastic greenhouses selected for the trials, the soil at the Borowa Wola and Jelonek locations was sandy loam and loamy sand at the Klwow location. All greenhouses were equipped with a drip irrigation system consisted of thin-walled drip tapes with emitters spaced 20 cm apart and a discharge rate of 1 L per hour.

The following treatments were applied: dazomet as a reference treatment, chloropicrin at three application rates (Table 1) and untreated control. Each treatment was arranged in one unheated plastic tunnel of 228 m^2 (7.6 × 30 m), which constituted an experimental unit. These greenhouses had not been exposed to soil disinfestation for at least past four years. On all farms pepper cultivar ‘Red Knight’ (De Ruiter Seeds) was grown and there were 800 plants in each greenhouse. The plants were grown according to the standard commercial practices commonly used in this region. The pre-plant application rates of fertilizers, necessary to obtain the recommended level of nutrients in the soil, were determined by chemical soil tests and, in consequence, were different at particular locations.

2.2. Application of fumigants

Tripicrin™ (Tris International, Italy), an emulsified formulation, containing 94% of chloropicrin and Basamid 97 GR (Kanesho Soil Treatment, Belgium), a commercial product containing 97% of dazomet were used in this study. Chloropicrin was applied through drip irrigation system at 20, 30 and 40 g m^{-2} of commercial formulation. The concentration of CP in water was constant, and the required dosages were obtained by delivering different amounts of the irrigation water per area unit (Table 1). Chloropicrin was released from steel cylinders using pressurized nitrogen and injected into the irrigation water via a metering device. To ensure better horizontal water distribution in CP treated greenhouses, additional drip tapes were added (before soil tarping) to each manifold to reduce the distance between them to about 50 cm. The soil was covered with a

Table 1
Details of the three greenhouse experiments.

Trial no.	Site	Application rates of CP[a] (g m^{-2})	Concentration of CP in irrigation water (mg l^{-1})	Amount of irrigation water (mm) per application rate	Amount of water for washing (mm)	Date of fumigant application	Date of pepper planting	Last harvest
1	Borowa Wola	20 (18.8), 30 (28.2), 40 (37.6)	1600 (1504)	12.5; 18.75; 25	4	20 April 2009	11 May 2009	30 Oct. 2009
2	Klwow	20 (18.8), 30 (28.2), 40 (37.6)	1200 (1128)	16.67; 25; 33	4	21 April 2009	11 May 2009	30 Oct. 2009
3	Jelonek	20 (18.8), 30 (28.2), 40 (37.6)	1600 (1504)	12.5; 18.75; 25	4	21 April 2009	7 May 2009	13 Oct. 2009

[a] Chloropicrin (CP) applied as Tripicrin™ containing 94% of CP. Values in parenthesis represent actual application rate or concentration of the active ingredient.

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