Management of *Allium* white rot [*Sclerotium cepivorum*] in onions on organic soil with soil-applied diallyl disulfide and di-*N*-propyl disulfide

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Abstract: The efficacy of two sclerotia germination stimulants, diallyl disulfide (DADS, 85.5%; related compounds, 4.5%) and di-*N*-propyl disulfide (DPDS, 88%; related compounds, 2%) were evaluated in naturally infested field plots and in the greenhouse for reduction in populations of sclerotia and control of onion white rot in organic soil. Field trials evaluated one or two applications of DADS or DPDS injected into soil at 10 L/ha in 500 L/ha of water. To determine the treatment effects on the survival of sclerotia, sacs of 100 sclerotia were exposed to treated and untreated soil in the field and greenhouse. In controlled greenhouse studies, survival of sclerotia was significantly decreased when sclerotia were exposed for 1 to 3 months to soil treated with DADS or DPDS compared with untreated soil. DADS was considerably more effective than DPDS. In field trials, survival of sclerotia decreased after 3 months exposure to DADS-treated soil. Single DADS applications reduced disease incidence on onions at harvest compared with the untreated checks at three of four sites. Following two DADS applications, disease was reduced to below 1% at all four sites. DADS applied to organic soil provided effective control of white rot under conditions of moderate disease pressure.

Key words: white rot, *Sclerotium cepivorum*, onion, *Allium cepa*, germination stimulants, disease management.

Résumé : L'efficacité du bisulfure d'allyle (BSA, 85,5%; substances apparentées, 4,5%) et du bisulfure de di-*N*-propyle (BDSP, 88%; substances apparentées, 2%), deux stimulants de germination des sclérotés, fut évaluée pour la réduction des populations de sclérotés et la répression de la pourriture blanche de l'oignon en sol organique dans des parcelles infectées naturellement et en serre. Les essais en champ évaluèrent une ou deux applications de BSA ou de BDSP injecté dans le sol à raison de 10 L/ha dans 500 L/ha d'eau. Afin d'évaluer les effets des traitements sur la survie des sclérotés, des sacs de 100 sclérotés furent exposés à du sol traité et non traité, au champ et en serre. Lors des études en serre, en conditions contrôlées, la survie des sclérotés fut significativement réduite lorsque ceux-ci furent exposés durant 1 à 3 mois à du sol traité avec du BSA ou du BDSP, par rapport à du sol non traité. Le BSA fut beaucoup plus efficace que le BDSP. Lors d'essais en champ, la survie des sclérotés fut réduite après 3 mois d'exposition à du sol traité au BSA. Des applications uniques de BSA réduisirent la fréquence de la maladie sur l'oignon à la récolte, par rapport à des témoins non traités, à trois sites sur quatre. À la suite de deux applications de BSA, la maladie fut abaissée à moins de 1% aux quatre sites. Le BSA appliqué au sol organique a procuré une répression efficace de la pourriture blanche dans des conditions de pression de maladie modérée.

Mots clés : pourriture blanche, *Sclerotium cepivorum*, oignon, *Allium cepa*, stimulants de germination, lutte antiparasitaire.

Introduction

Sclerotium cepivorum Berk causes the disease white rot on several *Allium* species. White rot of onion (*Allium cepa* L.) is a serious threat to the onion industry worldwide and is a major limiting factor in the production of onions in Ontario, Canada, where most of the crop is grown on organic (muck) soils. Disease incidence can exceed 65% in commercial onion fields in Ontario (Earnshaw et al. 2000).

Under favorable environmental conditions, sclerotia germination and host infection are stimulated by specific chemicals released by susceptible host roots (Coley-Smith 1960; Stewart et al. 1989). The alkenyl L-cysteine sulfoxides in *Allium* root exudates are precursors of the volatile allyl and propyl sulfides that stimulate eruptive germination of the sclerotia (Coley-Smith and King 1969; Somerville and Hall 1987).

Accepted 3 June 2002.

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There are few effective chemicals or other methods to control white rot in Canada (Banks and Edgington 1989), and host resistance is not sufficient to provide commercially acceptable control (Earnshaw et al. 2000). As a result, attempts to manage the disease have focused on reducing the populations of sclerotia in the soil.

Sclerotia of *S. cepivorum* normally germinate in the presence of root exudates of *Allium* species, but germination can be stimulated by products such as natural onion and garlic oil, which contain the same or similar compounds as the root exudates. In addition to natural products, synthetic germination stimulants have been derived from petroleum (Crowe et al. 1991). Diallyl disulfide (DADS), a primary decomposition product of allicin (Block 1992) which exudes from garlic and onion roots, is one such petroleum-derived product that can stimulate the germination of sclerotia (Coley-Smith and King 1969).

Once the sclerotia have germinated, the mycelium becomes susceptible to hyperparasitism and lysis (Utkhede and Rahe 1982). In the absence of a host, the fungus dies without reproducing. Germination of the sclerotia prior to an *Allium* crop, through the use of natural and synthetic stimulants, has been shown to reduce inoculum levels in the field (Utkhede and Rahe 1982; Crowe et al. 1994; Juárez 1998). Sommerville and Hall (1987) reported that onion root exudates and *Allium* extracts applied to the soil stimulate total germination of up to 60% of exposed culture-produced sclerotia, 45 days after soil treatment.

In mineral soil, two applications of the synthetic germination stimulant DADS in consecutive years resulted in no viable, recoverable sclerotia, and white rot incidence in the next garlic crop was reduced by 84–100% (Crowe et al. 1994). Soil application of DADS significantly reduced sclerotia populations by 83% and delayed and decreased the incidence of white rot on the following crop of garlic (Juárez 1998). Utkhede and Rahe (1982) found significant reductions in sclerotia number and onion infection on organic muck soils post-treatment with natural onion oil. Terry (1996) demonstrated that a single application of DADS, but not DPDS, reduced the recovery of sclerotia placed in organic muck soils.

Maximum germination of sclerotia occurs when soil temperatures are between 10 and 20°C (Crowe and Hall 1980). Therefore, products to stimulate the germination of sclerotia should be applied when soil temperatures will remain in this range for approximately 3 months. Soil moisture is also a factor in sclerotia germination (Crowe et al. 1994) and is necessary to ensure maximal and uniform spread of the volatile stimulant.

The objective of the research was to determine the efficacy of synthetic DADS and DPDS in reducing the survival of sclerotia of *S. cepivorum* and the incidence of white rot of onions grown on organic muck soil.

Materials and methods

Field trials

The germination stimulants DADS (diallyl disulfide, 85.5%; diallyl sulfide, 4.5%) and DPDS (di-*N*-propyl disulfide, 88%; related compounds, 2%; United Agri Products, 789 Donnybrook Drive, Dorchester, ON N0L 1G5,

Canada) were applied to soil in field plots in commercial onion fields (organic muck soil, 65% organic matter, pH 5.5–6.5) in the Holland Marsh, Ontario (44°15'N, 75° 60'W), known to be naturally infested with the pathogen. To maximize the effect of DADS and DPDS product diffusion through the soil and to provide sufficient moisture for sclerotia germination, soil moisture was monitored pre-treatment and for 3 months post-treatment through gravimetric means; samples were weighed and dried to determine the mass of water and dry soil. Soil moisture was maintained above 40% mass/mass through overhead irrigation as needed before treatment and at site 1 after treatment. At other sites, natural precipitation was sufficient to sustain soil moisture following treatment. The three treatments used in this research were DADS, DPDS, and an untreated check. Treatments were applied to the field sites in late summer or early fall (Table 1), a time when the soil temperatures would remain between 9 and 20°C for 2–3 months. The exception was site 1, where treatments were applied in June 1994. Sites were weed free prior to application of the products. The soil was tilled with a cultivator and disked the day before or day of treatment and rolled immediately following treatment to create a natural surface seal.

Both products were injected into the soil at 10 L/ha of product in 500 L/ha of water. The tanks were cleaned out between the DADS and DPDS application so no cross-product contamination would occur. For the DADS treatment, the final concentration of diallyl disulfide and diallyl sulfide in the tank was 16.7 and 0.88 g/L, respectively. For the DPDS treatment, the final concentration of di-*N*-propyl disulfide in the tank was 17.25 g/L. At site 1, where only DADS was applied, the final concentration in the tank was 8.35 g/L diallyl disulfide and 0.44 g/L diallyl sulfide. The products were injected into the soil using a modified soil fumigator with 11 injection hoses spaced 20 cm apart, five hoses injecting at a 10-cm depth and six hoses at 20 cm. Nothing was applied to the untreated check treatment. The field sites were sealed following treatment, using a tractor-pulled mechanical roller. Weed growth was minimal, and the soil remained undisturbed until the next spring. At site 1, the treated area was kept bare and weed free with herbicide application following treatment application in June. Field sites 1, 2, 3, and 6 received only one application of the treatments. Field sites 4, 5, 7, and 8 received two applications of each treatment, the applications separated by approximately 12 months. Carrots were grown each summer between the two applications. All field sites were arranged in a randomized complete block design with six replications, approximately 10 × 50 m, per treatment, except at site 1 where the treatments were replicated four times and replicate plots were 5 × 50 m. All replications were separated by a minimum of 0.3 m. Cultivation, application of fertilizer, and seeding of the crop was done along the long axis of the plots, and care was taken not to spread soil within the plot area. Onions were grown at sites 1, 2, and 3 in 1995; sites 4 and 5 in 1997; and sites 6, 7, and 8 in 1998. The onion cultivars grown at each field site differed, since they were chosen and managed by the grower. Recommended control procedures for fungal and bacterial pathogens, weeds, and insects were followed and implemented by the grower. In the years following the treatments, no irrigation was applied

Table 1. Effect of DADS and DPDS, injected one or two consecutive years preceding onions, on the incidence (%) of white rot in muck soils of the Holland Marsh, Ontario.

Site	Treatment	Check	DADS	DPDS	Year assessed	Date treated
1	1	7.9	2.2*	nt [†]	1995	27 June 1994
2	1	1.5	0.2*	0.3	1995	17 Aug. 1994
3	1	13.7	13.2	9.2	1995	17 Aug. 1994
4	2	5.2	0.0*	1.5*	1997	21 Aug. 1995 19 Sept. 1996
5	2	13.0	0.1*	7.0	1997	21 Aug. 1995 19 Sept. 1996
6	1	3.7	0.7*	nt	1998	19 Sept. 1996
7	2	1.0	0.1*	nt	1998	19 Sept. 1996 24 Sept. 1997
8	2	2.4	0.1*	nt	1998	19 Sept. 1996 24 Sept. 1997

*Not significantly different from the check at $P < 0.05$ using Fisher's protected LSD test.

[†]nt, not treated.

to the carrot crops. Irrigation was applied by the grower as required for onion growth at sites 1, 2, and 6.

At harvest, the incidence of white rot was assessed on 50 onions, in four randomly selected subplots per replication per treatment, for a total of 200 onions per replication. Subsample sites were approximately 1 m long and four rows wide and located in the center of the treated areas, to minimize possible interplot interference. Site 1 was harvested on 28 July 1995. All other sites were assessed in August or the first week of September. Data were analyzed using the general analysis of variance function of the linear models section of STATISTIX version 4.1.

Survival of sclerotia

Greenhouse trial

Mesh sacs (made from polyester pantyhose) containing 100 sclerotia of *S. cepivorum* and 20 g of muck soil, were placed in pots of organic soil treated with DADS and DPDS at 1 mL/m² in 50 mL water with 4.25 mL solution per pot in November 1995. Final concentration of DADS and DPDS in the soil were the same as the field applications of 10 L/ha of product in 500 L/ha of water. Sclerotia were collected from naturally infested field-grown onions and stored dry at room temperature for at least 4 months prior to use to avoid constitutive dormancy (Coley-Smith et al. 1987). Germination was greater than 90% at the start of each trial. Pots were placed in the greenhouse, and sclerotia were recovered at monthly intervals. Air temperatures were recorded using an Argus greenhouse environment monitoring system 1 m above the bench (Table 2). Sclerotia were extracted from bleached soil using the method of Utkhede and Rahe (1979) as modified by Oudemans (1984). Following wet sieving, soil containing sclerotia was bleached with 1.25% sodium hypochlorite for 0.5–1.5 min to bleach the muck soil for easier identification of the dark sclerotia. Extracted sclerotia were surface sterilized (1 min in 70% ethanol, 3 min in 0.6% sodium hypochlorite, followed by 3 min in sterile water), blotted dry and plated onto droplets of potato dextrose agar to test for viability. Sclerotia that germi-

Table 2. Effect of exposure to diallyl disulphide (85.5% DADS and 4.5% related compounds) treated organic muck soil on the survival of sclerotia of *S. cepivorum* after 1, 2, or 3 months exposure in the soil in pots placed in a greenhouse.

Treatment	Survival of sclerotia (%)		
	1 month	2 months	3 months
DADS	78.0 a	15.0 a	18.3 a
DPDS	82.0 a	88.3 b	60.0 b
Check	100.0 b	99.2 c	99.2 c
SE	4.6	2.2	10.4

Note: Mean minimum and maximum temperatures for each month, measured by an Argus greenhouse monitoring system 1 m above the bench: month 1, 14.6 and 31.4°C; month 2, 12.3 and 29.0°C; month 3, 9.7 and 25.9°C, respectively. Values in a column with different letters were significantly different at $P < 0.05$ using Fisher's protected LSD test.

nated within 28 days after plating and formed characteristic mycelia colonies and sclerotia were considered viable.

The efficacy of the treatments was assessed as percent recovery and survival of the sclerotia. Percent recovery was the proportion of the original 100 sclerotia that could be found after sieving and bleaching the contents of the sacs. Percent survival was based on the number of viable sclerotia obtained from each sac of 100 sclerotia.

Field trials

In 1996 and 1997, sacs of sclerotia were buried 10 cm deep in treated and nontreated field plots (sites 5, 6, 7, and 8) 1–7 days after the germination stimulants were applied. Sacs were recovered 3 (beginning of December) and 7 (beginning of April) months post-treatment. Sclerotia were recovered and tested for viability as described above. Temperatures were recorded (Table 3) using Red Flag portable ambient temperature dataloggers (Concepts by Phillips & Associates Inc., Pickering, Ont.), which were buried 10 cm deep approximately 50 cm from the sites where the sacs were placed in the field.

Results

Disease incidence: field trial

Incidence of white rot was relatively low in 1995, 1997, and 1998 (maximum 13.7, 13.0, and 3.7%, respectively; Table 1). Incidence of white rot following applications of DADS was 2% or lower in three of four trials. Following double applications of DADS, the incidence of white rot was below 1% in all four trials. In only one instance (site 3, 1995) did it appear that DADS was without effect. Single treatments with DPDS did not reduce white rot on onions compared with the untreated check. Two applications of DPDS reduced white rot at site 4 only (Table 1).

In 1995, air temperatures were above the long-term (26-year) mean for June (18.4°C) and August (21.2°C) and similar for May (12.2°C), July (20.8°C), and September (13.3°C). Total rainfall was below the long-term mean for June (67 mm) and September (63 mm), above for July (126 mm), and similar to the long-term mean for May (72 mm) and August (83 mm). In 1997, air temperatures were below the long-term mean for May (8.8°C) and July (19.4°C) and above for June (19.0°C), August (20°C), and September (14.6°C). Total rainfall was below the long-term mean for May (62 mm), June (66 mm), July (26 mm), and August (48 mm) and above for September (119 mm). In 1998, air temperatures were above the long-term mean for May (16.2°C), August (20.0°C), and September (16.6°C) and similar to the long-term mean for June (18.0°C) and July (19.8°C). Total rainfall was below the long-term mean for May (43 mm), July (50 mm), August (75 mm), and September (19 mm) and similar to the long-term mean for June (78 mm). Long-term mean air temperature for May was 12.9°C; June, 17.4°C; July, 20.2°C; August, 19.0°C; and September, 14.6°C. Long-term mean rainfall for May was 70 mm; June, 78 mm; July, 82 mm; August, 84 mm; and September, 84 mm.

Survival of sclerotia

Greenhouse trial

Exposure to DADS and DPDS resulted in reduced survival of sclerotia after 1, 2, and 3 months of exposure (Table 2). DADS was most effective in reducing sclerotia survival. After 2 months of exposure to DADS, survival was reduced to 15% compared with over 99% survival of sclerotia in untreated soil.

Field trial

The recovery and survival of sclerotia in sacs exposed to field soil was reduced in soils treated with DADS compared with untreated soil when sacs were recovered after 3 months (Table 3). There were no differences in recovery or survival of sclerotia after 7 months of exposure to field soils. There was no site by treatment interaction for either recovery or survival, so results from four field sites (sites 5, 6, 7, and 8) were pooled for analysis (Tables 4 and 5). There was no treatment $\times$ month interaction for the recovery of sclerotia (Table 4), but a treatment $\times$ month interaction was found for the survival of sclerotia (Table 5). Percent survival of sclerotia in untreated soil was much lower in the field trials than in the pot trial kept in the

Table 3. Effect of exposure to diallyl disulphide (85.5% DADS and 4.5% related compounds) and di-*N*-propyl disulfide (88% DPDS and 2% related compounds) applied at 10 L/ha of product in 500 L/ha of water on the recovery and survival of sclerotia of *S. cepivorum* after 3 and 7 months.

Treatment	Recovery of sclerotia (%)		Survival of sclerotia (%)	
	After 3 months	After 7 months	After 3 months	After 7 months
DADS	15.80 a	20.8 a	3.43 a	9.15 a
Check	25.10 b	26.2 a	9.78 b	9.37 a
SE	2.5	2.9	1.8	1.7

Note: Data are from field for sites 5, 6, 7, and 8 pooled. Mean soil temperature at 10-cm depth recorded by a Red Flag portable ambient temperature datalogger were 13, 10.1, and 6.6°C, for months 1, 2, and 3 and 3.6, -0.8, -1.8, and -3.2°C for months 4, 5, 6, and 7, respectively. Values in a column with different letters were significantly different at $P < 0.05$ using Fisher's protected LSD test.

greenhouse (9.37% as compared with 99.2%, field and greenhouse, respectively; Tables 2 and 3).

Discussion

Commercially acceptable levels of onion white rot control were obtained by treating naturally infested field sites with DADS for two consecutive years prior to growing onions on muck soils. In three of four field sites, a single application of DADS also reduced disease incidence at harvest; two applications of DADS reduced disease incidence to below 1%. These results are consistent with reports that DADS soil treatments reduced the incidence of *Allium* white rot on garlic and onions grown on mineral soils (Crowe et al. 1994; Juarez 1998).

Greenhouse and field studies demonstrated that soil treatments with DADS resulted in consistent reductions in the population of viable sclerotia within the first 1–3 months of treatment, based on assessments of sclerotia placed in treated and untreated soil. In the greenhouse study, DADS treatments resulted in a mean of 15% survival of sclerotia compared with over 99% survival of sclerotia in the untreated check. Exposure to soil treated with DPDS also reduced survival of sclerotia but not as effectively as DADS.

In the field, survival in untreated soil was higher (9.8%) than in the DADS treatments (3.4%) after 3 months of exposure but was still very low compared with the greenhouse trials. Again, the results were consistent with previous reports of reduced survival of sclerotia in treated mineral soils (Coley-Smith and Parfitt 1986; Crowe et al. 1994) and in muck soil (Terry 1996). Recovery and survival of sclerotia in untreated soil did not change as length of exposure increased from 3 to 7 months over the winter, and there were no differences in survival of sclerotia exposed to treated or untreated soil after 7 months.

One to 2 months of exposure to DADS was sufficient to decrease the viability of sclerotia in the greenhouse trial. Sommerville and Hall (1987) reported that the germination of sclerotia exposed to alkyl products was a linear response with time, increasing from 15% (at 15 days) to over 55% (at 45 days). Crowe (1998) reported that the residual capac-

Table 4. ANOVA for the effects of field site, month of assessment after treatment, and diallyl disulphide treatment (85.5% DADS and 4.5% related compounds) on the recovery of white rot sclerotia.

Source	df	MS	F	P
Field site	3	199.00	0.44	0.7246
Month	1	135.38	0.30	0.5857
Treatment	1	1785.38	3.95	0.0461
Block	5	2239.54	4.96	0.0006
Treatment × block	5	191.85	0.42	0.8298
Field site × treatment	3	445.15	0.99	0.4045
Month × treatment	1	96.00	0.21	0.6462
Site × month × treatment	6	484.66	1.07	0.3838

Note: Data are from field for sites 5, 6, 7, and 8 pooled. df, degrees of freedom; MS, mean square.

Table 5. ANOVA for the effects of field site, month of assessment after treatment, and diallyl disulphide treatment (85.5% DADS and 4.5% related compounds) on the survival of white rot sclerotia.

Source	df	MS	F	P
Field site	3	52.57	0.26	0.8554
Month	1	205.63	1.01	0.3186
Treatment	1	433.93	2.13	0.0290
Block	5	229.66	1.10	0.3297
Treatment × block	5	51.60	0.25	0.9368
Field site × treatment	3	180.65	0.89	0.4525
Month × treatment	1	240.35	1.18	0.0320
Site × month × treatment	6	160.20	0.79	0.5837

Note: Data are from field for sites 5, 6, 7, and 8 pooled. df, degrees of freedom; MS, mean square.

ity of stimulant-treated mineral soil was high for 1 month after application but declined by 6–8 weeks. The maximum temperature in the greenhouse during the first month was 31°C (Table 2), far above the upper limit of 24°C for germination of sclerotia. Thus, the temperatures may have been too high for the sclerotia to germinate for part of the time, reducing the effective exposure time. Also, volatilization, movement, adsorption, and microbial utilization of DADS and DPDS may be different in the muck soil, which had a higher content of organic matter (approximately 60%) than mineral soils. Soil type may be a factor in the differences in timing of sclerotial response to germination stimulants. Nevertheless, the overall effect of DADS and DPDS in reducing survival was the same.

Leggett and Rahe (1985) found that *S. cepivorum* sclerotia buried in muck soil decayed with time, and the rate of decay was influenced by environmental conditions. Decay appeared to be highest during the winter months when soil tended to be waterlogged and temperatures were less than 10°C. However, winter temperatures in the Fraser Valley tend to be milder than in Ontario. Mean soil temperatures at 10-cm depth in this trial were 6.6°C for November (month 3; Table 3) and were below freezing for January, February, and March (months 5, 6, and 7; Table 3). Soils tend to freeze during December and remain frozen until April. Sclerotial germination is inhibited when soil temper-

atures are below 10°C (Crowe and Hall 1980). No effect of the germination stimulants would be expected over the winter months, especially if the soil was frozen for most of that time. However, cool, wet soil conditions from September to November may have contributed to the rapid decay of sclerotia in both treated and untreated field soils in the Holland Marsh. In contrast, conditions in the greenhouse were much warmer and soil was moist but not saturated during the trial.

White rot disease develops annually in both the Fraser Valley and in the Holland Marsh area of Ontario, and disease incidence is high when the growing season is relatively cool and wet, as in 1992 (Earnshaw et al. 2000). Evidently, enough sclerotia survive in untreated soils to initiate disease each year when weather conditions are favorable and onions are sown in infested fields.

The number of viable *S. cepivorum* sclerotia per kilogram of soil ranges from 100 to 300 in most heavily infested commercial fields in the Holland Marsh (unpublished data). Tichelaar (1965) found that populations of 2–30 sclerotia/kg of mineral soil resulted in 25–40% infection, while Crowe et al. (1980) determined that sclerotia populations of over 1.5 sclerotia/kg of soil, could cause 40% disease on garlic. In muck soil, in the Fraser Valley, populations of 70–150 sclerotia/kg resulted in 5.9–21.6% infection (Leggett and Rahe 1985). Utkhede et al. (1978) found there was no clear relationship between populations of sclerotia and incidence of disease in Fraser Valley. This seems to be the situation in the Holland Marsh as well.

Some of the variability in the amount of disease that develops may be due to changes in the weather conditions from one year to the next. In the Holland Marsh area, incidence of white rot was low (1.0–13.7%) at all sites during the 3 years of the trial, most likely as a result of the relatively hot dry weather during the growing seasons. Air temperatures were above average during the month of August in the 3 years when onions were grown in this study, and rainfall was below average in August of 1997 and 1998. This is the time of year when there is the most symptom development. Soil temperatures at or above 22–24°C are unfavorable for white rot development (Leggett and Rahe 1985, Adams 1987). In cool wet growing seasons, disease incidence in commercial fields has been recorded at levels greater than 65% (Earnshaw et al. 2000).

In the spring, after 7 months of exposure to treated or untreated soil, results from four sites consistently showed that only 25% of the sclerotia remained and less than 10% germinated on potato dextrose agar. This does not explain the consistent effect of the DADS treatments in reducing the incidence of white rot in the onion crop in the following year. A second treatment of DADS tended to improve disease control and may be more effective in reducing the survival of the remaining sclerotia. Recovery and survival of sclerotia following a second treatment of DADS was not studied.

These studies examined the effect of DADS and DPDS on the germination of sclerotia of *S. cepivorum*. Two applications of DADS in the field were more effective in reducing disease than was a single application. The effect of a second application on sclerotia remains to be studied. Another consideration is the age of sclerotia. All of the

sclerotia used in these trials were from naturally infected onions and were used 3–6 months after collection. The specific effects of the germination stimulants on older sclerotia is not known.

The results reported here demonstrated that soil treatments with DADS effectively reduced the incidence of *Allium* white rot on onions grown on muck soils. Soil treatment with DADS, and to a lesser extent DPDS, reduced the survival of sclerotia within the first 2 or 3 months of treatment. Further research is needed to determine the effectiveness of these treatments under high disease pressure.

Acknowledgements

The authors thank Caroline Surjusingh for expert technical assistance. Financial support for this study was provided by the Ontario Research Enhancement Program of Agriculture and Agri-Food Canada; the Hort Farm Support and Adjustments Measures Program of the Ontario Fruit and Vegetable Growers Association; the Bradford and District Vegetable Growers; United Agri Products; and the Ontario Ministry of Agriculture, Food and Rural Affairs. Special thanks to the grower cooperators in the Bradford and District Marshes who provided test sites.

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