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Clubroot management of highly infested soils

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ABSTRACT

Clubroot (*Plasmodiophora brassicae*) is a disease that causes severe damage to cruciferous crops in Brazil. This study aimed to evaluate the chemical control of clubroot disease using flusulfamide at different concentrations compared with quintozene, chlorothalonil and pH reduction using lime. The efficiency of the chemical control and pH reduction combined with solarization was also tested in a commercial field. Three experiments were conducted using cauliflower cabbage and Chinese cabbage in fields located in Quatro Barras County (Paraná State, Brazil) to determine the efficacies of flusulfamide, quintozene, chlorothalonil and lime. A fourth experiment was performed using broccoli with various combined control methods (pH reduction with lime, chemical control using flusulfamide and physical control with soil solarization in a factorial design). The fresh weight (g), commercial units and gall severity in the roots were evaluated. The quintozene, chlorothalonil and lime treatments, when applied alone, were not effective in controlling clubroot. The best treatment was flusulfamide at a rate of 20 L ha^{-1} for the three studied species. The combination of lime to reduce pH with solarization and flusulfamide was effective to control clubroot and can be recommended to treat soils highly infested with *P. brassicae*.

1. Introduction

Clubroot is a disease caused by the soil-borne obligate parasite, *Plasmodiophora brassicae* Woronin. The pathogen is grouped within the Rhizaria eukaryotic supergroup. The disease causes serious yield loss of crucifers and is widely distributed throughout the world (Webster, 1980; Narisawa et al., 2005; Abbasi and Lazarovits, 2006; Fayolle et al., 2006; Hasse et al., 2007a; May De Mio et al., 2008).

Clubroot is more severe in excessive soil moisture conditions, especially in fields where the soil moisture is more than 70% of the field capacity (Horiuch and Hori, 1980). A temperature range of 18–25 °C and a low pH value favor the infection, but the disease can occur over a wide range of conditions, leading to serious crop losses (Karling, 1968; Myers and Campbell, 1985; Webster and Dixon, 1991; Murakami et al., 2002). The soils around the metropolitan region of Curitiba in southern Brazil can have a high density of the pathogen inoculum in the soil (Hasse et al., 2007a, 2007b; Ruaro et al., 2009, 2010).

Lime application provides some level of protection against clubroot disease (Myers and Campbell, 1985; Murakami et al., 2002). However, under high clubroot pressure and favorable conditions, disease control with lime is generally not satisfactory (Ruaro et al., 2009). Other products have been reported for clubroot control, such as AG3 phosphonate (Calirus 150, liquid formulation, 10.45% active ingredient (ai) phosphorus acid and copper sulfate with citrate as a chelating agent) (Abbasi and Lazarovits, 2006) and nitrogen (Coutinho et al., 1993). Solarization is another technique employed in clubroot control (Myers et al., 1983; Porter and Merriman, 1985; Porter et al., 1991; May De Mio et al., 2008).

Some soil fungicides can control clubroot, but they have limited efficacy when there is a high density of resting spores and highly virulent populations of *P. brassicae* (Tanaka et al., 1999). Quintozene, which contains pentachloronitrobenzene (PCNB), is a standard commercial chemical that has been used for clubroot control on cruciferous crops in Japan (Ogiso and Tanabe, 1982). The standard commercial PCNB concentrations range from 40 to 50 kg ai ha^{-1}; it is used as a broadcast treatment and is effective for 10–12 months. However, an environmental concern regarding the accumulation of PCNB in the soil has led to restrictions on the product's use (Nishimura et al., 1980; Ogiso and Tanabe, 1982). Flusulfamide has been recommended for clubroot control (Fujita, 1994). This fungicide can reduce the numbers of resting spores and secondary zoospores of the fungus (Tanaka et al., 1999).

Soil fungicides that reduce resting spore germination can be more effective when used in combination with cultural techniques such as solarization. This study aimed to evaluate the efficacies of different concentrations of flusulfamide in controlling clubroot in

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Table 1
Description of chemical treatments (flusulfamide, chlorothalonil, PCNB and lime) for clubroot (*Plasmodiophora brassicae*) control in different species of cruciferous crops under field conditions in fields located in Quatro Barras County (Paraná State, Brazil).

Common name	Dosage ai g kg^{-1}	Formulation	Chemical group	Cruciferous crops[a]
Flusulfamide	10 L ha^{-1}	SC	Sulfonanilide	CF, CC, CA
Flusulfamide	10 L ha^{-1} + lime	SC	Sulfonanilide	CF
Flusulfamide	15 L ha^{-1}	SC	Sulfonanilide	CA, CC
Flusulfamide	20 L ha^{-1}	SC	Sulfonanilide	CF, CC, CA
Chlorothalonil	40 kg ha^{-1}	PM	Phthalonitrile	CC, CA
Lime	5 ton ha^{-1}			CF
Quintozene	40 kg ha^{-1}	PM	Nitrobenzene	CC, CA
Quintozene	12 kg ha^{-1}	PM	Nitrobenzene	CC, CA

[a] Abbreviations are as follows: CF, Cauliflower (*B. oleraceae* var. *botrytis* – cv. Miay; hybrid); CA, cabbage (*B. oleraceae* var. *capitata* – cv. Coração de boi); and CC, Chinese cabbage (*B. rapa* ssp. *pekinensis* – cv. Kioto).

comparison with PCNB, chlorothalonil and lime on highly infested soils. The efficacy of the chemical control and pH reduction combined with solarization was also tested.

2. Materials and methods

2.1. Effect of chemical control on clubroot in cruciferous crops

The experiment was conducted in a commercial field located in Quatro Barras County (Paraná State, Brazil). The area is characterized by an abundance of cruciferous crops growing in soil that is classified as Distrophic Cambisol (Inceptsol) with a high level of infestation with *P. brassicae*; the lime application used has not been effective against the disease over the years. The soil of the experimental area was tested previously (data not shown) following the methodology of Hasse et al. (2007b), and it was classified as highly infested soil.

Cauliflower (*Brassica oleraceae* L. var. *botrytis* L) (cv. Miay; hybrid) was grown on this field from January to the end of March, and cabbage (*B. oleraceae* L. var. *capitata* L.) (cv. Coração de boi) was grown from February to May. The environmental conditions during the development experiment included 136 mm month^{-1} of rainfall, 80.7% relative humidity (RH) and a mean monthly temperature of 19.5 °C. Additionally, Chinese cabbage (*Brassica rapa* L. ssp. *pekinensis* (Lour.) Hanelt) (cv. Kioto) was grown from July to October, when the mean rainfall was 115 mm month^{-1}, the RH was 77.2% and the mean monthly temperature was 16.1 °C. The experiment was arranged in a randomized block design with six treatments and four replicates in addition to the control (Table 1). Each plot was 2.80 × 1.40 m with spacing of 0.80 × 0.50 m. The seedlings of the cruciferous crops were sown in multicellular trays containing PlantMax® (EucatexAgro, Paulinia-SP, Brazil) substrate 30 days prior to the planting date, when the seedlings were transplanted into the field. The treatments were applied one day before transplantation by irrigation (2 L m^{-2}).

Evaluation of the cabbage was performed 90 days after transplantation by assessing the fresh weight (g), counting the number of units that could be sold commercially (commercial units) and evaluating the clubroot severity. The following scale was used to classify the severity of the clubroot (Fig. 1): 0 = absence of galls in the roots; 1 = 1–25% of roots with galls; 2 = 26–50% of roots with galls; 3 = 51–75% of roots with galls; and 4 = 76–100% of roots with galls. Evaluation of the Chinese cabbage was performed 60 days after transplantation by analyzing the above-mentioned variables. Evaluation of the cauliflower was performed 74 days after transplantation by assessing the above-mentioned variables, except for the number of commercial units. All the assessments were performed in 12 plants per treatment, and the severity was expressed as the mean of all the evaluated plants per treatment, using the score scale with values between 0 and 4.

Soil analyses were performed using the method described by Lima et al. (2003) and using a composite sample of the experimental area for each species of cruciferous crop 40 days before the experimental set up. The chemical characteristics of the soils of each experimental area are provided in Table 3.

2.2. The use of integrated methods to control clubroot

The experiment was conducted with broccoli (*B. oleraceae* L. var. *italica* Plenck) (cv. Hana Midori Sakata) in the same location from July to October, following the season of the previous experiments described. The experiment was arranged in a factorial design with three factors (lime, soil solarization and chemical control) and four replicates. The eight treatments were: 1. Non treatment control; 2. pH reduction (pHr – lime applied at 4.5 ton ha^{-1}); 3. Chemical control (ChC – flusulfamide applied at 20 g ai ha^{-1}); 4. Physical control (PhC – solarization during 60 days); 5. ChC and pH reduction; 6. PhC and pH reduction; 7. PhC and ChC and 8. pHr, PhC and ChC. The plots were approximately 4 m^2 (Table 2).

The soil was homogenized with preexisting inoculum for the experiment. A hydrothermal process (soil solarization) that employs solar radiation to heat the soil under a transparent plastic film (length, 2 m) was applied in each treated parcel for 60 days from late January to late March. During this period, the soil temperature was monitored and reached 42 °C in late February.

Evaluation of the broccoli was performed 70 days after transplantation by assessing the fresh weight (g) as a productivity parameter and the clubroot severity and incidence as a disease

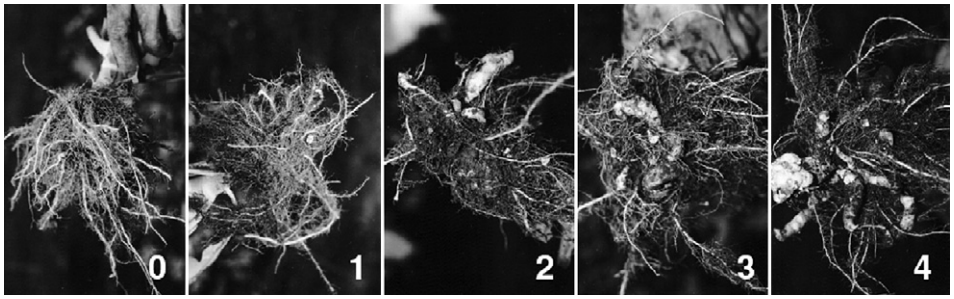

Fig. 1. Score scale of clubroot (*Plasmodiophora brassicae*) in roots of cruciferous crops: 0 = absence of galls in roots; 1 = 1–25% of roots with galls; 2 = 26–50% of roots with galls; 3 = 51–75% of roots with galls; and 4 = 76–100% of roots with galls.