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The effect of *Rhizoctonia fragariae,* soil type, compost, and mechanical root injury on strawberry growth

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Abstract

Three experiments were conducted to study the influence of *Rhizoctonia fragariae* anastomosis groups A and G in combination with different soil types, varying rates of compost, and following different methods of injuring the roots on strawberry vegetative growth. *R. fragariae* anastomosis groups were isolated from Pennsylvania (PA) strawberry farms and obtained from the Connecticut Agricultural Experiment Station. In the first experiment, plants were inoculated and grown in two Hagerstown soils and a sandy loam soil collected from Centre County, PA. Inoculated plants generally grew better than non-inoculated plants, but the effect of inoculation depended on soil type. In another experiment, inoculated plants were grown in Hagerstown soil with 0, 10, 20, and 30 percent compost by volume. Plant growth was generally negatively related to compost concentration and inoculation with both strains tending to partially alleviate the negative effects of compost. In the third experiment, plants with roots injured by crushing or scraping had significantly higher total dry mass when plants were inoculated with CT-G and PA-A. Results from the three experiments suggest that inoculation with *R. fragariae* may be beneficial to strawberry plant growth when roots are exposed to adverse conditions.

Throughout the world, strawberry plantings have been affected by a disease complex called Black Root Rot (BRR). BRR development is caused by multiple biotic and abiotic factors that include soil-borne fungi, injury by *Pratylenchus penetrans*, cultural practices, and environmental stresses. Many soil-borne fungi have been implicated in BRR development including *Pythium* spp., *Fusarium* spp., *Cylindrocarpon* spp., *Idriella lunata*, and *Rhizoctonia* spp.; however, *Rhizoctonia fragariae* is most commonly studied as a BRR pathogen (Husain and McKeen, 1963; LaMondia, 1999; LaMondia and Martin, 1989; Martin, 2000; Nelson and Wilhelm, 1956; Wilhelm et al., 1972; Wing et al., 1995). Other reports suggest that *R. fragariae* is an endophyte or is mycorrhizal in strawberry and orchid species (Martin, 1988; Ribeiro and Black, 1971; Sen et al., 1999). These discrepancies may be due to genetic variation among *R. fragariae* strains, referred to as anastomosis groups, or other factors relating to strawberry root health.

R. fragariae resides in sloughed off cortex tissue of structural roots and infects strawberry roots through appressoria formation and penetration through cell tissues or stomata (Wilhelm et al., 1972). *R. fragariae* infection may occur through a break in the epidermal layer or the rhizodermis of root tissue. The rhizodermis may be mechanically injured during strawberry plant harvest at the nursery or at planting time which could suppress water and nutrient uptake and allow infection of soil-borne fungi.

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The effects of soil type and quality on strawberry root health are not well understood. The physical quality of soil is very important for plant growth, and desirable soil qualities include good water infiltration, aeration, rootability, workability (Dexter, 2004) and aggregate stability. These qualities allow roots to respire properly, explore the soil for nutrients, and take up water more efficiently. Poor soil quality may stress the roots and suppress their natural structural and chemical defenses against pathogen infection.

Compost amendments are used to improve soil quality, provide nutrients, and increase soil organic matter (Tate, 1987). For strawberry production, the recommended soil organic matter is between two to six percent depending on the soil type. Soil organic matter may also influence soil microorganism biodiversity. Application of organic matter suppressed disease development related to pathogenic organisms such as *Pythium* spp. and *Rhizoctonia* spp. in organic strawberry production (Rosado-May et al., 1994). BRR development may be suppressed when compost or other organic matter is applied, but interactions of the microbial community involved in disease suppression are not well understood (Elmer and LaMondia, 1999; Seigies and Pritts, 2006). Husain and McKeen (1963) found that at root temperatures of 5 to 10°C, roots released higher levels of amino acids which may be important for communication with microbial organisms in the root zone. High levels of organic matter may absorb amino acids and prevent detection of roots by pathogenic organisms.

The objectives of this research were to determine the effects of various soil types, compost rates, and simulated mechanical root injury on strawberry plant growth and root health with and without *R. fragariae* inoculation. These experiments were conducted to determine if these factors could be involved in the development of BRR symptoms independently or in combination.

Materials and Methods

Plant material. Greenhouse experiments were conducted at University Park, Pennsylvania (PA). Dormant 'Jewel' strawberry plants from Nourse Farms (Whately, MA), were used to produce runners and new daughter plants. Daughter plants were removed from the mother plant and planted in Sunshine Mix #4 (Sun Gro Horticulture, Bellevue, WA) in propagation trays. After three weeks under mist, the largest daughter plants were selected for all experiments. During the course of the experiments, plants were fertilized with 25.0 g Osmocote® (Marysville, OH) once every four weeks.

Fungal inoculum. *R. fragariae* anastomosis groups A and G were selected for the following experiments (Table 1). Isolates PA-A and PA-G, were isolated from symptomatic strawberry roots from commercial fields in Centre County, PA (Lavely, 2013) and maintained on PDA from initial isolations. James LaMondia (Connecticut Agricultural Experiment Station, Windsor, CT) provided two isolates from Connecticut (CT), CT-A and CT-G. On 5 Sept. 2012, 22 days before inoculation, isolates were transferred to potato dextrose broth (PDB). The mycelia was filtered from PDB, and 0.5 g was used for inoculations based on preliminary experiments. Mycelia of each strain was placed in a blender with solutions of 500 mL of H_2O with 0.09% NaCl until well blended to form root slurries. Plants were inoculated on 27 Sept. 2012, using a modified bare-root dip method (Siddiqui and Shaukat, 2002) where roots were soaked in slurries for 30 min.

R. fragariae re-isolation. To confirm inoculation success, two plants from each treat-

Table 1. Identification and source of *R. fragariae* isolates used for inoculation.

Anastomosis group	Source	Notation
A	Centre County, PA	PA-A
G	Centre County, PA	PA-G
A	CT	CT-A
G	CT	CT-G

Table 2. Soil analysis values from the Agricultural Analytical Services Laboratory, University Park, PA for Hagerstown-1 (H-1), Hagerstown-2 (H-2), and sand loam (SL).

Soil type	pH	Phosphate (P_2O_5) ($kg \cdot ha^{-1}$)	Potash (K_2O) ($kg \cdot ha^{-1}$)	Magnesium (MgO) ($kg \cdot ha^{-1}$)	Calcium (CaO) ($kg \cdot ha^{-1}$)	Nitrogen (%)	OM (%)	Soluble salts ($mmhos \cdot cm^{-1}$)
H-1	7.1	81.8	430.4	391.2	7414.4	0.20	3.2	0.07
H-2	6.0	636.6	1320.4	1666.7	7859.4	0.27	2.9	3.30
SL	6.5	621.0	645.6	1004.3	9094.6	0.25	4.0	0.87

ment combination were selected for re-isolations of *R. fragariae*. Root tissue from each plant (0.1 g) was selected from the margins of symptomatic tissue. Root segments of 5 mm in length were placed on water agar amended with antibiotics (Gutierrez et al., 2010). After five to ten days, hyphal tips were transferred to potato dextrose agar (PDA) for macroscopic and microscopic identification. Isolates identified as *R. fragariae* by hyphal characteristics were transferred to PDB and incubated for 20 days. Isolates were selected for lyophilization and deoxyribonucleic acid (DNA) extraction using Nucleic Lysis Solution (Promega) with isopropanol and ethanol cleanup. ITS Primers 1 and 4 (White et al., 1990) were used in polymerase chain reaction (PCR) to detect the presence of ribosomal DNA of *R. fragariae* at an annealing temperature of 58°C (Okubara et al., 2008). Successful PCR products were prepared for DNA sequencing using shrimp alkaline phosphatase cleanup (ExoSAP-IT®). PCR products were sent to the Genomics Core Facility (University Park, PA) for sequencing. DNA sequences of re-isolated *R. fragariae* strains were compared to inoculation strains using Molecular Evolutionary Genetics Analysis 4 (MEGA 4) (The Biodesign Institute, 2007).

Experiment 1. The effect of soil type and R. fragariae AG-A inoculation on strawberry plant growth. On 27 Sept. 2012, 36 strawberry plants were non-inoculated (control) or inoculated with *R. fragariae* isolates PA-A and CT-A (Table 1). AG-A was selected for inoculation because it most strongly interacted with strawberry plant growth and root lesion development as compared to other anastomosis groups. Four plants from each inoculation treatment were planted in 1.2 L pots in pasteurized soils collected from three locations in Centre County, PA; Hagerstown-1 clay loam (40.71 N, 77.96 W), Hagerstown-2 clay loam (40.69 N, 77.93 W), and sandy loam (40.81 N, 78.07 W). Results from soil analysis are presented in Table 2. Plants were grown in the greenhouse for seven weeks under ambient conditions and final leaf and crown numbers were recorded. Roots were washed over a wire screen and structural root number and the number of structural roots with brown to black lesions were recorded. Plants were dried in a 60°C drying oven for seven days, and leaf (including petioles), crown, and root dry mass were recorded.

The experimental design was completely randomized, and the treatment structure was a full factorial (three inoculation treatments x three soil types) with four single-plant replications per treatment combination. Data were analyzed using analysis of variance (ANOVA) with SAS's Mixed procedure (SAS Institute, Cary, NC). Least squares means were compared using PDIFF.

Experiment 2. The effect of compost soil amendments and R. fragariae AG-A inoculation on strawberry plant growth. On 27 Sept. 2012, 48 strawberry plants were non-inoculated (control) or inoculated with *R. fragariae* isolates PA-A and CT-A. Plants from each inoculation treatment were planted in 1.2 L pots containing Hagerstown-2 loam amended with compost at rates of 0, 10, 20,

Table 3. Soil analysis values for each soil-compost treatment (Hagerstown-2) from the Agricultural Analytical Services Laboratory, University Park, PA.

Compost (%)	pH	Phosphate (P_2O_5) ($kg \cdot ha^{-1}$)	Potash (K_2O) ($kg \cdot ha^{-1}$)	Magnesium (MgO) ($kg \cdot ha^{-1}$)	Calcium (CaO) ($kg \cdot ha^{-1}$)	Nitrogen (%)	OM (%)	Soluble salts ($mmhos \cdot cm^{-1}$)
0	6.0	636.6	1320.4	1666.7	7859.4	0.27	2.9	3.30
10	6.6	1052.5	1508.7	1838.2	10687.3	0.46	4.8	3.88
20	6.9	1345.0	2063.5	1916.7	13068.0	0.65	7.0	4.79
30	6.9	1545.7	2822.3	1976.1	13970.3	0.77	8.9	5.54

and 30 percent by volume. Compost was obtained from the Penn State Organic Materials Processing and Education Center at University Park, PA (Table 3). Plants were grown in the greenhouse under ambient conditions for the duration of the experiment.

Seven weeks after planting, final leaf and crown numbers were recorded. Roots were washed over a wire screen, and structural root number and the number of structural roots with brown to black lesions were recorded. Plants were dried at 60°C for 10 days and leaf, crown, and root dry mass were recorded.

The experimental design was completely randomized, and the treatment structure was a full factorial (three inoculation treatments x four compost rates) with four single-plant replications per treatment combination. Data were first analyzed using SAS's general linear model (GLM) procedure where the model included compost as a quantitative variable and inoculation treatment as a qualitative variable plus the interaction term. When inoculation treatment and the interaction were not significant, regression analysis was performed with SAS's regression (REG) procedure, to evaluate the relationship between plant growth variables and compost rate averaged over all inoculation treatments. When inoculation treatment was significant, but the interaction was not, main effect means for inoculation treatments were compared using PDIFF.

Experiment 3. The effect of root abrasion and inoculation with R. fragariae AG-A and AG-G on strawberry plant growth. On 27 Sept. 2012, 60 strawberry plants were not inoculated (control) or inoculated with *R. fragariae* isolates of PA-A, PA-G, CT-A, and CT-G. Before inoculation, the roots of four plants from each inoculation treatment were either scrape or crush injured to simulate the potential injury caused during transplanting. Scrape injury was achieved using a wire brush against structural roots, and crush injury was achieved by application of pressure to structural roots with the smooth surface of a hammer. After roots were injured, plants were inoculated as previously described and planted in 1.2 L pots containing pasteurized clay loam mixed with perlite (3:1: v/v).

Plants were grown in the greenhouse for eight weeks under ambient conditions, and final leaf and crown numbers of surviving plants were recorded. Plants were harvested, and roots were washed over a wire screen. The number of structural roots and structural roots with brown to black lesions was recorded. Plants were dried at 60°C for 10 days, and leaf, crown, and root dry mass were recorded.

The experiment was completely randomized, and the treatment structure was a full factorial (five inoculation treatments x three root injury treatments) with four replications per treatment combination. Growth and plant survival data were analyzed using ANOVA with SAS's Mixed procedure. Least squares means were compared using PDIFF.

Table 4. Effect of three soil types and inoculation with *R. fragariae* AG-A isolates collected in PA and CT on number of leaves, crowns, and structural roots and dry mass (DM) of 'Jewel' strawberry plants.

Treatment	Leaf number	Crown number	Structural roots	Crown DM (g)	Root DM (g)	Total DM (g)	SRL[y]
Inoculation							
None	6.9a[z]	1.9b	24.8a	0.32a	0.72a	2.5a	28.6a
CT-A	9.0b	1.8a	25.9a	0.51b	0.92a	4.0b	29.0a
PA-A	8.9b	1.7a	21.8a	0.41ab	0.81a	2.9b	29.0a
Soil Type							
Hagerstown-1	6.8a	1.0a	22.4a	0.36a	0.79a	2.5a	39.5b
Hagerstown-2	9.4b	1.8b	26.5a	0.46a	0.91a	4.3b	29.6b
Sandy loam	8.7b	1.9b	23.7a	0.41a	0.75a	3.8ab	17.7a
P-value from ANOVA							
Inoculation (IN)	0.01	0.01	0.18	0.03	0.70	0.04	0.99
Soil type (ST)	0.01	0.04	0.18	0.34	0.78	0.02	0.01
IN x ST	0.05	0.28	0.10	0.90	0.43	0.16	0.07

[z] Least squares means within columns for inoculation treatments and soil types followed by common letters do not differ at the 5% level, by PDIFF.

[y] The percentage of structural roots with lesions.

Results

Experiment 1. Plants inoculated with either isolate of *R. fragariae* AG-A had significantly more leaves than non-inoculated control plants, but control plants had significantly more crowns than inoculated plants (Table 4). Leaf and crown number were lowest when plants were grown in the Hagerstown-1 loam. Structural root number was not significantly affected by soil type or inoculation treatments. Plants grown in sandy loam soil had a significantly lower percentage of structural roots with lesion development.

The affect of inoculation treatment on leaf dry mass depended on soil type (Table 5). For non-inoculated plants, leaf dry mass was lowest in sandy loam, but for inoculated plants, leaf dry mass was lowest in Hagerstown-1 loam. When inoculated with either isolate of *R. fragariae*, plants grown in Hagerstown-1 loam had the lowest leaf dry mass (Table 5). Crown dry mass was significantly higher when plants were inoculated with CT-A but was not influenced by soil type. Total plant dry mass was lowest for non-inoculated plants and plants growing in Hagerstown-1 loam (Table 4).

Experiment 2. Inoculation and compost treatments did not interact for any response variables. Plants inoculated with CT-A had significantly more leaves, crowns, and higher leaf dry mass than control plants (Table 6). Crown dry mass and total dry mass were greater for plants inoculated with CT-A than for control plants. Crown number and total dry mass were negatively related to compost rate. The number of structural roots with lesions was not influenced by inoculation treatment, but declined linearly as compost rate increased (Table 6).

Experiment 3. Plants inoculated with CT-A, CT-G, and PA-A had significantly higher plant survival than control and PA-G inoculated plants. The only response variable affected by root injury was plant survival. Uninjured plants had significantly higher plant survival than plants with crushed roots, and survival of plants with scraped roots was intermediate. All control plants with crushed roots died during the course of the experiment.

Leaf and crown numbers were not significantly affected by inoculation or root injury treatments (Table 7). For structural root number, there was a significant inoculation x root injury interaction. Plants injured by crushing had significantly fewer structural roots than uninjured plants when plants were inoculated

Table 5. Effect of inoculatioun with two *R. fragariae* anastomosis groups collected in PA and CT and three soil types on leaf dry mass (g) of 'Jewel' strawberry plants.

	Inoculation treatment			
Soil type	None	CT-A	PA-A	Means
	Leaf dry mass (g)			
Hagerstown-1	1.4ab[z]	1.3a	1.5a	1.4a
Hagerstown-2	2.3b	3.2b	3.2b	2.9b
Sandy loam	0.9a	3.3b	3.6b	2.6b
Means[y]	1.5b	2.6a	2.8a	
P-value from ANOVA				
Inoculation (IN)	0.01			
Soil type (ST)	0.01			
IN x ST	0.04			

[z] Least squares means within columns for inoculation treatment followed by a common letter are not significantly different at the 5% level, by PDIFF.
[y] Least squares means within the row followed by a common letter are not significantly different at the 5% level, by PDIFF.

Table 6. Effect of inoculation with two *R. fragariae* anastomosis groups and four rates of compost on number of leaves, crowns, and structural roots, and dry mass (DM) of 'Jewel' strawberry plants.

Treatment	Leaf number	Crown number	Structural roots	Leaf DM (g)	Crown DM (g)	Root DM (g)	Total DM (g)	SRL[y]
Inoculation								
None	7.2a[z]	1.2a	21.5ab	1.7a	0.30a	0.57a	2.7a	25.6a
CT-A	8.9b	1.8b	23.9b	2.9b	0.41b	0.79a	4.1b	25.3a
PA-A	7.9ab	1.4ab	19.1a	2.2ab	0.31ab	0.52a	2.9a	25.3a
Compost treatment (%)								
0	9.4	1.5	26.5	2.9	0.46	0.91	4.3	29.6
10	8.1	1.3	21.9	2.3	0.32	0.55	3.2	26.9
20	7.8	1.4	20.4	2.3	0.34	0.61	3.2	21.4
30	6.8	1.4	17.3	1.5	0.23	0.43	2.3	21.4
P-value	0.01	0.20	0.03	0.02	0.02	0.06	0.01	0.04
R^2	0.23	0.04	0.29	0.13	0.22	0.09	0.01	0.10

[z] Least squares means within columns for inoculation treatments and compost rates followed by common letters do not differ at the 5% level, by PDIFF.
[y] The percentage of structural roots with lesions.

with the CT isolates, but plants inoculated with PA-A with crushed roots had significantly more structural roots than non-injured plants (data not shown). The percentage of structural roots with lesions was also significantly lower in control plants except when plants were inoculated with PA-A.

Plants inoculated with PA-A had significantly higher leaf dry mass than all other treatments whereas control plants had the lowest leaf dry mass. Inoculated plants had significantly higher crown dry mass than control plants when averaged across all injury treatments except when plants were inoculated with PA-G or CT-A (Table 7). Root dry mass of inoculated plants was also significantly higher than control plants except for CT-A and PA-G, and non-inoculated plants had significantly fewer structural roots compared to inoculated plants (Table 7).

Discussion

Hagerstown-1 loam supported the least amount of plant growth which may have been due to high pH of 7.1. Optimal pH for strawberry plants is between 6.0 and 6.5

Table 7. Effect of inoculation with *R. fragariae* anastomosis groups and root injury on number of leaves, crowns, and structural roots and dry mass (DM) of surviving 'Jewel' strawberry plants.

	Survival (%)	Leaf number	Crown number	Structural roots	Leaf DM (g)	Crown DM (g)	Root DM (g)	Total DM (g)	SRL[y]
None	30a[z]	7.0a	1.0a	15.5a	0.8a	0.12a	0.24a	1.1a	12.9a
CT AG-A	100b	7.2a	1.2a	23.8b	1.4ab	0.21a	0.38a	1.9ab	23.4b
CT AG-G	80b	7.6a	1.3a	26.9b	1.9b	0.29a	0.59b	2.8b	23.1b
PA AG-A	100b	8.9a	1.4a	28.8b	2.6c	0.30b	0.70b	3.6c	20.5ab
PA AG-G	40a	7.4a	1.0a	27.0b	1.6b	0.23ab	0.43a	2.2ab	28.1b
Damage treatment									
Undamaged	85a	8.5a	1.4a	26.7a	1.9a	0.28a	0.57a	2.8a	23.4a
Scraped	75ab	7.4a	1.1a	25.0a	1.7a	0.22a	0.42a	2.3a	20.8a
Crushed	55b	7.2a	1.1a	24.3a	1.7a	0.25a	0.52a	2.5a	23.8a
P-value from ANOVA									
Inoculation	0.01	0.07	0.27	0.09	0.01	0.04	0.01	0.05	0.55
Damage	0.03	0.16	0.15	0.58	0.41	0.24	0.08	0.28	0.85
IN x Damage	0.35	0.92	0.94	0.04	0.32	0.01	0.05	0.15	0.49

[z] Least squares means within columns for inoculation treatments and soil types followed by common letters do not differ at the 5% level, by PDIFF.

[y] The percentage of structural roots with lesions.

(Demchak, 2013). Hagerstown-1 loam had high clay content which may have restricted water availability and nutrient uptake. Plants grown in the Hagerstown-2 and sandy loams had more growth than plants grown in the Hagerstown-1 loam. Salt levels in the Hagerstown-2 loam were much higher than other soil types; however, no marginal necrosis from salt injury was observed. Strawberry plants are very sensitive to high salt levels (Kaya et al., 2002) and had reduced growth when electrical conductivity was above 1.0 $dS \cdot m^{-1}$ (Maas, 1985). Salt levels may have decreased over the course of the experiment due to leaching following watering. Wing et al. (1995) also found that soil characteristics such as high clay and silt content and soil compaction were correlated with poor root health whereas well drained, sandy soils were correlated with healthy roots.

Compost is often used in strawberry plantings to achieve soil organic matter of two to six percent depending upon the soil type (Demchak, 2013). In experiment 2, plant dry mass decreased linearly with increasing compost rate. These results are similar to those of Viator et al. (2002) who found that, in sugar cane, compost applied in the root zone reduced root surface area as compared to application in the row middle. Negative responses of plants to high compost levels may be due to N immobilization, allelopathic chemicals, high salt content, high pH, or toxic metabolites from anaerobic interactions (Hoitink and Kuter, 1986) or residual effects from compost components.

In experiment 3, plants inoculated with PA-A, CT-A, and CT-G had higher leaf and crown numbers and dry mass than control and PA-G inoculated plants. These results confirm results reported by Martin (1988) where *R. fragariae* isolates from CT increased plant growth. Ribeiro and Black (1971) also reported that *R. fragariae* was mycorrhizal and increased plant growth but also caused disease symptoms on strawberry.

Structural root number was also significantly higher in experiments 2 and 3 when plants were inoculated. Inoculation with *R. fragariae* may support above ground growth by serving as fine roots in the soil. In other agricultural systems, beneficial fungi absorb immobile nutrients in the soil, such as phosphorus, more readily due to the amount of hyphae in the soil. Hyphae then transport these nutrients into root tissue in exchange for plant carbohydrates (Jeffries and Rhodes, 1987; Bethlenfalvay and Schüepp, 1994).

In our experiment, the exchange of nutrients may have had a greater benefit to plant tissues than reduction of carbohydrates if this interaction occurred.

The percentage of structural roots with lesions was not significantly different among inoculation treatments in experiments 1 and 2. This suggests that the *R. fragariae* isolates used in this study may not significantly impact BRR symptom development. The effect of *R. fragariae* may depend on soil type. In preliminary experiments, inoculated plants did not develop root lesions when plants were grown in sand or peat-based potting media. In experiment 1, plants grown in the sandy loam had fewer lesions possibly due to improved water drainage or increased pore space. Well drained soils are recommended for many agricultural systems and commonly result in less disease development as compared to poorly drained soils (Nelson and Wilhelm, 1981). There was also a negative linear relationship between compost level and lesion development. High levels of compost may have suppressed the relationship of *R. fragariae* with strawberry roots by creating an unfavorable environment for infection or by blocking allelochemical signals used for communication (Bethlenfalvay and Schüepp, 1994). It is also important to note that control plants exhibited lesion development. This may be due to the presence of fungi in nursery stock which was observed in strawberry plants from previous experiments (Lavely, 2013).

When roots were injured, overall growth was reduced and many plants died. Disruption of the rhizoderm and vascular tissue could inhibit water and nutrient flow into root tissue and allow carbohydrate leakage resulting in suppressed plant growth. Experiment 3 suggests that some strains of *R. fragariae* may allow strawberry plants to tolerate root injury. *R. fragariae* could stimulate root growth (Martin, 1988; Ribiero and Black, 1971) or initially provide the roots with water and nutrients needed for growth through hyphal interactions.

These results confirm that sandy loam or soils with good drainage are beneficial for strawberry growth and suppress root lesion development following inoculation with *R. fragariae*. Also, compost levels higher than 10% may be detrimental to plant growth and a lower rate should be used for strawberry. When handling plants, it is best to prevent any root injury, particularly crushing roots, before planting. If *R. fragariae* is present in root tissue at planting, root injury may not adversely affect strawberry plant growth.

Results from these experiments indicate that some isolates *R. fragariae* may be beneficial to strawberry plants in some situations. In future experiments, rates of compost below 10% should be used to determine an optimal rate that supports plant vigor and provides sufficient organic matter to increase soil quality. The affects of soil properties and *R. fragariae* inoculation on root health, BRR symptom development, and yield requires further investigation. Inoculation and co-inoculation experiments with other pathogenic fungi, such as *Pythium* spp. or *Fusarium* spp. are needed to determine the role of these fungi in the development of BRR symptoms and growth reduction in strawberry.

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