BioOne DIGITAL LIBRARY

Soil fumigation with Vapam (metam sodium) to control clubroot (Plasmodiophora brassicae) of canola (Brassica napus)

Authors: Zuzak, Krista A., Strelkov, Stephen E., Turnbull, George D., Manolii, Victor P., and Hwang, Sheau-Fang

Source: Canadian Journal of Plant Science, 103(1) : 29-38

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/cjps-2022-0086

The BioOne Digital Library (https://bioone.org/) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (https://bioone.org/subscribe), the BioOne Complete Archive (https://bioone.org/archive), and the BioOne eBooks program offerings ESA eBook Collection (https://bioone.org/esa-ebooks) and CSIRO Publishing BioSelect Collection (https://bioone.org/csiro-ebooks).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commmercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Canadian Journal of Plant Science

Article

Soil fumigation with Vapam (metam sodium) to control clubroot (*Plasmodiophora brassicae*) of canola (*Brassica napus*)

Krista A. Zuzak, Stephen E. Strelkov, George D. Turnbull, Victor P. Manolii, and Sheau-Fang Hwang

Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB T6G 2P5, Canada

Corresponding author: **Sheau-Fang Hwang** (email: sheau.fang.hwang@ualberta.ca)

Abstract

Clubroot, a damaging disease of canola (*Brassica napus* L.) caused by the soilborne parasite *Plasmodiophora brassicae* Woronin, is spreading across Alberta and other provinces of western Canada. The movement of infested soil on field machinery is the main mechanism of dispersal, with clubroot generally occurring first as localized patches near field entrances. In this study, the soil fumigant Vapam (metam sodium) was evaluated as a management option for foci of *P. brassicae* infestation. Replicated experiments at two field sites in central Alberta showed reductions in clubroot severity ranging from 9% to 51% following treatment with varying rates of Vapam. Decreases in clubroot severity of up to 28% were observed in the year following Vapam treatment, indicating some potential residual effects and (or) a reduction in the amount of inoculum returned to the soil in the previous year. While Vapam shows some promise as a clubroot management tool, an integrated approach will be required for the sustainable management of this disease on canola.

Key words: canola, clubroot, *Plasmodiophora brassicae*, soil fumigation

1. Introduction

Plasmodiophora brassicae Woronin is the causal agent of clubroot, a soilborne disease of the family Brassicaceae. As an obligate parasite, *P. brassicae* requires a living host for growth and completion of its life cycle. Potential hosts include cultivated crop species such as canola (*Brassica rapa* L. and *Brassica napus* L.), mustard (*Brassica hirta* Moench and *Brassica kaber* (DC.) L.C. Wheeler), and cruciferous vegetables, as well as weeds including stinkweed (*Thlaspi arvense* L.) and shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.) (Dixon 2009*a*, 2009*b*; Hwang et al. 2012*a*).

The clubroot pathogen spreads mainly through the movement of infested soil and water (Dixon 2009*b*; Kageyama and Asano 2009), although significant levels of inoculum have also been identified in wind-borne dust (Rennie et al. 2015). In addition, quantifiable levels of resting spores have been found to occur as external contaminants of crop seeds and tubers, but seed-borne contamination may be effectively mitigated by seed cleaning and seed treatments (Rennie et al. 2011; Hwang et al. 2012*a*). Resting spores of *P. brassicae* are extremely robust, prolonging pathogen survival in the soil. The half-life of the resting spores has been estimated to be 3.6–4.4 years, and they can survive in the soil for nearly 20 years (Wallenhammar 1996; Dixon 2009*a*; Hwang et al. 2013). Recent studies (Peng et al. 2015; Ernst et al. 2019) suggest that resting spore numbers drop significantly in the first 2 years after a canola crop, but later stabilize, with the remaining component of the spore population persisting for much longer. This longevity of the resting spores makes clubroot management difficult. Host plants infected with *P. brassicae* exhibit external symptoms, including poor aboveground plant growth, premature and patchy stand ripening, and the characteristic galled roots. Plants often display chlorotic leaves, wilting, and may even succumb entirely to the disease. There can be severe yield and quality losses associated with *P. brassicae* infection, and the value of infested land may be depressed (Dixon 2009*a*). In canola, infected plants produce fewer seeds with lower oil content and quality (Pageau et al. 2006), with clubroot severity highly dependent on pathogen virulence, inoculum concentration, and host genetics (Botero-Ramírez et al. 2022). Worldwide, losses due to clubroot are estimated at between 10% and 15% (Dixon 2006, 2009*a*). Clubroot is proving to be a serious concern for farmers as it spreads to new areas. Brassica crops are increasingly important for both the food market and industrial applications, and as a result, more Brassicas are being grown, with many representing species and varieties susceptible to *P. brassicae* infection (Dixon 2009*a*).

In western Canada, clubroot was not reported on canola until 2003, when a dozen infested fields were identified in central Alberta. Previous reports of clubroot in Alberta were restricted to home and market gardens (Strelkov et al. 2006).

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

The intensive production of canola is associated with the use of large pieces of field equipment, which can act as vectors for the movement of infested soil. Machinery can therefore help spread *P. brassicae* from field to field, facilitating its dissemination across borders and into previously uninfested regions (Dixon 2009*a*). An increase in the area and intensity of canola cultivation, combined with the spread of the pathogen, has resulted in a sharp rise in the number of infested fields to over 3300 confirmed cases by 2019 (Strelkov et al. 2020). While the first infestations were identified in central Alberta, where the outbreak remains most severe, cases of clubroot have been reported with increasing frequency in other regions, including the Canadian provinces of Saskatchewan and Manitoba (Cao et al. 2009; Dokken-Bouchard et al. 2012; Strelkov et al. 2012; Strelkov and Hwang 2014), as well as in North Dakota in the United States (Chittem et al. 2014).

Several management strategies have been recommended for clubroot. In the canola production systems of the Canadian Prairies, however, most farmers have relied on the cropping of clubroot-resistant canola cultivars (Rahman et al. 2014; Strelkov and Hwang 2014). Genetic resistance, while often highly effective, does not eliminate soilborne *P. brassicae* inoculum (Ernst et al. 2019). Moreover, repeated cropping of resistant varieties can cause shifts in the virulence of pathogen populations, which can result in a loss or erosion of resistance (LeBoldus et al. 2012). Strategies aimed at reducing the movement of *P. brassicae* inoculum, such as the sanitization of field equipment, may help to slow spread of the pathogen. Most farmers, however, do not regularly clean or sanitize equipment, citing costs, time, and logistical concerns (Hwang et al. 2014). As such, the number of infested fields continues to increase.

Within 4 years of the introduction of clubroot-resistant canola to western Canada, the first strains of *P. brassicae* able to overcome resistance were identified (Strelkov et al. 2016). The loss of genetic resistance as a clubroot management tool on canola could have serious implications for the production of this crop (Hwang et al. 2014), making alternate management options even more valuable. Fungicides have been utilized in multiple ways to manage clubroot, and have been evaluated in canola as soil drench applications and as treatments against seed-borne inoculum (Gossen et al. 2012; Hwang et al. 2012*b*). Hwang et al. (2011) assessed 10 soil fungicides for their efficacy in controlling clubroot of canola, and found that both Ranman (cyazofamid) and Terraclor (quintozene) significantly reduced the severity of the disease. Soil amendments including lime, wood ash, and calcium cyanimide have also been evaluated for the management of clubroot (Murakami et al. 2002; Hwang et al. 2011; Fox et al. 2021) and, in some cases, reduced disease severity. Nevertheless, despite varying levels of efficacy with respect to disease control, neither fungicides nor soil amendments have been relied upon as primary clubroot management tools in canola. While fungicides have been used with some success in higher-value crops such as cruciferous vegetables (Donald and Porter 2014), the lower economic returns associated with canola, combined with the much larger scale in which this crop is typically grown, have made chemical control cost-prohibitive in most cases.

Fumigants differ from fungicides in that they produce vapours that are toxic to organisms in the soil. Fumigants are often more general in their target range than fungicides. Fumigation of the soil has been used as a strategy for the management of soilborne pests and pathogens in many high-value crops (Papiernik et al. 2004). Soil fumigants have several common characteristics that make them particularly effective for suppressing viable spore populations, including relatively high vapour pressures, low boiling points, and high air–water partitioning coefficients (Papiernik et al. 2004). The soil fumigant Vapam (metam sodium; sodium *N*-methyldithiocarbamate) has a low adsorption to soil and a comparatively slow diffusion within soil. It also possesses a high rate of decomposition at high soil temperatures, and a relatively greater partition into water from air relative to some other fumigants (Smelt and Leistra 1974). These characteristics suggest that Vapam may be a good candidate for clubroot management in Canadian canola crops. Vapam degrades in the soil, yielding methyl isothiocyanate (MITC), carbon disulfide, carbonyl sulfide, and hydrogen sulfide (Smelt and Leistra 1974; Saeed et al. 2000; Triky-Dotan et al. 2010). MITC is water soluble and toxic, with a relatively high vapour pressure (Saeed et al. 2000), and is the active ingredient postulated to have toxic effects on soilborne target organisms such as fungi, nematodes, weeds, and some soil arthropods (Smelt and Leistra 1974; Triky-Dotan et al. 2010). Nonetheless, it is important to keep in mind that fumigants are non-specific in their activity, so other organisms may be harmed unintentionally (Smelt and Leistra 1974).

The application of soil fungicides and fumigants often aims to reduce *P. brassicae* inoculum density, either directly by causing death of the resting spores or indirectly by reducing the amount of spores returned to the soil due to reduced symptom development (i.e., smaller root galls). A minimum threshold of about 1×10^3 to 1×10^5 resting spores g^{-1} soil is required for clubroot symptom development under field conditions, depending on soil type and environmental conditions (Faggian and Strelkov 2009). As soil inoculum levels increase beyond 1×10^6 resting spores g^{-1} soil, control measures such as genetic resistance can be overwhelmed, making management of the disease more challenging (Hwang et al. 2017). In canola fields in Alberta, inoculum densities as high as 1×10^8 resting spores g^{-1} soil have been reported (Hwang et al. 2015). This inoculum, however, usually has a patchy distribution, with foci of infection often found around field edges and entrances (Cao et al. 2009; Botero-Ramírez et al. 2021). This has been postulated to reflect the introduction of *P. brassicae* to new fields on farm and other machinery (Cao et al. 2009). Intensive treatments such as soil fumigation can be applied to these localized infestations that might not be practical or economical over an entire field.

In this context, the objective of this study was to evaluate Vapam as a tool to eradicate or contain localized *P. brassicae* field infestations before they become widespread. Both the

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

in-season and residual effects of Vapam on clubroot severity and associated plant growth traits were assessed.

2. Materials and methods

2.1. Vapam soil fumigation

Trials to evaluate the impact of different concentrations of Vapam on clubroot severity and various plant growth parameters were established in 2012 and 2013 at two field locations in Edmonton, AB. Both locations (Henwood site: 53°38′48″N, 113°22′33″W; 50th Street site: 53°38′39″N, 113°24′41″W) are naturally infested with *P. brassicae*. The placement of the research plots within each field location was moved in the second year of the study, so that the plots were not placed exactly in the same spot as the previous year, and so that the first year site could be used to study the longer-term effects of Vapam application (see below). The soil at the Henwood and 50th Street sites is a Black Chernozemic loam, with pH 5.0 and 4.8 and an organic content of 10% and 8%, respectively. Each location was prepared by cultivating the plot areas and measuring out the plot squares before treatment. The experiments were arranged in a randomized complete block design with four replications. Each plot was 1.4 m × 1.4 m, with a 1 m × 1 m treatment area in the centre, 0.6 m spacing between plots, and a 0.6 m buffer between replications (Fig. 1).

Vapam HL (42% sodium methyldithiocarbamate, AMVAC Chemical Corporation2005) was applied to the soil water as per the "watering can method" on the product label, typically used for small areas such as gardens, and which was practical for the small size of the plots. The recommended label rate for the watering can method of Vapam application is 74 mL m^{-2} (31.1 mL active ingredient (AI)). Treatments of 10% (3.1 mL m^{-2} AI), 25% (7.8 mL m^{-2} AI), 50% (15.5 mL m^{-2} AI), 100% (31.1 mL m^{-2} AI), and 200% (62.2 mL m^{-2} AI) of the recommended label rate of Vapam were selected. The treatments were applied in a plastic watering can as evenly as possible, with a sweeping side-to-side motion, to achieve uniform coverage of the soil in each plot. Control plots were treated in the same manner, except that water without Vapam was applied.

After the soil was treated with the appropriate concentration of Vapam, each plot was covered with a black plastic tarp (approximately 1.2 m × 1.2 m), the edges of which were trenched approximately 10 cm deep into the soil to secure the covering and prevent volatilization. The tarps remained on the plots for 72 h and were then removed. After a minimum of 2 days without the tarps (see seeding dates below), the plots were seeded with the clubroot-susceptible canola "73-15RR" (Dekalb, Monsanto Canada Inc., Winnipeg, MB, Canada). Plots were hand-seeded, with four rows of 20 seeds at a depth of 2 cm, with the seeds spaced about 5 cm apart, representing a seeding rate of 80 seeds m^{-2} plot. Row spacing was approximately 25–30 cm. The plots at the Henwood site were fumigated on 21 June 2012 or 16 May 2013, and seeded on 28 June 2012 or 28 May 2013. At the 50th Street site, the plots were fumigated on 16 July 2012 or 17 May 2013, and seeded on 23 July 2012 or 29 May 2013. The plants were grown for approximately 8 weeks after emergence (canola growth stage 7, "development of seeds"; www.canolacouncil.org/canola-encyclopedia/growth-stages/), when they were dug out from the soil, and the roots were washed with water and rated for clubroot severity on a 0–3 scale (Horiuchi and Hori 1980), where 0 = no galling, 1 = a few small galls, 2 = moderate galling, and 3 = severe galling (Fig. 2). The harvest dates were selected to ensure clubroot gall development, but avoid maturity to the point of gall decomposition in the soil. The plots at the Henwood site were harvested on 27 August 2012 or 20 August 2013. The plots at the 50th Street site were harvested on 1 October 2012 or 20 August 2013.

All plants within each plot were assessed for clubroot severity, and individual disease ratings were used to calculate an index of disease (ID) according to the formula of Kuginuki et al. (1999) as modified by Strelkov et al. (2006):

$$\mathrm{ID}\,(\%) = \frac{\sum (n \times 0 + n \times 1 + n \times 2 + n \times 3)}{N \times 3} \times 100\%$$

where n is the number of plants in a class; N is the total number of plants in an experimental unit; and 0, 1, 2, and 3 are the symptom severity classes (Fig. 2). Fresh and dry gall weights, fresh and dry stem weights, plant height, and pod count per plant were also recorded for all plants within each plot.

2.2. Effects of Vapam in the soil 1 year after application

Further experimentation was conducted to assess whether there were any effects on clubroot severity from the application of Vapam HL in the year following treatment (2013). The plots established at the Henwood and 50th Street sites in 2012 were maintained until the 2013 growing season, when they were tilled in preparation for planting of a new crop, without mixing the soil between plots. No additional Vapam was applied, and the plots were seeded with the clubroot-susceptible canola "73-15RR" at a density of 80 seeds m^{-2} plot on 9 May 2013 at both sites. The plants were allowed to grow for approximately 8 weeks after emergence (canola growth stage 7, development of seeds; www.canolacouncil.org/canola-encyclopedia/growth-stages/), when they were dug from the soil, washed with water, and rated for clubroot symptom development. Ten plants from each plot were sampled on 9 or 10 July 2013, respectively, at the Henwood and 50th Street sites. Clubroot severity was assessed on the 0–3 scale described above (Horiuchi and Hori 1980). Other measurements taken for each of the sampled plants included plant height, fresh biomass, fresh gall weight, dry plant weight, number of pods per plant, and dry gall weight.

2.3. Statistical analysis

Statistical analysis was performed with SAS Release 9.4, SAS Institute Inc., Cary, NC. A mixed model analysis of variance (ANOVA) was used to analyze the treatment effects on plant height, fresh aboveground biomass per plant, number of pods per plant, fresh gall weight per plant, and dry gall weight per plant, which were considered as fixed effects. The random effects were blocking factors in the field. The treatments were compared based on the Tukey's test. A

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 1. Field plots to evaluate the effects of soil fumigation with Vapam on growth and clubroot severity in canola.

Fig. 2. Illustration of clubroot symptom severity ratings on canola roots (0 = no galling, 1 = a few small galls, 2 = moderate galling, and 3 = severe galling).

logarithmic transformation was applied to the plant weight, fresh gall weight, pod count, and dry gall weight data to correct for potential deviations from normality in both 2012 and 2013. A logarithmic transformation was also applied to the stem height data in 2012. Non-transformed means are presented for consistency, as normality was tested on residuals produced from the data.

The CATMOD procedure was used to analyze treatment effects for the disease severity data, as it performs modelling of categorical data. Clubroot severity was rated on the 0–3 scale, which indicated the disease category from healthy to severely diseased plants, and the CATMOD procedure allows categorical severity data to be analyzed without transformation. The data are presented as an index of disease. For all analyses, differences were considered to be significant at $p < 0.05$, unless otherwise stated. The majority of growth traits in the study on the residual effects of Vapam showed a significant interaction between site and treatment, meaning the treatment may have affected the plants differently depending on the site growth environment. As a result, the data from the two trials are presented separately.

3. Results

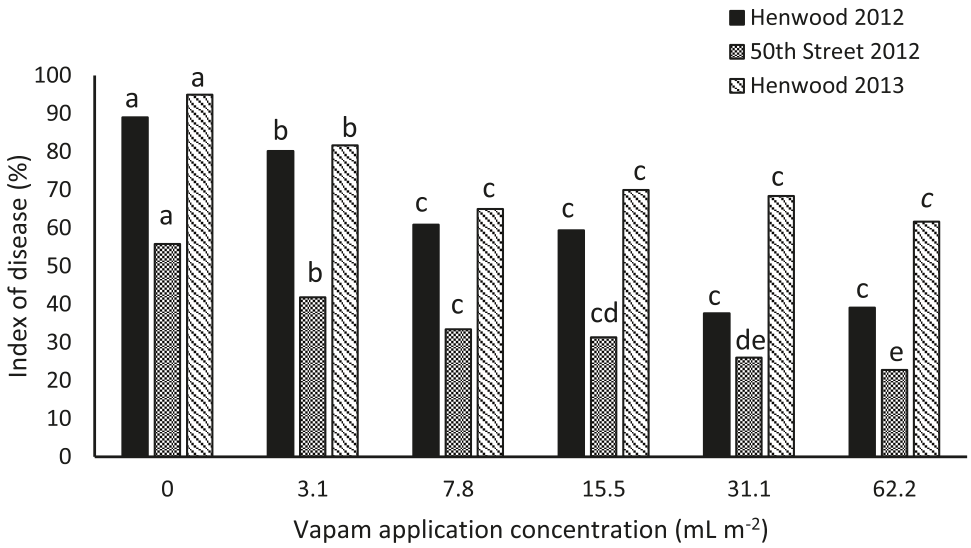
3.1. Vapam soil fumigation

3.1.1. Disease severity

At the Henwood site, all treatments reduced clubroot disease severity when compared with the control treatment in

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 3. Effect of Vapam (metam sodium) on clubroot index of disease severity on canola under field conditions over 3 site-years at two locations in Edmonton, AB. Data are the means of four replicates. Means were compared with the Tukey's test and different letters indicate significant differences at $p < 0.05$.



both years. The average index of disease for the control was 89% in 2012 and 95% in 2013. The indices of disease severity in treated plots ranged from 39% to 80% in 2012 and from 62% to 68% in 2013. The 31.1 mL m^{-2} rate resulted in a 51% reduction in disease severity in 2012, the greatest reduction among the treatments assessed (Fig. 3). However, there was not a significant difference in indices of disease as the rates increased from 7.8 to 62.2 mL m^{-2}. Application of Vapam reduced the indices of disease by 28%–51% in 2012 and by 27%–33% in 2013 at rates of 7.8 mL m^{-2} or higher.

At the 50th Street site in 2012, the control treatment had a lower average index of disease (56%) than at Henwood (89%). Indices of disease in the treated plots ranged from 23% to 42%, with the 62.2 mL m^{-2} rate of Vapam giving the greatest reduction in index of disease relative to the control. It should be noted that despite the numerical decreases in index of disease, there was not a significant difference between treatments as the application rate increased from 7.8 to 62.2 mL m^{-2} (Fig. 3). The 50th Street site experienced early and mid-season flooding in 2013, so these data were removed from subsequent analyses.

3.1.2. Plant growth characteristics

Soil treatment with Vapam at the 7.8 mL m^{-2} rate and above significantly increased plant height and pod numbers per plant, and resulted in a decrease in fresh gall weight per plant at Henwood in both years (Fig. 4). The application of the label rate of Vapam, 31.1 mL m^{-2}, resulted in a 53% increase in aboveground plant biomass and a 42% decrease in fresh clubroot gall weight in 2012 and 2013. Although not all differences between treatments were statistically significant, increases in plant height ranged from 14% to 24%, increases in plant biomass ranged from 63% to 150%, and increases in pod counts ranged from 62% to 105% relative to the control. The label rate of fumigant resulted in plants with an average stem height of 95.5 cm, compared with the control plot plants averaging 82.5 cm ($p = 0.0197$). The average fresh biomass resulting from the label rate treatment was, on average, 52.7 g heavier than control plants ($p = 0.0002$), whereas pod numbers per plant for the label rate plots averaged approximately 114 pods, compared with only 62 pods ($p = 0.0354$) per plant in plots where no Vapam was applied. There were no significant differences in fresh or dry gall weight (Fig. 4). There was no significant difference between the control and 10% label rate (3.1 mL m^{-2}) treatments for plant height or number of pods produced. At the 50th Street site, there were no significant differences in plant height and fresh or dry gall weights in 2012 (Fig. 4).

3.2. Effects of Vapam in the soil 1 year after application

3.2.1. Disease severity

At the Henwood site, indices of disease were significantly lower for canola plants grown in soil that had received Vapam at rates of 15.5, 31.1, and 62.2 mL m^{-2} in the previous year, relative to plants grown in control plots that had not received any Vapam in the previous year (Fig. 5). The greatest reduction in index of disease (28% relative to the control) was observed in plants grown in soil that had received the 200% Vapam rate (62.2 mL m^{-2}) the year before ($p < 0.0001$). At the 50th Street site, index of disease was significantly ($p = 0.0004$) reduced only in those plots that had received the 31.1 mL m^{-2} Vapam treatment in the previous year. These plants had an average index of disease of 53.3%, compared with 71.7% in the control plots. The plots that had received the 200% (62.2 mL m^{-2}) treatment rate did not exhibit a significant reduction in index of disease relative to either the control or the label rate of Vapam (31.2 mL m^{-2}).

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 4. Effect of Vapam (metam sodium) on height (A), number of pods (B), fresh biomass (C), and dry gall weight (D) of canola plants under clubroot-infested field conditions over 3 site-years at two locations in Edmonton, AB. Data are the means of four replicates. Means were compared with the Tukey's test and different letters indicate significant differences at $p < 0.05$.

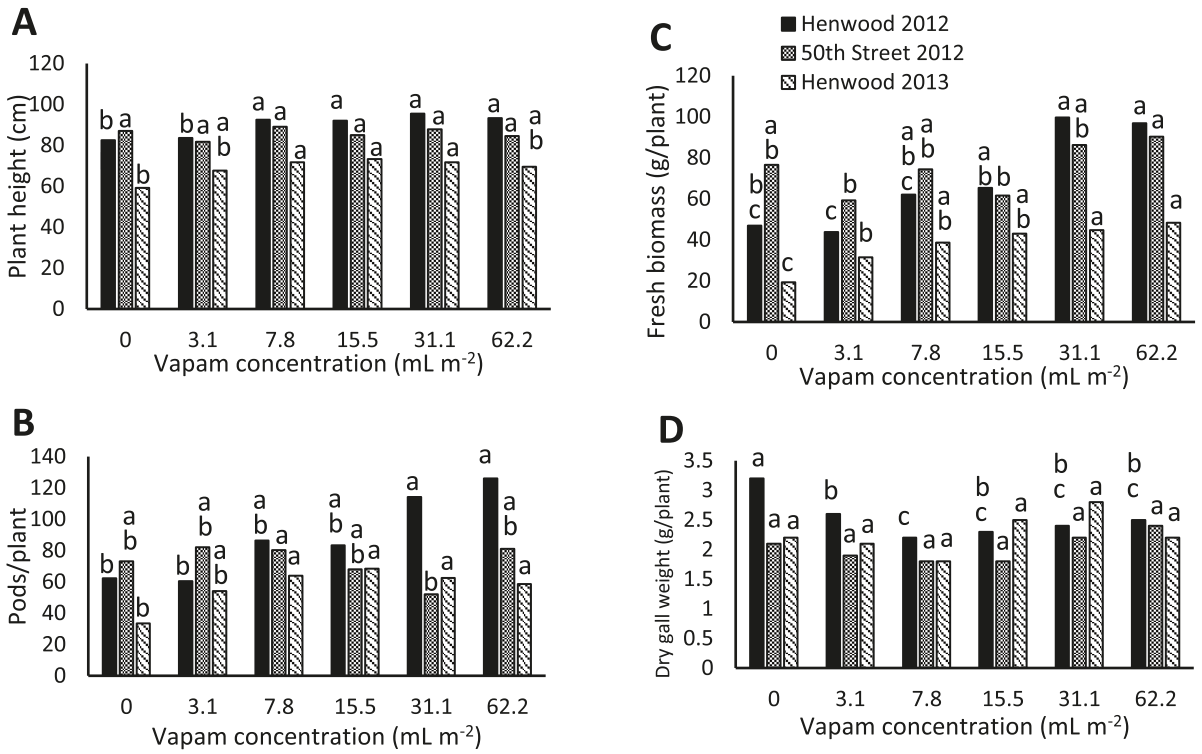
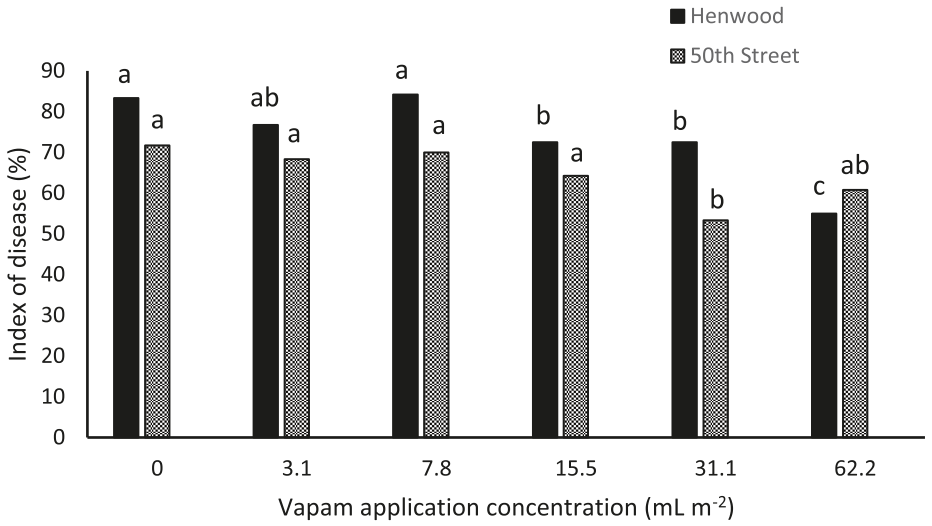


Fig. 5. Effect of Vapam (metam sodium) applied in the previous year on clubroot index of disease severity in canola plants grown under clubroot-infested field conditions over 2 site-years at two locations in Edmonton, AB. Data are the means of four replicates. Means were compared with the Tukey's test and different letters indicate significant differences at $p < 0.05$.

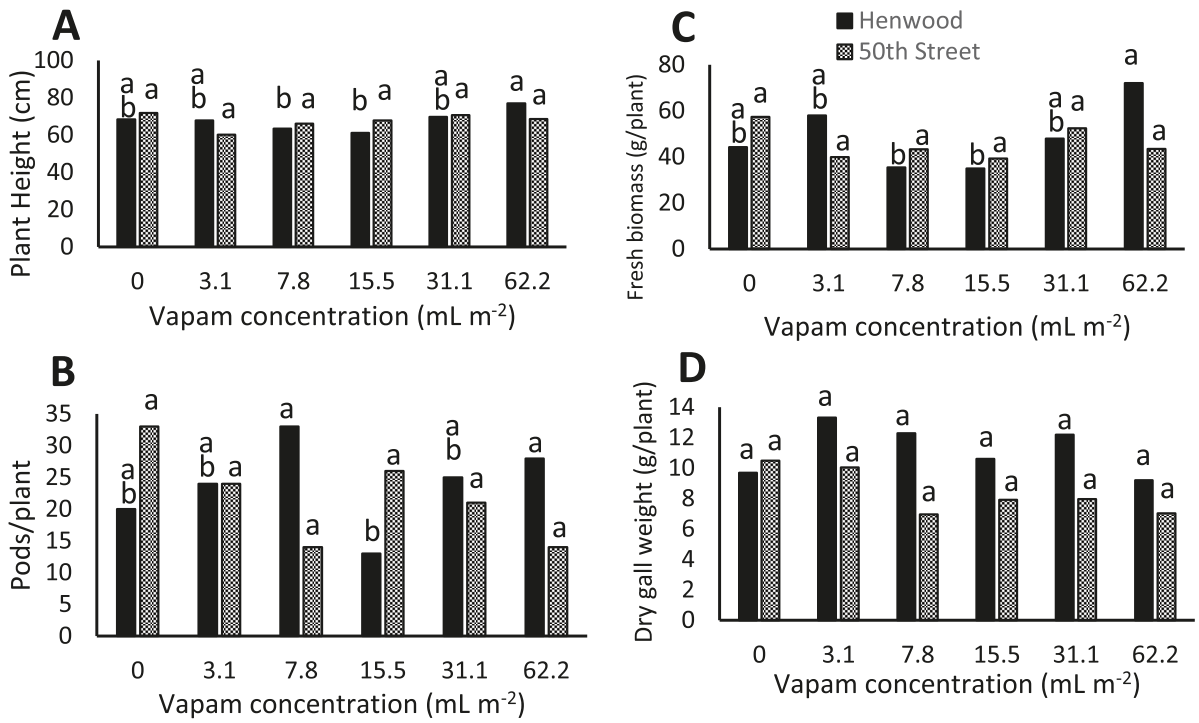


3.2.2. Plant growth characteristics

At the Henwood site, differences in stem height were observed between plants grown in plots that had been treated with 7.8 or 62.2 mL m^{-2} Vapam in the previous year ($p = 0.0361$), as well as between plants grown in plots that had received the 15.5 or 62.2 mL m^{-2} treatment rates ($p = 0.0113$) (Fig. 6). Significant differences were also found between these same treatments with respect to aboveground plant biomass ($p = 0.0297$ and $p = 0.0058$) (Fig. 6). Statistically significant differences in pod counts resulted from comparisons between the 7.8 and 15.5 mL m^{-2} rates ($p = 0.0239$), and between the 15.5 and 62.2 mL m^{-2} rates ($p = 0.0500$) (Fig. 6). In contrast, no significant differences were observed for fresh or dry gall

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 6. Effect of Vapam (metam sodium) 1 year after application on plant height (A), number of pods (B), fresh biomass (C), and dry gall weight (D) of canola plants grown under clubroot-infested field conditions at two locations in Edmonton, AB. Data are the means of four replicates. Means were compared with the Tukey's test and different letters indicate significant differences at $p < 0.05$.



weight between any of the treatments, or between the treatments and the control plots for any of plant growth characteristics examined (Fig. 6). At the 50th Street site, no significant differences were observed for any of the plant growth traits between any of the treatments or control.

4. Discussion

Based on the efficacy of Vapam as a tool for the control of weeds, nematodes, insects, and various soilborne pathogens (Triky-Dotan et al. 2010), this fumigant may have potential as a management tool for clubroot disease of canola. However, it is important to note that Vapam is a non-selective toxic compound. Soil fumigation with a volatile chemical, which is also water soluble, poses threats to the adjacent environment at treatment sites as well as the applicator. It is of paramount importance for soil fumigation to be conducted in accordance with application regulations and label recommendations (AMVAC Chemical Corporation2005).

At the Henwood site in both 2012 and 2013, all treatments reduced clubroot disease severity when compared with the control treatment. At the 50th Street site in 2012, the control treatment had a lower average index of disease than at Henwood, indicating lower disease pressure. Moreover, because of flooding of the site in 2013, only the 2012 data from 50th Street site could be included in the analysis. A study by Hwang et al. (2014) at different locations within the same field sites also assessed the efficacy of Vapam as a soil fumigant against clubroot. At the Henwood site, treatment with Vapam product at a rate of 100 mL m^{-2} (42 mL m^{-2} AI) resulted in a 62% decrease in clubroot severity relative to a non-treated control; at the 50th Street site, clubroot severity decreased by 54% with Vapam treatment (Hwang et al. 2014). The treatment rates evaluated in this study were lower than those used by Hwang et al. (2014); in the earlier study, only one rate was examined, while in this study multiple rates (above and below the recommended rate) were assessed. The label rate of 31.1 mL m^{-2} and the 200% label rate of 62.2 mL m^{-2} both resulted in decreases in clubroot severity at the Henwood and 50th Street sites in 2012. These decreases in disease severity, while lower than those observed by Hwang et al. (2014), were nevertheless significant.

The decreases in clubroot disease severity were sometimes reflected in significant reductions in root gall weight. This would be expected, since lower levels of disease would indicate a reduction in hyperplasia and hypertrophy of the root tissues. Consequently, the roots would be better able to maintain normal function, allowing the plants to produce taller stems and commit more energy to the production of aboveground biomass (Hwang et al. 2015). Indeed, significant increases in various plant growth characteristics including plant height, fresh biomass, and pod number were observed at the Henwood site in 2012 and 2013. Given its non-specific activity (Smelt and Leistra 1974), it is also possible that treatment with Vapam affected other components of the soil microbial community, including inoculum of other soilborne pathogens, which may have contributed to some of the

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

observed growth benefits. Fungal propagules have been reported to be greatly reduced in Vapam-treated soil (Sinha et al. 1979).

Treatment with Vapam also appeared to have some beneficial effects on the following year's canola crop, as significant decreases in clubroot severity were observed on canola grown in soil that had been treated with the fumigant in the previous year. This may have reflected a residual effect of the Vapam in the soil, and (or) a reduction in the inoculum quantity returned to the soil in the previous year due to reduced disease severity. Nonetheless, while Vapam application in the previous year resulted in less severe disease symptoms on the roots of affected plants, numerical increases in stem height, pod number, and aboveground biomass for plants grown in soil treated with the fumigant in the previous year were in general not significant. Therefore, the residual effects of Vapam may not be sufficient to control clubroot on canola adequately in the year following its application.

One of the reasons for evaluating multiple application rates of Vapam in this study was to enable identification of the optimal rate for canola. Both the label and 200% rates provided comparable levels of clubroot control. Thus, the label rate seems more appropriate for several reasons. The first is from an environmental safety perspective, by limiting the amount of a toxic fumigant applied in a field. The second is from an economic perspective, as less fumigant would be required. The third, and perhaps the most important reason from a disease management perspective, relates to the observation that higher levels of chemical applied did not always result in an increase in plant height, aboveground plant biomass, or pods per plant. Indeed, given that similar decreases in indices of disease were observed down to 25% (7.8 mL m^{-2} AI) of the label dosage, it may be feasible to apply this lower rate, which would be less expensive and potentially less harmful to the environment. High rates of Vapam have been associated with phytotoxicity in a study by White and Buczacki (1977). Similarly, Smelt and Leistra (1974) also recognized the considerable phytocidal activity of Vapam, and more recently, Hwang et al. (2014) reported that higher rates of Vapam resulted in reduced seedling emergence. In this study, a delay and reduction in plant emergence was noted in soil treated with the 200% label rate of Vapam (data not shown), also suggesting some phytotoxic effects. This study may have relied upon an inadequate ventilation period after the coverings were removed, particularly in the first year, resulting in these effects. An opportunity also exists for further studies on the management of clubroot based on soil fumigation in conjunction with various crop rotations.

The manufacturer label suggests that treated areas be kept covered for 48 h after treatment to prevent product dissipation from occurring too soon (AMVAC Chemical Corporation 2005). The manufacturer also recommends seeding 14–21 days after fumigant application when the soil is covered or tarped over following treatment (AMVAC Chemical Corporation 2005). Given the short growing (frost-free) season on most of the Prairies (Cutforth et al. 2004), a prolonged wait prior to seeding may not be possible for most growers. In this study, the Vapam was allowed to dissipate for 2 days after the tarp coverings were removed from the plots before seeding the canola, which may not have been sufficient time to allow the fumigant to dissipate. For the 200% label rate, introducing more chemical may have meant that more time should have been allotted between tarp removals and seeding. A high rate of decomposition of Vapam was noted by Smelt and Leistra (1974), but the soil conditions in that study included higher temperatures (21 °C) over a period of 3 weeks.

Weather conditions may also have been suboptimal for Vapam treatment. Cold soil temperatures can cause slower conversion to MITC, the primary bioactive ingredient (AMVAC Chemical Corp. 2005). Turner and Corden (1963) found that the rate of metam sodium transformation to MITC in soils was increased by both lower moisture content and higher temperature. In 2012, the plots were treated later in the season and temperatures were in the range of 23–24 °C in June and July. The plots were treated earlier in 2013 when temperatures were lower on average, but still within the recommended window for soil fumigation.

Another factor that could have an effect on the efficacy of Vapam treatment is the product application method. In this study, the Vapam was applied using the "watering can method" on the product label, which was practical for the small size of the plots. However, depending on the particular crop and location, various methods can be utilized for the application of fumigants. In California and Florida, for example, fruit growers use chloropicrin and 1,3-dichloropropene as alternatives to methyl bromide (Chellemi et al. 2013), which they apply by shank injection, or more effectively and safely through drip irrigation systems. More effective application methods allow for less of the active ingredient to be released into the atmosphere. The amount of ingredient leaving the soil surface is influenced by the rate of diffusion and degradation (Dungan and Yates 2003). In this study, rototilling the chemically treated soil may have resulted in more effective incorporation of the product, and more pronounced treatment effects (Hwang et al. 2014). Similarly, additional watering may also have improved the efficacy of the Vapam treatments, since soil fumigant activity will not move past the point of the water front, either horizontally or vertically within the soil (White and Buczacki 1977). Water volumes applied were based on the amount of water saturating the ground at a test site. Field conditions in each plot may have differed and been drier. The volume of water applied with the chemical may also play a role in the erratic and inconsistent control of clubroot in Brassica crops using Vapam (White and Buczacki 1977).

While the rates of Vapam evaluated in this study were not sufficient to eradicate the disease completely, they could limit symptom development. The field sites assessed in this study were heavily infested with *P. brassicae*, with estimated inoculum densities of $\sim 1 \times 10^8$ spores g^{-1} soil at both sites, and it is possible that clubroot severity could be reduced to negligible levels at field sites where low levels of inoculum have been recently introduced. As such, the application of Vapam may represent a useful tool to contain localized clubroot infestations within fields, and (or) to prevent more widespread dissemination of the pathogen in regions where it is not yet endemic. Fumigation could be used in

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

conjunction with other tactics, such as the sanitization of field machinery (Hwang et al. 2014) and the planting of resistant canola cultivars (Rahman et al. 2014), to reduce the impact of clubroot. Nonetheless, there are constraints to its application, including the safety risks posed to the environment and applicator, the water volumes required to apply the fumigant, and the need for labour-intensive tarping operations, all of which must be balanced against the anticipated returns from canola production. Covering the treated area to prevent loss of the chemical to volatilization may prove prohibitively expensive or impractical in many circumstances. Of additional concern is the non-specific nature of metam sodium, which could result in significant reductions in the populations of non-target or beneficial soil organisms (Smelt and Leistra 1974; Sinha et al. 1979). A cost/benefit analysis should be conducted prior to the application of Vapam or other fumigants in specific fields. Ultimately, multiple approaches will be needed for the sustainable management of clubroot on canola.

Acknowledgements

This research was conducted as part of a Master of Science dissertation by the first author (Zuzak 2016). The authors thank technical staff at the University of Alberta and Alberta Agriculture, Forestry and Rural Economic Development for helping with plot preparation, harvest, and measurement of plant materials. The financial support of the Clubroot Risk Mitigation Initiative and Growing Forward 2 Program (Grant number 2013-3.3, sponsored by the Canola Council of Canada, Agriculture and Agri-Food Canada, and the Alberta Crop Industry Development Fund) is gratefully acknowledged.

Article information

History dates

Received: 27 April 2022
Accepted: 28 September 2022
Accepted manuscript online: 7 October 2022
Version of record online: 1 November 2022

Copyright

© 2022 The Author(s). Permission for reuse (free in most cases) can be obtained from copyright.com.

Data availability

The data presented in this study are available on request from the corresponding author.

Author information

Author ORCIDs

Sheau-Fang Hwang https://orcid.org/0000-0001-5185-3052

Competing interests

The authors declare no conflict of interest.

References

AMVAC Chemical Corporation. 2005. Vapam HL: a soil fumigant solution for all crops. Available from http://www.amvac-chemical.com/products/documents/Vapam%20TB.sprd.c21%20copy.pdf [accessed 17 October 2012].

Botero-Ramírez, A., Hwang, S.F., and Strelkov, S.E. 2021. *Plasmodiophora brassicae* inoculum density and spatial patterns at the field level and relation to soil characteristics. Pathogens, **10**: 499. doi:10.3390/pathogens10050499.

Botero-Ramírez, A., Hwang, S.F., and Strelkov, S.E. 2022. Effect of clubroot (*Plasmodiophora brassicae*) on yield of canola (*Brassica napus*). Can. J. Plant Pathol. **44**: 372–385. doi:10.1080/07060661.2021.1989801.

Cao, T., Manolii, V.P., Strelkov, S.E., Hwang, S.F., and Howard, R.J. 2009. Virulence and spread of *Plasmodiophora brassicae* [clubroot] in Alberta, Canada. Can. J. Plant Pathol. **31**: 321–329. doi:10.1080/07060660909507606.

Chellemi, D.O., Jirusso, J., Ajwa, H.A., Sullivan, D.A., and Unruh, J.B. 2013. Fumigant persistence and emission from soil under multiple field application scenarios. Crop Prot. **43**: 94–103. doi:10.1016/j.cropro.2012.09.012.

Chittem, K., Mansouripour, S.M., and del Río Mendoza, L.E. 2014. First report of clubroot on canola caused by *Plasmodiophora brassicae* in North Dakota. Plant Dis. **98**: 1438. doi:10.1094/PDIS-04-14-0430-PDN. PMID: 30703968.

Cutforth, H., O'Brien, E.G., Tuchelt, J., and Rickwood, R. 2004. Long-term changes in the frost-free season on the Canadian prairies. Can. J. Plant Sci. **84**: 1085–1091. doi:10.4141/P03-169.

Dixon, G.R. 2006. The biology of *Plasmodiophora brassicae* Wor.—a review of recent advances. Acta Hortic. **706**: 271–282. doi:10.17660/ActaHortic.2006.706.32.

Dixon, G.R. 2009a. The occurrence and economic impact of *Plasmodiophora brassicae* and clubroot disease. J. Plant Growth Regul. **28**: 194–202. doi:10.1007/s00344-009-9090-y.

Dixon, G.R. 2009b. *Plasmodiophora brassicae* in its environment. J. Plant Growth Regul. **28:** 212–228. doi:10.1007/s00344-009-9098-3.

Dokken-Bouchard, F.L., Anderson, K., Bassendowski, K.A., Bouchard, A., Brown, B., Cranston, R., et al. 2012. Survey of canola diseases in Saskatchewan, 2011. Can. Plant Dis. Surv. **92**: 125–129.

Donald, E.C., and Porter, I.J. 2014. Clubroot in Australia: the history and impact of *Plasmodiophora brassicae* in Brassica crops and research efforts directed towards its control. Can. J. Plant Pathol. **36**: 66–84. doi:10.1080/07060661.2013.873482.

Dungan, R.S., and Yates, S.R. 2003. Degradation of fumigant pesticides. Vadose Zone J. **2**: 279–286.

Ernst, T.W., Kher, S., Stanton, D., Rennie, D.C., Hwang, S.F., and Strelkov, S.E. 2019. *Plasmodiophora brassicae* resting spore dynamics in clubroot resistant canola (*Brassica napus*) cropping systems. Plant Pathol. **68**: 399–408. doi:10.1111/ppa.12949.

Faggian, R., and Strelkov, S.E. 2009. Detection and measurement of *Plasmodiophora brassicae*. J. Plant Growth Regul. **28**: 282–288. doi:10.1007/s00344-009-9092-9.

Fox, N.M, Hwang, S.F., Manolii, V.P., Turnbull, G.D., and Strelkov, S.E. 2021. Evaluation of lime products for clubroot (*Plasmodiophora brassicae*) management in canola (*Brassica napus*) cropping systems, Can. J. Plant Pathol. **44**: 21–38. doi:10.1080/07060661.2021.1940590.

Gossen, B.D., Adhikari, K.K.C., and McDonald, M.R. 2012. Effect of seeding date on development of clubroot in short-season Brassica crops. Can. J. Plant Pathol. **34**: 516–523. doi:10.1080/07060661.2012.722129.

Horiuchi, S., and Hori, M. 1980. A simple greenhouse technique for obtaining high levels of clubroot incidence. Bull. Chugoku Natl. Agric. Exp. Stn. E, **17**: 33–55

Hwang, S.F., Ahmed, H.U., Zhou, Q., Strelkov, S.E., Gossen, B.D., Peng, G., and Turnbull, G.D. 2011. Influence of cultivar resistance and inoculum density on root hair infection of canola (*Brassica napus*) by *Plasmodiophora brassicae*. Plant Pathol. **60**: 820–829. doi:10.1111/j.1365-3059.2011.02457.x.

Hwang, S.F., Ahmed, H.U., Zhou, Q., Strelkov, S.E., Gossen, B.D., Peng, G., and Turnbull, G.D. 2012a. Assessment of the impact of resistant and susceptible canola on *Plasmodiophora brassicae* inoculum potential. Plant Pathol. **61**: 945–952. doi:10.1111/j.1365-3059.2011.02582.x.

Hwang, S.F., Cao, T., Xiao, Q., Ahmed, H.U., Manolii, V.P., Turnbull, G.D., et al. 2012b. Effects of fungicide, seeding date and seedling age on

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use

clubroot severity, seedling emergence and yield of canola. Can. J. Plant Sci. **92**: 1175–1186. doi:10.4141/cjps2011-149.

Hwang, S.F., Ahmed, H.U., Zhou, Q., Rashid, A., Strelkov, S.E., Gossen, B.D., et al. 2013. Effect of susceptible and resistant canola plants on *Plasmodiophora brassicae* resting spore populations in soil. Plant Pathol. **62**: 404–412. doi:10.1111/j.1365-3059.2012.02636.x.

Hwang, S.F., Howard, R.J., Strelkov, S.E., Gossen, B.D., and Peng, G. 2014. Management of clubroot (*Plasmodiophora brassicae*) on canola (*Brassica napus*) in western Canada. Can. J. Plant Pathol. **36**: 49–65. doi:10.1080/07060661.2013.863806.

Hwang, S.F., Ahmed, H.U., Zhou, Q., Turnbull, G.D., Strelkov, S.E., Gossen, B.D., and Peng, G. 2015. Effect of host and non-host crops on *Plasmodiophora brassicae* resting spore concentrations and clubroot of canola. Plant Pathol. **64**: 1198–1206. doi:10.1111/ppa.12347.

Hwang, S.F., Strelkov, S.E., Ahmed, H.U., Manolii, V.P., Zhou, Q. Fu, H., et al. 2017. Virulence and inoculum density-dependent interactions between clubroot resistant canola (*Brassica napus*) and *Plasmodiophora brassicae*. Plant Pathol. **66**: 1318–1328. doi:10.1111/ppa.12688.

Kageyama, K., and Asano, T. 2009. Life cycle of *Plasmodiophora brassicae*. J. Plant Growth Regul. **28**: 203–211. doi:10.1007/s00344-009-9101-z.

Kuginuki, Y., Hiroaki, Y., and Hirai, M. 1999. Variation in virulence of *Plasmodiophora brassicae* in Japan tested with clubroot-resistant cultivars of Chinese cabbage (*Brassica rapa* L. ssp. *pekinensis*). Eur. J. Plant Pathol. **105**: 327–332. doi:10.1023/A:1008705413127.

LeBoldus, J.M., Manolii, V.P., Turkington, T.K., and Strelkov, S.E. 2012. Adaptation to Brassica host genotypes by a single-spore isolate and population of *Plasmodiophora brassicae* (clubroot). Plant Dis. **96**: 833–838. doi:10.1094/PDIS-09-11-0807. PMID: 30727354.

Murakami, H., Tsushima, S., Kuroyanagi, Y., and Shishido, Y. 2002. Reduction of resting spore density of *Plasmodiophora brassicae* and clubroot disease severity by liming. Soil Sci. Plant Nutr. **48**: 685–691. doi:10.1080/00380768.2002.10409258.

Pageau, D., Lajeunesse, J., and Lafond, J. 2006. Impact of clubroot [*Plasmodiophora brassicae*] on the yield and quality of canola. Can. J. Plant Pathol. **28**: 137–143. doi:10.1080/07060660609507280.

Papiernik, S.K., Yates, S.R., Dungan, R.S., Lesch, S.M., Zheng, W., and Guo, M. 2004. Effect of surface tarp on emissions and distribution of drip-applied fumigants. Environ. Sci. Technol. **38**: 4254–4262. doi:10.1021/es035423q.

Peng, G., Pageau, D., Strelkov, S.E., Gossen, B.D., Hwang, S.F., and Lahlali, R. 2015. A >2-year crop rotation reduces resting spores of *Plasmodiophora brassicae* in soil and the impact of clubroot on canola. Eur. J. Agron. **70**: 78–84. doi:10.1016/j.eja.2015.07.007.

Rahman, H, Peng, G, Yub, F, Falk, K.C., Kulkarni, M, and Selvaraj, G. 2014. Genetics and breeding for clubroot resistance in Canadian spring canola (*Brassica napus* L.). Can. J. Plant Pathol. **36**: 122–134. doi:10.1080/07060661.2013.862571.

Rennie, D.C., Manolii, V.P., Cao, T., Hwang, S.F., Howard, R.J., and Strelkov, S.E. 2011. Direct evidence of surface infestation of seeds and tubers by *Plasmodiophora brassicae* and quantification of spore loads. Plant Pathol. **60**: 811–819. doi:10.1111/j.1365-3059.2011.02449.x.

Rennie, D.C., Holtz, M.D., Turkington, T.K., LeBoldus, J.M., Hwang, S.F., Howard, R.J., and Strelkov, S.E. 2015. Movement of *Plasmodiophora brassicae* resting spores in windblown dust. Can. J. Plant Pathol. **37**: 188–196. doi:10.1080/07060661.2015.1036362.

Saeed, I.A.M., Rouse, D.I., and Harkin, J.M. 2000. Methyl isothiocyanate volatization from fields treated with metam-sodium. Pest Manag. Sci. **56**: 813–817. doi:10.1002/1526-4998(200009)56:9⟨813::AID-PS205⟩3.0.CO;2-M.

Sinha, A.P., Agnihotri, V.P., and Singh, K. 1979. Effect of soil fumigation with Vapam on the dynamics of soil microflora and their related biochemical activity. Plant Soil, **53**: 89–98. doi:10.1007/BF02181882.

Smelt, J.H., and Leistra, M. 1974. Conversion of metham-sodium to methyl isothiocyanate and basic data on the behaviour of methyl isothiocyanate in soil. Pestic. Sci. **5**: 401–407. doi:10.1002/ps.2780050405.

Strelkov, S.E., and Hwang, S.F. 2014. Clubroot in the Canadian canola crop: 10 years into the outbreak. Can. J. Plant Pathol. **36**: 27–36. doi:10.1080/07060661.2013.863807.

Strelkov, S.E., Tewari, J.P., and Smith-Degenhardt, E. 2006. Characterization of *Plasmodiophora brassicae* populations from Alberta, Canada. Can. J. Plant Pathol. **28**: 467–474. doi:10.1080/07060660609507321.

Strelkov, S.E., Manolii, V.P., Liu, J., Jurke, C., Rennie, D.C., Orchard, D., et al. 2012. The occurrence of clubroot on canola in Alberta in 2011. Can. Plant Dis. Surv. **92**: 1–157.

Strelkov, S.E., Hwang, S.F., Manolii, V.P., Cao, T., and Feindel, D. 2016. Emergence of new virulence phenotypes of *Plasmodiophora brassicae* on canola (*Brassica napus*) in Alberta, Canada. Eur. J. Plant Pathol. **145**: 517–529. doi:10.1007/s10658-016-0888-8.

Strelkov, S.E., Manolii, V.P., Harding, M.W., Daniels, G.C., Nuffer, P., Aigu, Y., and Hwang, S.F. 2020. The occurrence and spread of clubroot on canola in Alberta in 2019. Can. Plant Dis. Surv. **100**: 117–120.

Triky-Dotan, S., Ofek, M., Austerweil, M., Steiner, B., Minz, D., Katan, J., and Gamliel, A. 2010. Microbial aspects of accelerated degradation of metam sodium in soil. Phytopathology, **100**: 367–375. doi:10.1094/PHYTO-100-4-0367.

Turner, N. J., and Corden, M.E. 1963. Decomposition of sodium *N*–methyldithiocarbamate in soil. Phytopathology, **53**: 1388–1394.

Wallenhammar, A.C. 1996. Prevalence of *Plasmodiophora brassicae* in a spring oilseed rape growing area in central Sweden and factors influencing soil infestation levels. Plant Pathol. **45**: 710–719. doi:10.1046/j.1365-3059.1996.d01-173.x.

White, J.G., and Buczacki, S.T. 1977. The control of clubroot by soil partial sterilization: a review. Ann. Appl. Biol. **85**: 287–300. doi:10.1111/j.1744-7348.1977.tb01802.x.

Zuzak, K. 2016. An assessment of the fumigant metam sodium and a *Brassica juncea*-derived biofumigant as management tools for clubroot (*Plasmodiophora brassicae*) of canola (*Brassica napus*). M.Sc. thesis, University of Alberta, Edmonton, AB. 83pp.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Plant-Science on 25 Jun 2025
Terms of Use: https://complete.bioone.org/terms-of-use