Disease control / Moyens de lutte

Effect of fish emulsion used as a preplanting soil amendment on verticillium wilt, scab, and tuber yield of potato

P.A. Abbasi, K.L. Conn, and G. Lazarovits

Abstract: Fish emulsion is used mainly as a fertilizer for crop production but, in a previous study, we have demonstrated its efficacy in suppressing damping-off [*Rhizoctonia* and *Pythium* spp.] in radish and cucumber in a peat-based substrate or soil. In the present study, fish emulsion was tested as a preplanting soil amendment to control soilborne diseases of eggplant and potato such as verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and scab [*Streptomyces* spp.]. Tests were conducted on 11 soils with different characteristics (pH, 5.2–7.2; organic-matter content, 1.0%–3.7%), originating from commercial potato fields in Ontario, New Brunswick, and Prince Edward Island with a history of verticillium wilt and scab. The amendment of soil with fish emulsion at rates of 0.5% and 1% (*m/m*) protected eggplant from verticillium wilt, and the 1% fish-emulsion treatment increased fresh and dry plant biomasses in the greenhouse. Microplot experiments with potato showed that the 1% fish-emulsion treatment significantly ($P < 0.05$) reduced scab severity (by 0.6–2.1 units on a scale of 0–6) in seven soils with low to moderate scab-disease pressure and significantly increased total tuber yield (by 41%–170%) in nine soils, compared with the control treatments. Fish emulsion also reduced potato petiole infection by *V. dahliae* in one soil. In potato field trials at two sites in 2004, treatment with 1% fish emulsion (20 000 L/ha) significantly ($P < 0.05$) reduced scab severity (by 0.8–1 units) and significantly increased scab-free tubers (by 132%–366%) and marketable-tuber (surface scab < 5%) yield (by two fold), compared with the control treatments. Total tuber yield was reduced at one site and not affected at the other. No effect of fish emulsion on scab and verticillium wilt or tuber yield was observed in a 2005 field trial. The reduction of scab or verticillium wilt by fish emulsion was not soil-specific and varied from year to year. The results indicated that fish emulsion was not effective in soils with high disease pressure.

Key words: organic soil amendment, scab, *Streptomyces* spp., verticillium wilt, *Verticillium dahliae*, *Verticillium albo-atrum*, disease management, potato, eggplant.

Résumé : L’émulsion de poisson est utilisée principalement comme engrais pour la production végétale, cependant, au cours d’une étude antérieure, nous avons démontré son efficacité à combattre la fonte des semis [*Rhizoctonia* et *Pythium* spp.] du concombre et du radis dans un substrat à base de tourbe ou dans du sol. Dans la présente étude, l’émulsion de poisson fut testée comme amendement du sol en prélevée pour lutter contre des maladies telluriques de l’aubergine et de la pomme de terre telles la verticilliose [*Verticillium dahliae* et *Verticillium albo-atrum*] et la gale [*Streptomyces* spp.]. Des tests furent effectués dans 11 sols possédant diverses caractéristiques (pH, 5,2–7,2; teneur en matière organique, 1,0%–3,7%) et provenant de champs commerciaux de pommes de terre de l’Ontario, du Nouveau-Brunswick et de l’Île-du-Prince-Édouard ayant des antécédents de verticilliose et de galle de la pomme de terre. L’amendement du sol avec une émulsion de poisson à des taux de 0,5% et 1% (*m/m*) protégea l’aubergine de la verticilliose, et l’émulsion de poisson à 1% augmenta la biomasse (matières fraîche et sèche) en serre. Dans des expériences en microparcelles avec la pomme de terre, le traitment avec l’émulsion de poisson à 1% réduisit significativement ($P < 0,05$) l’intensité de la gale (de 0,6–2,1 unités sur une échelle de 0–6) dans sept sols faiblement à moyennement affectés par la gale et augmenta significativement le rendement en tubercules (de 41%–170%) dans neuf sols comparativement aux traitements témoins. L’émulsion de poisson a aussi réduit l’infection des pétioles de la pomme de terre par le *V. dahliae* dans un sol. Sur deux sites d’essais dans les champs de pommes de terre en 2004, le traitement avec l’émulsion de poisson à 1% (20 000 L/ha) a significativement ($P < 0,05$) réduit l’intensité de la gale (de 0,8–1 unité) et significativement augmenté le pourcentage de tubercules exempts de la galle (de 132%–366%) et le rendement (doublé)

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en tubercules commercialisables (surface affectée par la gale < 5%) comparativement aux traitements témoins. Le rendement total en tubercules fut réduit à un site et resta inchangé à l'autre site. Lors d'un essai au champ en 2005, aucun effet de l'émulsion de poisson sur la gale et la verticilliose ou sur le rendement en tubercules ne fut observé. La diminution de la gale ou de la verticilliose par l'émulsion de poisson n'était pas tributaire du sol et varia d'une année à l'autre. Les résultats ont indiqué que l'émulsion de poisson n'était pas efficace dans les sols sous forte pression de maladie.

Mots clés : amendement organique du sol, gale, *Streptomyces* spp., verticilliose, *Verticillium dahliae*, *Verticillium albo-atrum*, lutte contre les maladies, pomme de terre, aubergine.

Introduction

The potato has been used as a model system to investigate the effects of various soil amendments on plant diseases caused by soilborne plant pathogens (Lazarovits 2001; Lazarovits et al. 2001, 2005). In particular, we have been examining the effect of soil amendment on scab [*Streptomyces* spp.] and verticillium wilt [*Verticillium dahliae* Kleb. and *Verticillium albo-atrum* Reinke and Berthier], two economically important soilborne diseases. Both diseases often affect potatoes in a same field. Potato scab is caused by several *Streptomyces* spp. (Goyer et al. 1996; Loria et al. 1997), of which *S. scabies* (Thaxter) Lambert & Loria (= *S. scabiei*) (Trüper and de' Clari 1997) is the predominant causal agent (Lambert and Loria 1989). Depending on the strain of *Streptomyces* spp. and the soil environment, bacterial invasion can lead to shallow, raised, or deep-pitted lesions (Goyer et al. 1996; Loria et al. 1997). Verticillium wilt is caused by *V. dahliae* and *V. albo-atrum*. *Verticillium dahliae* is the more widespread and predominant of the two species in Ontario (G. Lazarovits, unpublished data). The disease causes early dying of leaves and stems, leading to severe yield reductions in a variety of important crops, including potato and tomato worldwide (Powelson and Rowe 1993). *Streptomyces* spp. and *V. dahliae* can survive in soil for long periods in the absence of susceptible hosts and pose a long-term threat to potato production in infested soils (Kritzman and Grinstein 1991; Mace et al. 1981).

There is no effective strategy currently available to control potato scab or verticillium wilt. Fumigation with chemical sterilants such as methyl bromide, Vapam®, and chloropicrin can reduce soil populations of these pathogens, which may lead to disease suppression. However, these chemicals are not always available, can be expensive, are potentially dangerous to apply, and are environmentally undesirable. They can lower populations of nontarget beneficial soil microorganisms, which could lead to an increase in pathogen populations as antagonism and competition are eliminated (Powelson and Rowe 1993). Various soil amendments have been shown to influence the severity of potato scab and verticillium wilt (Conn and Lazarovits 1999; Davis et al. 1996; Huber and Watson 1970; Jordan et al. 1972; Lazarovits et al. 1999; Patrick and Toussoun 1965). In general, plant diseases caused by soilborne plant pathogens are less severe in soils receiving organic amendments (Davis et al. 2001; Hiddink et al. 2005; van Bruggen and Termorshuizen 2003).

Fish emulsions or fish soluble nutrients are liquid byproducts of the processing of fish into fish meal. They have been used mainly as fertilizers (Aung and Flick 1980; Aung et al. 1984; Ceci 1975), although other uses have been reported as well (Abbasi et al. 2003, 2004a; El-Tarabily et al. 2003; Wyatt and McGourty 1990). Foliar sprays of a mixture of fish emulsion and bacteria were used to control moths (Wyatt and McGourty 1990), and Abbasi et al. (2003) recently demonstrated that dilute solutions of fish emulsion could control bacterial spot [*Xanthomonas vesicatoria* (Doidge) Vauterin et al.] of tomato and pepper. Fish emulsion as a preplanting amendment to potting substrates and organic soil has shown effectiveness for controlling damping-off [*Rhizoctonia* and *Pythium* spp.] in cucumber and radish (Abbasi et al. 2004a). Fish meal, the dried protein obtained from processed fish, has been used as a soil amendment with great success in vegetable production (Blatt and McRae 1998; Gagnon and Berrouard 1994). Fish solid waste has also been known to reduce populations of plant-parasitic nematodes (Akhtar and Mahmood 1995). However, there are no reports of the use of fish emulsion to control potato scab or verticillium wilt of eggplant and potato.

The objectives of this study were to investigate the effects of fish emulsion, as a preplanting soil amendment, on verticillium wilt and plant biomass of eggplant under greenhouse conditions and on scab, verticillium wilt, and tuber yield of potato in various soils from commercial potato fields with a disease history of verticillium wilt and potato scab, under microplot and field conditions. Preliminary reports on some portions of this work have been published as abstracts (Abbasi et al. 2004b, 2005).

Materials and methods

Plant material, soils, and fish emulsion

Eggplant (*Solanum melongena* L. var. *esculentum* Nees 'Black Beauty') seed was purchased from William Dam Seeds Ltd., Flamborough, Ontario. Whole or cut disease-free seed potatoes (*Solanum tuberosum* L. 'Snowden') of Elite II quality, 5–6 cm in diameter, were obtained from a registered seed producer in Ontario.

Soils from commercial potato fields with a history of verticillium wilt and potato scab (low, moderate, and high disease levels) (Table 1) were used in this study: five loamy-sand soils (sites D, GM, GH, L1, and V4) and one sandy-loam soil (site B2) from Ontario, one loam soil (site AF) from New Brunswick, and four sandy-loam soils (sites MS, BC, BPF, and HB) from Prince Edward Island. Soils were analyzed for physical characteristics (Table 1) by A&L Canada Laboratories East, Inc., London, Ontario.

Fish-emulsion samples prepared from menhaden fish (*Brevoortia tyrannus* (Latrobe)) were provided by Omega Protein, Houston, Texas. Nutrient analysis by A&L Labora-

Table 1. Physical characteristics of soils used in this study, originating from commercial potato fields in Ontario, New Brunswick, and Prince Edward Island with a history of verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and potato scab [*Streptomyces* spp.] and the associated scab severity on potato tubers for 2003–2005.

Soil code (site)	Location	Soil type*	Scab severity†	Clay (%)	Sand (%)	Silt (%)	Organic matter (%)	Water-holding capacity‡	pH§
B2	Everett, Ont.	SL	Moderate	9	60	31	2.0	25	5.2
GM	Palmer Rapids, Ont.	LS	Moderate	9	84	7	1.5	22	5.7
D	Delhi, Ont.	LS	Low	8	84	8	1.0	15	5.9
L1	Aylmer, Ont.	LS	Moderate	13	84	3	3.7	30	6.9
GH	Palmer Rapids, Ont.	LS	High	9	84	7	1.5	22	7.0
V4	Alliston, Ont.	LS	Moderate	4	20	76	1.7	24	7.2
AF	New Brunswick	L	Low	21	44	35	2.6	27	6.6
MS	Prince Edward Island	SL	Moderate	17	76	7	3.7	31	6.1
BC	Prince Edward Island	SL	Moderate	13	72	15	2.7	30	6.3
BPF	Prince Edward Island	SL	Moderate	13	76	11	3.1	28	6.6
HB	Prince Edward Island	SL	Moderate	13	68	19	3.2	31	6.9

*L, loam; LS, loamy sand; SL, sandy loam.

†Low, scab-severity index (SSI) < 1; moderate, SSI = 1–3; high, SSI > 3. The SSI was based on the percentage of tuber surface covered with scab lesions, using the following scale: 0, 0%; 1, trace to 5%; 2, 6%–15%; 3, 16%–25%; 4, 26%–35%; 5, 36%–60%; and 6, 61%–100%.

‡Determined by placing soils on filter papers in funnels, saturating the soils with water, transferring the soils to an oven 24 h later, and calculating water loss in grams per 100 g of dry soil.

§pH was determined from mixtures of soil (8 g) and water (40 mL) shaken for 1 h.

tories East, Inc. showed that various fish-emulsion samples contained 50%–54% dry matter, 5%–6% total nitrogen, 1.8%–2% P_2O_5, and 1.2%–2.7% K_2O. According to information provided by Omega Protein, fish emulsion contains some heavy metals at nontoxic concentrations (e.g., chromium < 4.0 ppm). The concentration of total volatile fatty acids (VFAs) in the fish-emulsion samples, as determined by chemical suppression – ion-exclusion chromatography and conductivity detection (Dionex model 100, Dionex Corp., Sunnyvale, Calif.), was 190 mmol/L. Major VFAs in the fish emulsion were acetate (95 mmol/L), formate (40 mmol/L), *n*-butyrate (35 mmol/L), and propionate (13 mmol/L).

Effect of fish emulsion on verticillium wilt and plant biomass of eggplant in greenhouse trials

The effect of fish-emulsion preplanting soil amendment on verticillium wilt of eggplant was determined in site-GM soil naturally infested with *V. dahliae*. The soil was also artificially infested with *V. dahliae* inoculum grown in an autoclaved peat-based mix (Pro-Mix® BX, Premier Horticulture Inc., Rivière-du-Loup, Que.) for 2 weeks to increase the number of propagules of the wilt pathogen in the soil. The isolate of *V. dahliae* used for inoculum production was obtained from an 'Imperial Black Beauty' eggplant grown in infested potato soil. Inoculum (15 g at 3.3×10^6 colony-forming units per gram) was mixed with 3.4 kg of soil in a plastic bag. This was sufficient soil to fill six replicate plastic pots (10 cm diameter) per treatment. Infested soil amended with starter fertilizer 20–20–20 (1.6 g) and ammonium sulfate (1.85 g) served as a control. Fish emulsion was mixed with the infested soil at rates of 0.5% and 1% (*m*/*m*) in plastic bags, and the bags were incubated for 2 weeks at 24 °C in the dark. The amended soil from each bag was mixed again and transferred to six pots. One 4-week-old eggplant seedling growing in a peat-based plant-growth mix was transplanted into each pot and maintained in a greenhouse at 22–24 °C under a combination of daylight and supplemental lighting (photoperiod, 16 h light; light intensity, 225 $\mu E \cdot m^{-2} \cdot s^{-1}$) in a completely randomized design. Pots were watered daily as required. Plants were monitored weekly for symptoms and disease progression and rated for overall disease severity after 7 weeks, using a scale of 1–5 (1, healthy; 2, leaves yellowing; 3, yellowing and wilting; 4, severe wilting; 5, dead). Percent disease incidence was calculated on the basis of the number of symptomatic plants. After rating, plants were removed from the soil, then roots were washed to remove soil and weighed to determine their fresh mass. Dry masses were taken after these samples were air-dried on a greenhouse bench for 2 weeks. The trial was repeated once.

Effect of fish emulsion on scab, verticillium wilt, and tuber yield of potato in microplot trials

Microplots at the Agriculture and Agri-Food Canada Research Farm in London, Ontario, were used for experiments in 2003–2005. These plots consisted of plastic drainage tiles (25 cm diameter, 25 cm long) buried in a sandy-loam soil. Four soils (B2, GM, D, and GH) were tested in 2003, eight soils (B2, GM, L1, AF, BC, MS, HB, and BPF) in 2004, and three soils (B2, L1, and V4) in 2005. New soil was used each year. Fish emulsion was incorporated into 11–15 kg soil at a rate of 1% (*m*/*m*) in plastic bags and transferred to six replicate microplots per treatment (five in 2003). One bag of soil was used per microplot. One piece of potato tuber of the susceptible 'Snowden' was planted in each microplot, 2 weeks after the fish-emulsion treatment during the first week of June. Tubers were planted for a second year in 2005 in all eight soils from the 2004 microplot trial without additional fish-emulsion treatment. Microplots with fish-emulsion treatment did not receive inorganic fertilizer, whereas control microplots received fertilizer according to the recommended standard regime (200 kg N/ha, 150 kg P_2O_5/ha, and 150 kg K_2O/ha). The incidence of *V. dahliae* was determined by collecting a leaf petiole from the lower portion of each plant from each of the six replicate plants in mid-August. The petioles were surface-sterilized by placing them in 1.5% sodium hypochlorite for 2 min. Three sections from each petiole were plated onto a semiselective medium (Hawke and Lazarovits 1994), the dishes were incubated at 24 °C in the dark for 2 weeks, and the presence or absence of *V. dahliae* was determined visually or with a binocular microscope. A plant was scored as infected if *V. dahliae* was present in just one petiole section. After 12 weeks, all tubers from each plant were harvested and sorted. Only tubers with a diameter ≥ 3 cm were rated for scab severity as a percentage of the tuber surface covered with scab lesions, using the following scale: 0, 0%; 1, trace to 5%; 2, 6%–15%; 3, 16%–25%; 4, 26%–35%; 5, 36%–60%; and 6, 61%–100%. The tubers were weighed to determine yield.

Effect of fish emulsion on scab, verticillium wilt, and tuber yield of potato in field trials

Experimental plots were established in commercial potato fields in Ontario in the spring of 2004 (sites B2 and L1) and the spring of 2005 (site L1). Each plot was 9 m × 3.6 m in size. Treatments at all sites in both years included an untreated control and 1% fish emulsion applied as a preplanting amendment at a rate of 20 000 L/ha replicated 4 times in a randomized block design. All treatments at both sites in 2004 received the usual fertilizer regime (200 kg N/ha, 150 kg P_2O_5/ha, and 150 kg K_2O/ha) used by growers. The fish-emulsion treatment in the 2005 plot received no inorganic fertilizer. All other aspects of the treatments were the same in all the plots at all sites. Immediately before application, the fish emulsion was diluted 1:1 with water in 20 L containers. The dilute solution was then poured into watering cans and manually applied to the surface of the plots. The plots were immediately rototilled or cultivated to a depth of 15 cm. Four rows per plot of ‘Snowden’ potato tubers were planted 25 cm apart by the growers 2 weeks after the fish-emulsion amendment. Dry-weather conditions prevailed at the time of planting at both sites in 2004, and potato plants showed stunting, which was severe at site L1, in the fish-emulsion-treated plots. The incidence of *V. dahliae* in a leaf petiole from each of 25 plants from the middle two rows (approximately half of the plants from each row) of each replicate plot was determined in mid-August as described above. All tubers from the middle two rows were harvested mechanically and sorted, and tubers with a diameter ≥ 5 cm were rated for scab severity as described above. The tubers were also weighed to determine total yield per plot.

The field plots set up in 2004 at site L1 were replanted with ‘Snowden’ in 2005 without adding more fish emulsion. All treatments received the usual fertilizer regime used by the farmer as described above. Potato scab severity and yield were determined as described above.

Statistical analyses

The repeated greenhouse trials showed similar results and homogeneous variances, as determined by Bartlett’s and Levene’s tests for equal variances, therefore, the data from these trials were pooled for statistical analysis. The microplot data from each soil were analyzed separately and subjected to analysis of variance, using MINITAB® statistical software version 13.0 (Minitab Inc., State College, Penn.), and if P values indicated a significant difference ($P \leq 0.05$), means were separated by Fisher’s protected least significant difference (LSD) test. Disease-severity data were analyzed using SigmaStat statistical software (Jandel Scientific, San Rafael, Calif.). Data were subjected to one-way analysis of variance with Kruskal–Wallis nonparametric test statistics, and means were separated according to the Student–Newman– Keuls test.

Table 2. Effect, in a greenhouse environment, of fish-emulsion preplanting soil amendment on verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and plant biomass of eggplant in a soil from an Ontario potato field with a history of verticillium wilt and potato scab [*Streptomyces* spp.].

	Verticillium wilt		Plant biomass (g/plant)	
Treatment*	Incidence (%)	Severity†	Fresh	Dry
Control	75±13 a	3.4±0.5 a	43±5 b	8.3±0.8 b
Fish emulsion				
0.5%	17±11 b	1.3±0.2 b	58±2 b	10.0±0.3 b
1%	8±8 b	1.2±0.2 b	87±2 a	16.5±0.4 a

Note: Values are given as the mean ± standard error calculated from six replicates for each of two trials (n = 12). Values followed by a different letter within each column are significantly different ($P < 0.05$) according to Fisher’s protected least significant difference (LSD) test for disease incidence and plant biomass and the Student–Newman–Keuls test for disease severity.

*Fish emulsion (*m/m*) was incorporated into the infested soil 2 weeks before transplanting 4-week-old ‘Black Beauty’ eggplant. The infested soil was from site GM (see Table 1).

†Plants were rated for verticillium wilt on a 1–5 scale of severity (1, healthy; 2, leaves yellowing; 3, yellowing and wilting; 4, severe wilting; 5, dead) 7 weeks after planting.

Results

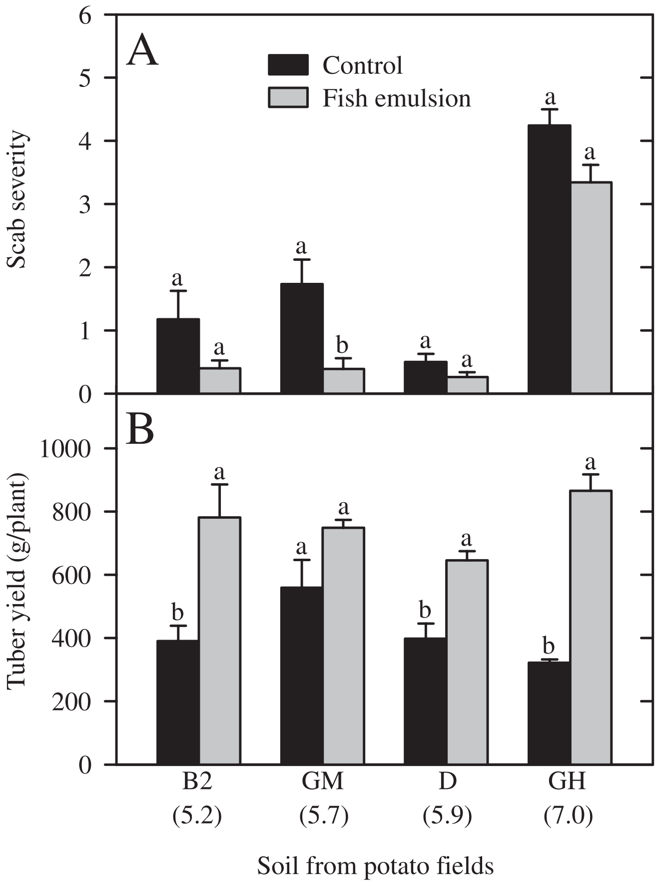
Effect of fish emulsion on verticillium wilt and plant biomass of eggplant in greenhouse trials

Adding fish emulsion at rates of 0.5% and 1% to infested soil 2 weeks prior to planting significantly ($P < 0.05$) reduced verticillium wilt of eggplant (Table 2). There were reductions of 77%–89% in disease incidence and 2.1–2.2 units in disease severity for the fish-emulsion treatments relative to the control treatment. However, only the 1% fish-emulsion treatment significantly ($P < 0.05$) increased fresh and dry plant biomasses, which were doubled compared with those of the control treatment (Table 2). No phytotoxic symptoms due to the fish-emulsion treatments were observed on the eggplant.

Effect of fish emulsion on scab, verticillium wilt, and tuber yield of potato in microplot trials

At site GM, a 1% fish-emulsion preplanting soil amendment significantly ($P < 0.05$) reduced scab severity (by 80%, or 1.3 units), compared with the control treatment for which scab severity on tubers was moderate in 2003 (Fig. 1A). There were no significant differences between the control and fish-emulsion-treated soils for potato scab

Fig. 1. Effect of fish-emulsion preplanting soil amendment on potato scab [*Streptomyces* spp.] severity (A) and tuber yield (B) in microplot trials in 2003 on five soils from Ontario commercial potato fields (sites B2, GM, D, and GH) with a history of verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and potato scab. Fish emulsion was incorporated into the soils in the spring of 2003 at a rate of 1% (*m*/*m*). Tubers were harvested in the fall and rated for scab severity, using a scale of 0–6 (see Table 1 for definition), and the yield was determined. Values (mean + standard error) are the average of five replicates. Different letters above the bars within a site indicate a significant difference in scab severity or yield ($P < 0.05$), according to Student–Newman–Keuls test. The numbers in parentheses below each site denotes pH.



on tubers produced in the B2, D, and GH soils (Fig. 1A). Total yield of tubers (>3 cm diameter) in 2003 was significantly ($P < 0.05$) increased by fish emulsion in D, B2, and GH soils (by 62%, 100%, and 170%, respectively) over the control (Fig. 1B). The percentage of potato plants infected with *V. dahliae* was very high in all four soils, on the basis of petiole analysis, and the fish-emulsion treatment did not reduce the number of infected plants, compared with the control treatment (data not shown).

The amendment of soil with 1% fish emulsion significantly ($P < 0.05$) reduced scab severity (by 80%–90%, or 0.6–2.1 units on the scale of 0–6) in five of the eight soils tested in 2004, including B2 and GM (Fig. 2A). However, tubers produced in these soils during the second year without the addition of more fish emulsion had scab severity in comparison similar to that of tubers in the control treatments (data not shown). The petiole analysis indicated that the fish-emulsion treatment did not significantly reduce the number of plants infected with *V. dahliae* (data not shown). In the 2004 microplot trials, the total yield of tubers was significantly ($P < 0.05$) increased in four of the eight soils by the fish-emulsion treatment compared with the control treatment (Fig. 2B), but the effect was not carried over to the second year, as the tuber yield in fish-emulsion-treated soils was similar to their respective controls in 2005 (data not shown).

Scab severity on tubers in L1 and B2 soils in 2005 was low, and the effect of fish emulsion on potato scab was not apparent in these soils (Fig. 3A). Site V4 had a history of moderate scab-disease pressure, and fish-emulsion treatment significantly ($P < 0.05$) reduced scab severity on tubers (by 90%, or 1.7 units), compared with the control treatment (Fig. 3A). Total yield of tubers was significantly ($P < 0.05$) increased by the fish-emulsion treatment in L1 soil (by 102%) and V4 soil (by 41%), but not in B2 soil (Fig. 3B). Fish emulsion significantly ($P < 0.001$) reduced the percentage of petiole infection due to *V. dahliae* in V4 soil. The control plants had 83% infected petioles compared with 0% infected petioles for the fish-emulsion-treated plants.

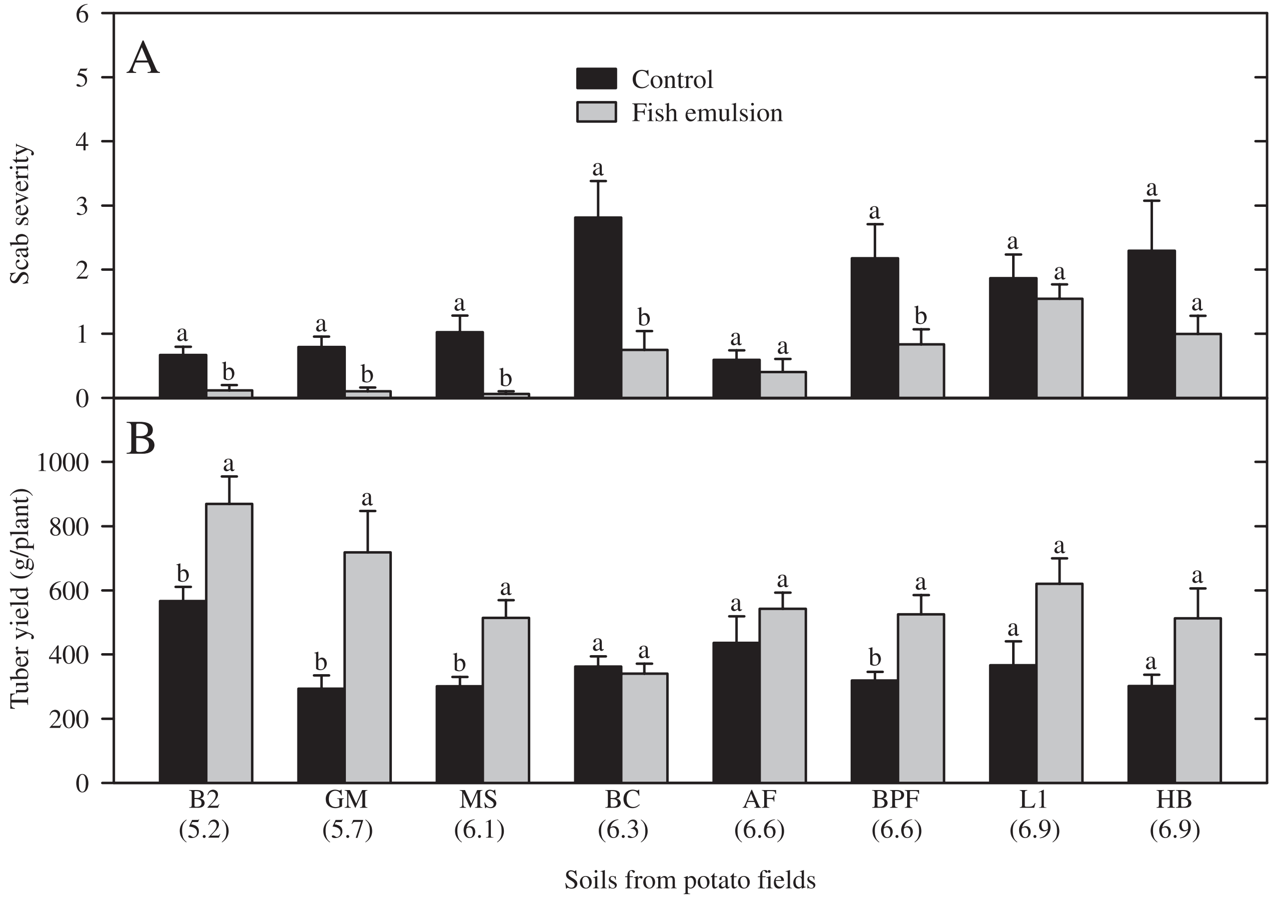
Effect of fish emulsion on scab, verticillium wilt, and tuber yield of potato in field trials

A single application of 1% fish-emulsion preplanting soil amendment at site B2 in the 2004 field trial significantly ($P < 0.05$) reduced scab severity (by 0.8 unit) and significantly increased scab-free tubers (by 132%), compared with the control treatment (Table 3). There was some stunting of plants in one of the plots treated with fish emulsion. Total tuber yield (>5 cm diameter) was not affected by the fish-emulsion treatment (Table 3). Marketable-tuber (surface scab < 5%) yield was almost doubled in the fish-emulsion-treated soil compared with the control (Table 3). The percentage of potato plants infected with *V. dahliae* at site B2 did not differ significantly between the fish-emulsion-treated plots and control plots (43% and 65%, respectively).

A single application of 1% fish emulsion as a preplanting soil amendment at site L1 in the 2004 field trial significantly ($P < 0.05$) reduced scab severity (by 1 unit) and significantly increased scab-free tubers (by 366%) in the year of application, compared with the control treatment (Table 3). Stunting of potato plants in the fish-emulsion-treated plots was widespread. Total tuber yield (>5 cm diameter) was significantly reduced (by half) in the fish-emulsion treatment compared with the control treatment (Table 3). The yield of marketable tubers was more than doubled by the fish-emulsion treatment (Table 3). The percentages of potato plants infected with *V. dahliae* were similar in the control (74%) and fish-emulsion (81%) treatments, on the basis of petiole analysis.

Tubers were planted for a second year in 2005 in the same plots as in 2004 at site L1, without adding more fish emulsion. No differences in the severity of scab on tubers, the percentage of scab-free tubers, or total or marketable tuber yields were observed between the control and the fish-emulsion treatments (data not shown).

Fig. 2. Effect of fish-emulsion preplanting soil amendment on potato scab [*Streptomyces* spp.] severity (A) and tuber yield (B) in microplot trials in 2004 on eight soils from commercial potato fields (sites B2, GM, L1 (Ontario), AF (New Brunswick), and MS, BC, BPF, HB (Prince Edward Island)) with a history of verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and potato scab. Fish emulsion was incorporated into the soils in the spring of 2004 at a rate of 1% (*m*/*m*). Tubers were harvested in the fall and rated for scab severity, using a scale of 0–6 (see Table 1 for definition), and yield was determined. Values (mean + standard error) are the average of six replicates. Different letters above the bars within each site indicate a significant difference in scab severity or yield ($P < 0.05$), according to Student–Newman–Keuls test. The number in parentheses below each site denotes pH.



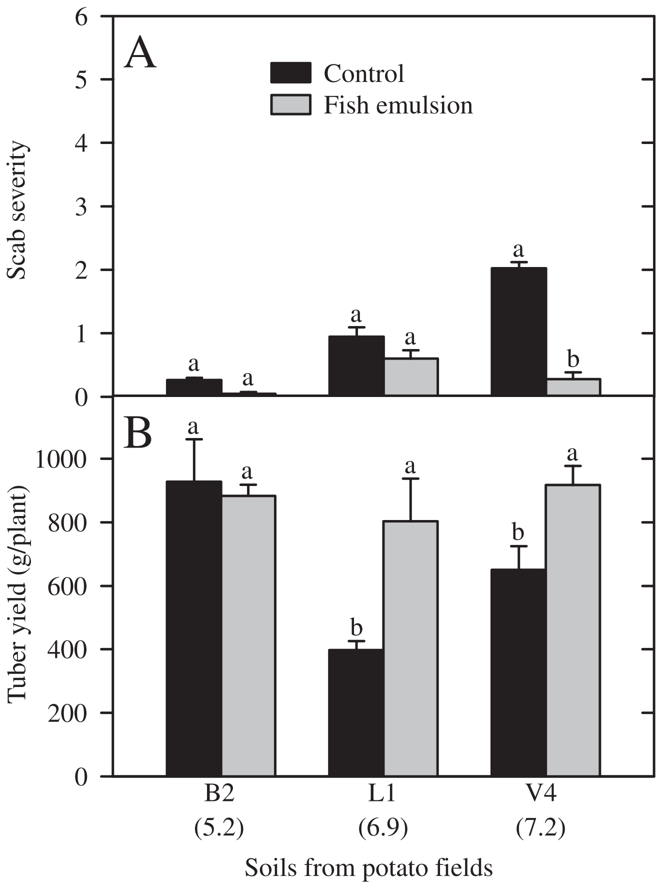
A new field trial at site L1 in 2005, in plots adjacent to those used in 2004, resulted in no differences between the control treatment and the 1% fish-emulsion treatment in the severity of scab on tubers, percentage of scab-free tubers, or total or marketable tuber yields (Table 4). There was no phytotoxicity of the fish emulsion to the potato plants at this site in 2005.

Discussion

This study demonstrates the efficacy of fish emulsion for controlling potato scab and verticillium wilt of eggplant and potato. A single application of fish emulsion as a preplanting soil amendment at a rate of 1% (*m*/*m*) was effective in reducing verticillium wilt of eggplant, verticillium wilt of potato, and potato scab in some soils in the year of application. Fresh and dry biomasses of eggplant were enhanced by 1% fish emulsion. The effect of fish emulsion on total tuber yield was positive in most soils in microplot trials, but the same yield responses were not seen in the field trials. Microplots treated with fish emulsion did not receive any additional nitrogen fertilizer, but in the field trials, the grower applied fertilizer according to the normal regime to all plots. This extra dose of nitrogen may have contributed to the stunting of potato plants observed in a fish-emulsion-treated plot at both B2 and L1 sites in 2004. Also, the dry-weather conditions at the time of planting in 2004 may have increased the concentration of fish emulsion to toxic levels and delayed the breakdown of the fish-emulsion material by soil microbes. The percentage of scab-free tubers and marketable tuber yield were higher in the fish-emulsion-treated plots at both field sites during 2004. The disease-control or yield effect was not obvious in the 2005 field trial. This inconsistency in the effect of fish emulsion on disease and tuber yield in some soils between years and between microplot and field trials could be due to nonuniform distribution and mixing of the material into the soil, variation in soil chemistry, microbiology, or pathogen populations, or environmental factors that vary annually.

The soils used in this study had different characteristics, and potato tubers produced in these soils showed different levels of scab severity. For example, the organic-matter content ranged from 1.0% to 3.7% and the pH from 5.2 to 7.2, and low (scab-severity index (SSI) < 1), moderate (SSI =

Fig. 3. Effect of fish-emulsion preplanting soil amendment on potato scab [*Streptomyces* spp.] severity (A) and tuber yield (B) in microplot trials in 2005 on three soils from Ontario commercial potato field sites (B2, L1, and V4) with a history of verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and potato scab. Fish emulsion was incorporated into the soils in the spring of 2005 at a rate of 1% (*m*/*m*). Tubers were harvested in the fall and rated for scab severity, using a scale of 0–6 (see Table 1 for definition), and yield was determined. Values (mean + standard error) are the average of six replicates. Different letters above the bars within each site indicate a significant difference in scab severity or yield ($P < 0.05$), according to Student–Newman–Keuls test. The number in parentheses below each site denotes pH.



1–3), and high (SSI > 3, on a scale of 0–6) levels of scab severity were all found on tubers. Fish emulsion reduced potato scab and verticillium wilt in soils covering the full range of organic-matter content and pH. Thus, the efficacy of fish emulsion in reducing verticillium wilt or potato scab in this study was not site- or soil-specific, whereas other amendments have been shown to be greatly influenced by organic-matter content and soil pH (Conn and Lazarovits 1999, 2000; Tenuta 2001; Tenuta and Lazarovits 2002). However, the level of scab severity on potato tubers in natural soil had an impact on the efficacy of fish emulsion as a disease-control product. The results of this study clearly indicate that fish emulsion may not work in soils in which scab severity on tubers is very high. Fish emulsion was not effective in soils showing very low scab severity on tubers.

One mechanism by which some organic soil amendments, such as liquid swine manure, can reduce soilborne diseases is through the presence of VFAs, including acetic acid (Conn et al. 2005). VFAs have been shown to kill microsclerotia of *V. dahliae* in soils with pH below 6 (Conn et al. 2005; Tenuta et al. 2002). At low pH, VFAs, which are in nonionized forms (e.g., acetic acid, not acetate) that are toxic to *V. dahliae* (Tenuta et al. 2002). Fish emulsion also contains VFAs (total VFAs, 190 mmol/L), with acetate being the major one. It is possible that VFA toxicity was one of the mechanisms of disease reduction of fish emulsion in the two low-pH soils (B2 and GM, pH 5.2 and 5.7, respectively) used in this study. Taking into account the concentration of VFAs in fish emulsion, the amount of fish emulsion added to the soil, soil pH, and soil moisture, the concentration of the nonionized forms of VFAs in the B2 and GM soils (calculated from the mass fraction of nonionized VFAs in soil water at 22–24 °C, using the Henderson–Hasselbalch equation) would have been approximately 5 and 2 mmol/L, respectively. A concentration of about 3 mmol/L of the nonionized forms of VFAs from liquid swine manure in soil is needed to kill *V. dahliae* (Conn et al. 2005). The fact that 20% of the VFAs in fish emulsion is formic acid increases the toxicity of the VFAs in fish emulsion compared with liquid swine manure, which does not contain formic acid. This is because formic acid is 7 times more toxic to pathogens such as *V. dahliae* than acetic acid (Tenuta et al. 2002).

Ammonia, which is present after the addition of some organic amendments to soil, can also play a role in reducing the population of plant pathogens (Conn et al. 2005; Tenuta and Lazarovits 2002). Some of the ammonium in soils of pH 8 or higher is in the form of ammonia, which is toxic to *V. dahliae* (Tenuta and Lazarovits 2002). None of the soils used in this study, however, had a pH over 8, and fish emulsion did not cause the pH of any of the soils to increase above 8 (data not shown), so toxicity due to ammonia cannot account for any of the reduction of disease in these soils after the addition of fish emulsion.

Increased soil biological activity and stimulation of biological control after the application of organic amendments to soil is another mechanism that can reduce soilborne diseases. Both competition and antibiosis have been implicated in the biological control of potato scab (Neeno-Eckwall et al. 2001). Davis et al. (1996, 2001) showed that the incidence of verticillium wilt decreased after 2 years of green manuring, although inoculum levels of the pathogen stayed the same, or in some cases increased two to four fold. They attributed disease reduction to biological control. It is possible that fish emulsion stimulated microbial activity, including that of biocontrol agents, in the amended soils, which may have been partly responsible for the disease reduction observed. Abbasi et al. (2004a) showed that incorporation of fish emulsion into soil or substrate caused an increase in numbers of bacteria and fungi. The use of fish emulsion as a substrate for plant-growth-promoting rhizobacteria has been reported recently (El-Tarabily et al. 2003).

Organic matter is one factor that can be manipulated to improve potato crop health and productivity. Soil organic matter can impact soil and plant health by moisture retention, infiltration, and nutrient retention and release (Weil and Magdoff 2004). The factors that are most closely related

Table 3. Effect of fish-emulsion preplanting soil amendment on potato scab [*Streptomyces* spp.] severity and tuber yield in 2004 in two Ontario commercial potato fields (sites B2 and L1) with a history of verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and potato scab.

			Tuber yield (kg/18 m row)†	
Treatment*	Scab-severity index	Scab-free tubers (%)	Total	Marketable‡
Site B2				
Control	1.1±0.4 a	37±17 b	18.2±3.6 a	7.2±4.3 b
1% fish emulsion	0.3±0.2 b	86±9 a	16.2±3.7 a	14.3±4.2 a
Site L1				
Control	1.4±0.3 a	15±5 b	26.8±2.2 a	4.2±1.4 b
1% fish emulsion	0.4±0.1 b	70±4 a	13.8±3.2 b	9.5±2.2 a

Note: Values are given as the mean ± standard error calculated from four replicate plots. Values followed by a different letter within each column for each site are significantly different ($P < 0.05$) according to Student–Newman–Keuls test.

*Fish emulsion (20 000 L/ha) was incorporated into the soils of sites B2 and L1 in the spring of 2004. See Table 1 for soil properties.

†All tubers from the middle two rows of each plot were harvested in the fall and rated for scab severity on a scale of 0–6 based on the percentage of tuber surface covered with scab lesions: 0, 0%; 1, trace to 5%; 2, 6%–15%; 3, 16%–25%; 4, 26%–35%; 5, 36%–60%; and 6, 61%–100%.

‡Tubers with surface scab < 5%.

Table 4. Effect of fish-emulsion preplanting soil amendment on potato scab [*Streptomyces* spp.] severity and tuber yield in 2005 in an Ontario commercial potato field (site L1) with a history of verticillium wilt [*Verticillium dahliae* and *Verticillium albo-atrum*] and potato scab.

			Tuber yield (kg/18 m row)†	
Treatment*	Scab-severity index	Scab-free tubers (%)	Total	Marketable‡
Control	1.2±0.3 a	17±9 a	19.5±2.3 a	12.7±1.6 a
1% fish emulsion	1.0±0.1 a	27±14 a	18.9±4.8 a	16.2±5.0 a

Note: Values are given as the mean ± standard error calculated from four replicate plots. Values followed by a different letter within each column are significantly different ($P < 0.05$) according to Student–Newman–Keuls test.

*Fish emulsion (20 000 L/ha) was incorporated into the soil of sites L1 in the spring of 2005, next to the 2004 plots. See Table 1 for soil properties.

†All tubers from the middle two rows (9 m each) of each plot were harvested in the fall and rated for scab severity on a scale of 0–6 based on the percentage of tuber surface covered with scab lesions: 0, 0%; 1, trace to 5%; 2, 6%–15%; 3, 16%–25%; 4, 26%–35%; 5, 36%–60%; and 6, 61%–100%.

‡Tubers with surface scab < 5%.

to soil integrity, such as organic-matter content, organic-nitrogen concentration, and increased nutrient availability, were associated with a reduction of diseases and higher tuber yields in commercial potato fields (Davis et al. 2001). Increasing the organic-matter content in soil has been shown to increase the activity and diversity of the resident microbial community (Mäder et al. 2002). Fish emulsion is a promising material for increasing soil organic-matter content and changing the disease profile of a potato soil. A potential benefit of fish emulsion lies particularly in organic crop production systems, where growers rely heavily on organic-residue management to control diseases caused by soilborne plant pathogens. Fish emulsion is approved by the Organic Materials Review Institute for organic production in the United States.

The use of fish emulsion as a control agent for soilborne diseases such as potato scab and verticillium wilt needs to be further validated in the context of improving soil organic-matter content and for improvement of soil and crop health in general. The broadcast rates of fish emulsion that are effective against potato scab are currently not economical (approximately $10 000/ha). The 1% broadcast rate is also not feasible, since it provides excessive amounts of N–P–K fertilizer (1000–1200 kg N/ha, 360–400 kg P_2O_5/ha, and 240–540 kg K_2O/ha, assuming that 100% of all constituents are available immediately). Banding or in-furrow applications of fish emulsion could possibly lower costs without compromising efficacy. Ideally, the material required could be further reduced by application through a drip irrigation system. There is also a need to conduct long-term studies with fish emulsion applied serially over time at lower rates that can be economically feasible. For instance, applying the material yearly at lower rates for several years may improve its efficacy over time in terms of yield improvement and disease suppression.

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