The Influence of Mineral Nutrition on Strawberry Black Root Rot[1]

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Abstract: Our objective was to identify fertilization regimes that may suppress black root rot of strawberry, incited by the fungus, *Rhizoctonia fragariae,* and lesion nematodes, *Pratylenchus penetrans.* 'Honeoye' strawberry crowns were planted at Hamden, and Windsor, CT in soil naturally infested with both pathogens. Fertilization treatments included $Ca(NO_3)_2$ or $(NH_4)_2SO_4$ (112 kg N/ha) and supplemented with KCl, $CaCl_2$, K_2SO_4 or $CaSO_4$ combined with and without a granular slow-release micronutrient product in a 2 X 4 X 2 factorial design with four replicate plots. Compared to $Ca(NO_3)_2$, plots that were fertilized with $(NH_4)_2SO_4$ had 9 or 10% less black root rot and yielded 12 or 13% more berries in Hamden or Windsor, respectively. Root densities of lesion nematodes were not affected by the nitrogen fertilizers. The inclusion of the K and Ca salts and the micronutrients did not consistently affect disease or berry yield. Tissue analyses revealed that $(NH_4)_2SO_4$-treated plots had more N and Mn per g dry leaf than plants treated with $Ca(No_3)_2$. Fertilization with $(NH_4)_2SO_4$ may be useful in management of black root rot.

Introduction

Black root rot is the major root disease of strawberry and a threat to the industry in North America. This disease causes root death and reduces plant vigor, productivity and winter survival (5,6,23,37). Disease severity and damage increase with the age of planting. Cultivars may vary in resistance to black root rot, but all known cultivars are susceptible (4).

Species of binucleate *Rhizoctonia* spp. [*Rhizoctonia fragariae* Hussain and McKeen (18)] in anastomosis groups AG-A, AG-G, and AG-I (27) were found in Connecticut to be the primary pathogens of the disease complex (24). Other fungi, such as *Pythium* spp., *Cylindrocarpon* spp., *Fusarium* spp., and *Idriella* spp., have also been implicated in the disease complex (5,6,23,37,40). Additionally, lesion nematodes (*Pratylenchus penetrans* (Cobb) Filip. & Shur.Stek) were shown to independently produce symptoms of black root rot (3,5,11,12,21,30,36), and can interact with *R. fragariae* and cause more damage than with either organism alone (21).

Recommendations for growers with black root rot are to avoid heavy wet compacted soils, to pre-plant fumigate their soils, and to follow two-year rotations with cereals (5,29). However, these practices often do not suppress black root rot, in part, because these practices can not be applied to the established perennial planting when disease symptoms appear. While pre-plant fumigation provides multiple pest control (38,40), it often provides black root rot suppression for only the first year and may even result in higher levels of black root rot in later years than in fields that were not fumigated (23). More importantly, the impending loss of fumigants, such as methyl bromide (22), have further reduced options for short term suppression. Recent findings have also shown that certain rotation crops that have been recommended in strawberry culture may not lower pathogen levels or disease severity (19).

Our attempts to reduce black root rot with chitin amendments (20) or to induce resistance to black root rot with chitosan treatments (10) have been ineffective in field studies. Thus, existing cultural practices need to be reassessed for their influence on strawberry black root rot so an integrated management approach can be implemented.

It is well known that the nutritional status of a plant directly influences its susceptibility to disease (14,16,17). While there have been reviews on the nutritional requirements of strawberries (25), information on how strawberry nutrition influences susceptibility or resistance to black root rot is not known. Our objectives were to evaluate the nitrogen fertilization effects of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on black root rot, yield and mineral composition of strawberry in the field. Since the companion ions SO_4^{-2} and Ca^{+2} may also influence disease, different salts that contained Ca, K, Cl, and SO_4 were also studied so their individual and combined effects could be detected. Accordingly, the contribution of the micronutrient supplements on strawberry growth and disease was also included for study.

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Materials and methods

Plot Establishment and Fertilizer Treatments.

Two strawberry plantings were established. In May 1992, plots that were 3.1 m long and 0.9 m apart were prepared in Hamden, CT (Cheshire fine sandy loam, pH = 6.2) and planted with ten 1-yr-old crowns of black root rot susceptible 'Honeoye' strawberries (Nourse Farms, South Deerfield, MA) that were spaced 0.3 m apart. The other planting was established in May 1993 at Windsor, CT (Wethersfield fine loamy sand pH = 6.1) and contained plots that were 1.9 m long and spaced 0.9 m apart and contained six 'Honeoye' crowns/row that were spaced 0.3 m apart. Both sites had previously been cropped to strawberry more than 3 years and had severe black root rot the previous year.

One month after planting, nitrogen fertilizers, $Ca(NO_3)_2$ or $(NH_4)_2SO_4$ (112 kg N/ha), were combined with one of four Ca or K salts, KCl, $CaCl_2$, K_2SO_4 and $CaSO_4$, and supplemented with a granular slow release application of micronutrients (Esmigran, Grace Sierra, Milpitas, CA) applied at 100 kg/ha, or no micronutrient treatment. Therefore, at both sites a 2 X 4 X 2 factorial experiment was designed with four blocks (16 treatments, one replicate/block). In Hamden, the K and Ca salts were applied at 56 kg/ha, but in the Windsor planting, the Ca or K salts were adjusted to standardize the concentrations of K^+ at 33 kg/ha, Cl^- at 22 kg/ha, Ca^{2+} at 10 kg/ha, and S at 14 kg/ha so the actual amounts of KCl, $CaCl_2$, K_2SO_4 or $CaSO_4$ applied was at 55, 35, 75, and 39 kg/ha, respectively. To balance the amount of sulfur, 5 kg/ha of elemental S was added to the $CaSO_4$ treatment. Each year in both fields the fertilizers were applied in two applications. In the first year half was applied one month after planting, and the other half was applied in early August. In the following year 70% of the total amount was applied following harvest in July at renovation, and the remainder was applied in late August.

To stabilize the ammonium forms of nitrogen and to prevent microbial conversion to nitrate, nitrapyrin (N-Serve 24E, DowElanco, Indianapolis, IN) was applied to the Hamden planting after the fertilizers were broadcast in 1992 at the recommended rate of 2.5 l/ha. No nitrapyrin was applied to the Windsor plots. Due to a poor stand resulting from a May drought and heavy rains in early June, the Hamden field was re-planted with new crowns on 10 June 1992, and one half of the fertilizer treatments were applied again.

Based on soil analyses and fertilizer recommendations, 20 kg of P/ha was uniformly applied at planting in Hamden, whereas 45 kg of P/ha was applied at Windsor. Napropamide herbicide (as Devrinol 50WP) was applied in late June at 8.8 kg/ha. Grey mold fungicides were not required in 1993, but vinclozolin (as Ronilan 50WP) was applied in 1994 at 10% bloom, and captan (as Captan 50WP) was applied at 90% bloom. Azinphos-methyl (as Guthion 35WP) was applied once following harvest to suppress insects.

Plant and Yield Measurements:

Flowers were removed from plants at both sites during the first year. Leaf area per plant was recorded 2–5 July 1992 at Hamden and 22 July 1993 at Windsor by measuring the length (L) and width (W) of the center leaflet of every expanded leaf of every plant in the row. Leaf area was estimated using the equation, LA = 3.02 + 1.77 L X W, and was expressed as total leaf area (dm^2) per plant. This equation was generated by regressing the products of the lengths and widths from 84 'Honeoye' strawberry leaves against their leaf areas (r^2 = 0.98) which were determined on a leaf area meter (Delta-T Devices, Pullman, WA).

At Hamden in August 1992, two plants were randomly dug and removed from each plot. Soil adhering to the roots was shaken loose, and its pH was determined. Roots were washed and then rated for the percentage of black root rot by the line intersect method (21,34), or by visual estimation. *Pratylenchus penetrans* juveniles and adults were recovered from roots by agitating 3 g of roots in 25 ml water for 5 days, and collecting the nematodes, and then agitating the roots for another 5 days and collecting again (2). Leaves were separated from the crowns, washed in deionized water, dried, and ground in a Wiley mill to pass through a 1 mm sieve. The ground leaf samples were analyzed for mineral composition as described below. During late October, the total number of stolons produced per plant during the season was recorded by counting the number of cut ends present on each plant and expressed as total number of runners per plant. In Windsor, one plant per plot was destructively sampled in late September 1993 and processed as above for mineral composition. Berries were harvested, counted and weighed every four to five days in 1993 at Hamden and every three days in 1994 at Windsor.

Tissue analyses.

Two leaf tissue subsamples (0.5 g) were digested in H_2SO_4 and analyzed colorimetrically for total N by the Nestler reaction and P by reaction in molybdate (15). Potassium, Mg, Mn, Zn, Cu, and Fe were analyzed by inductively coupled plasma emission (ICP) spectroscopy on an ARL 3520 ICP-OES spectrophotometer (Fison Instruments, Deerborn, MI). Free chlorides were detected by ion exchange chromatography on a Dionex 2010i ion detector (Dionex Corp. Sunnyvale, CA). Mineral concentrations are expressed as µMol/g tissue. Problems in this digestion procedure prevented us from measuring Ca, B, and S concentrations so these elements were not compared in this study. The leaf tissue from plots in Windsor was analyzed for N and P as described before, but in this study the tissue was digested in HNO_3 and HCl in a CEM MDS 81D microwave (CEM Co., Matthews, NC), and analyzed for B, Ca, Cu, Fe, K, Mg, Mn, S, and Zn by ICP spec-

Table 1. Effect of different fertilizer combinations on growth and yield of 'Honeoye' strawberries, populations of Pratylenchus penetrans, and black root rot severity in Hamden, CT in a sandy loam soil during 1992–1993.

Treatments[a] N	S	leaf area (dm²)[b] 7 Jul	9 Aug	No Run.	P. pen. Soil	P. pen. Root	Root[d] Length (m)	%[d] Black RR	1993 Yield t/ha
$(NH_4)_2SO_4$	KCl	1.27[e]	5.24	7.1	5	34	14.6	45	12.1
$(NH_4)_2SO_4$	$CaCl_2$	1.30	5.90	6.7	8	20	18.0	41	13.4
$(NH_4)_2SO_4$	K_2SO_4	1.30	5.40	6.3	4	19	17.2	38	12.4
$(NH_4)_2SO_4$	$CaSO_4$	1.37	4.63	8.0	6	6	16.1	54	14.8
$Ca(NO_3)_2$	KCl	1.13	4.43	5.5	7	6	14.8	55	11.8
$Ca(NO_3)_2$	$CaCl_2$	1.19	4.60	5.3	2	3	12.0	47	11.8
$Ca(NO_3)_2$	K_2SO_4	1.29	5.71	6.4	8	22	13.9	63	12.4
$Ca(NO_3)_2$	$CaSO_4$	1.27	4.70	5.1	7	65	12.9	55	11.3
Averaging over the K/Ca salts									
$(NH_4)_2SO_4$		1.31	5.29	7.0	6	19.8	16.5	44	13.2
$Ca(NO_3)_2$		1.22	4.86	5.6	6	24.0	13.4	55	11.8
Analysis of variance									
N-form (N)		0.050	ns[f]	0.044	-[g]	ns	0.030	0.020	0.055
N X M[h]		ns	0.048	ns	-	ns	ns	ns	ns
All other interactions had P >0.10									

[a] Treatments N = N-form [$(NH_4)_2SO_4$ or $Ca(NO_3)^2$], M = micronutrients added as a slow release formulation, S = K or Ca salts.

[b] Leaf area per plant was estimated by totaling the sum from the products of lengths (L) and widths (W) of center leaflets and used in the equation 3.02 + 1.77 (L X W).

[c] Numbers of adults and juveniles of *Pratylenchus penetrans* extracted from roots and soil in August 1992.

[d] Total root lengths and the percent black root rot were determined in August using line intersect method (34).

[e] Values represent the means of four replicates.

[f] ns = P >0.10.

[g] Parametric statistics could not be performed on these variables.

[h] Micronutrient data are not presented.

troscopy (9,15). An analysis of variance was used to detect treatment interactions and/or main effects on pathogen populations, disease levels, plant growth and yield.

Results

The most noticeable response to any treatment at the Hamden planting was the 7–9% increase in leaf area throughout July and August and the 25% increase in runners in $(NH_4)_2SO_4$-fertilized plots compared to $Ca(NO_3)_2$-fertilized plots (Table 1). The increased vigor in $(NH_4)_2SO_4$-fertilized plots was apparent the next spring with a 12% increase in berry yield. Ammonium sulfate-treated plots had more healthy feeder roots and a 10% reduction in the amount of black root rot. The root densities of lesion nematodes were not affected by fertilizers. There were no significant effects from the K or Ca salts when evaluated individually or in combination. Likewise, the inclusion of micronutrients had no significant effect on yield, growth, or the black root rot disease and are not presented.

Table 2. Effect of different fertilizer combinations on growth and yield of 'Honeoye' strawberries, populations of Pratylenchus penetrans, and black root rot severity in Windsor, CT on a sandy loam soil during 1993–1994.

Treatments[a] N	S	leaf area (dm²)[b] 7 Jul	9 Aug	No Run.	P. pen. Soil	P. pen. Root	Root[d] Length (m)	%[d] Black RR	19934 Yield t/ha
$(NH_4)_2SO_4$	KCl	5.0[e]	8.9	10		89	14.8	56	15.9
$(NH_4)_2SO_4$	$CaCl_2$	4.8	8.7	8		28	16.0	43	14.7
$(NH_4)_2SO_4$	K_2SO_4	5.4	8.8	8		154	12.1	49	15.7
$(NH_4)_2SO_4$	$CaSO_4$	4.9	10.2	7		67	15.2	45	18.2
$Ca(NO_3)_2$	KCl	5.2	11.9	9		110	9.8	50	14.7
$Ca(NO_3)_2$	$CaCl_2$	5.1	7.9	7		21	14.1	49	13.3
$Ca(NO_3)_2$	K_2SO_4	5.6	9.7	8		50	16.4	57	14.7
$Ca(NO_3)_2$	$CaSO_4$	4.8	10.8	10		164	11.9	73	14.2
Averaging over the K/Ca salts									
$(NH_4)_2SO_4$		5.0	9.2	8		85	14.5	48	16.1
$Ca(NO_3)^2$		5.2	10.1	9		86	13.1	57	14.2
Averaging over the N-form									
KCl		5.1	10.3	9		100	12.3	53	15.3
$CaCl_2$		5.0	8.3	7		24	15.0	46	14.0
K_2SO_4		5.5	9.2	8		105	14.2	53	15.2
$Ca(SO_4)$		4.9	10.5	9		115	13.6	59	16.2
Analysis of variance									
N-form (N)		ns[f]	ns	ns		ns	ns	0.063	0.025
Salt (S)		ns	ns	0.087		ns	ns	0.012	ns
N X S		ns	ns	ns		ns	ns	0.012	ns
N X S X M[g]		ns	ns	0.019		ns	ns	ns	ns
Orthogonal contrasts (P)									
Cl salts vs non-Cl salts		ns	ns	ns		ns	ns	0.007	ns

[a] Treatments N = N-form [$(NH_4)_2SO_4$ or $Ca(NO_3)_2$], M = micronutrients added as a slow release formulation, S = K or Ca salts.

[b] Leaf area per plant estimated from the products of lengths (L) and widths (W) of center leaflets and used in the equation 3.02 + 1.77 (L X W).

[c] Numbers of adults and juveniles of *Pratylenchus penetrans* extracted from roots.

[d] Total root length and the percent black root rot were determined using line intersect method (34).

[e] Values represent the means of four replicates.

[f] ns = P > 0.10.

[g] Micronutrient data are not presented.

In Windsor, black root rot severity in the $(NH_4)_2SO_4$-fertilized plots was marginally reduced by 9% when compared to $Ca(NO_3)_2$-fertilized plots, but the $(NH_4)_2SO_4$-fertilized plots also produced almost 2.0 t/ha more berries (a 13% increase) than plots fertilized with $Ca(NO_3)_2$ (Table 2). Applications of the K and Ca salts or micronutrient treatments had no effect on strawberry growth or yield, and the micronutrient data were not presented. Significantly more lesion nematodes were recovered from the roots at Windsor (Table 2) than at Hamden (Table 1), but the nematode densities were not affected by the fertilizer treatments.

The mineral concentrations in the leaves at Hamden were affected by the nitrogen fertilizer and K and Ca salt treatments (Table 3). Compared to $Ca(NO_3)_2$ treatment, $(NH_4)_2SO_4$ increased the leaf concentrations of N, Cl, and Mn, while it decreased the levels of P, K, Fe, and Cu; levels of Mg and Zn were not affected (Table 3). The major effect from the K and Ca salts were from the Cl-containing salts which increased N, Cl, and Mn concentrations more than the non Cl-containing salts. There were no effects from the K, Ca, or S amendments. The micronutrient treatment had no significant effect on the mineral composition of leaves, but when the micronutrients were combined with $(NH_4)_2SO_4$, there was an increase in N, Cl, and Mn levels compared to the $Ca(NO_3)_2$ treatment. When micronutrients were combined with the Cl-containing salts, there was an increase in *P* compared to salts not containing Cl.

The percentage of roots with black root rot was positively correlated with K levels ($r = 0.62$, $P = 0.01$), but black root rot decreased as the levels of N and Mn in the leaves increased ($r = -0.57$, $P = 0.04$; $r = -0.64$, $P = 0.008$, respectively). Root lengths were similarly affected.

In Windsor, leaves from plots treated with $(NH_4)_2SO_4$ had more N, P, K, S, and Mn and less Ca than plants fertilized with $Ca(NO_3)_2$; levels of Mg, Cl, Fe, B, Zn and Cu were not affected (Table 4). Leaf concentrations of Cl were increased by Cl-containing salts when compared to non Cl-containing salts. Micronutrient applications had no main or interaction effect. There were similar trends between the Windsor planting and the Hamden planting in relation to the percentage of black root rot and the tissue levels of N, K, and Mn, but the correlation coefficients were not significant.

Discussion

The results of these field studies suggest that fertilization with $(NH_4)_2SO_4$ is suppressive to black root rot compared to $Ca(NO_3)_2$ fertilization. However, the severity of black root rot in first year plantings is usually low compared to older fields (37), and information on how $(NH_4)_2SO_4$ fertilization effects the longevity of the planting is still not clear, but badly needed. Strawberry growers commonly apply nitrogen either as urea, calcium nitrate or in an ammonium form, and their choice is usually based on cost, availability, and/or soil pH management (5). The optimal soil pH for strawberries is in the range of 5.8-6.2, (5,25), but this may vary depending the on soil type. Applications of ammonium fertilizers tend to acidify soil pH faster than nitrate forms of nitrogen (5,16), we found a 0.5-0.6 unit faster decrease in the soil pH from the rhizosphere of $(NH_4)_2SO_4$-treated plants when compared to $Ca(NO_3)_2$ (W. H. Elmer, unpublished data). Liming may deserve more attention under ammoniacal fertilization regimes. We suggest that black root rot management should be considered when deciding on nitrogen fertilizer.

Table 3. Effect of different fertilizer combinations on mineral composition of strawberry in Hamden, CT in 1992.

Treatments[a]			N	µMol per/g dry tissue							
N	M	S	mMol	P	K	Cl	Mg	Fe	Mn	Zn	Cu
$(NH_4)_2SO_4$	-	KCl	1.7[b]	363	488	68.1	146	29	5	0.26	0.17
$(NH_4)_2SO_4$	-	CaCl	1.6	366	438	62.5	160	36	5	0.31	0.19
$(NH_4)_2SO_4$	-	K_2SO_4	1.6	382	445	49.6	150	27	4	0.26	0.15
$(NH_4)_2SO_4$	-	$CaSO_4$	1.6	405	474	62.6	142	11	4	0.44	0.15
$(NH_4)_2SO_4$	+	KCl	1.7	386	473	68.6	154	24	5	0.52	0.18
$(NH_4)_2SO_4$	+	$CaCl_2$	1.7	343	421	93.2	151	20	7	0.45	0.16
$(NH_4)_2SO_4$	+	K_2SO_4	1.7	382	482	71.0	154	30	5	0.52	0.17
$(NH_4)_2SO_4$	+	$CaSO_4$	1.6	400	497	67.1	154	31	5	0.39	0.17
$Ca(NO_3)_2$	-	KCl	1.6	449	508	70.3	147	41	3	0.32	0.28
$Ca(NO_3)_2$	-	$CaCl_2$	1.6	481	565	68.1	140	24	2	0.77	0.24
$Ca(NO_3)_2$	-	K_2SO_4	1.5	434	577	47.9	135	19	2	0.38	0.18
$Ca(NO_3)_2$	-	$CaSO_4$	1.5	439	534	42.4	139	36	3	0.25	0.24
$Ca(NO_3)_2$	+	KCl	1.5	493	568	48.1	141	26	2	0.58	0.23
$Ca(NO_3)_2$	+	$CaCl_2$	1.5	459	514	45.3	144	41	3	0.35	0.25
$Ca(NO_3)_2$	+	K_2SO_4	1.4	452	557	37.8	138	33	2	0.26	0.23
$Ca(NO_3)_2$	+	$CaSO_4$	1.5	445	518	29.7	146	38	2	0.40	0.24

Analysis of variance *(P)*	N	P	K	Cl	Mg	Fe	Mn	Zn	Cu
N-form(N)	<0.001	<0.001	<0.001	<0.001	ns[c]	0.007	<0.001	ns	<0.001
Salt (S)	0.033	ns	ns	0.003	ns	ns	0.004	ns	ns
N X Micro	0.017	ns	ns	0.001	ns	ns	0.015	ns	ns
N X S	ns	<0.001	ns	ns	ns	0.032	0.02	ns	ns
M X S	ns	0.014	ns	ns	ns	0.008	ns	ns	ns
N X M X S	ns	ns	ns	ns	ns	0.001	ns	0.044	ns

Orthogonal contrasts(P)	N	P	K	Cl	Mg	Fe	Mn	Zn	Cu
Cl salts vs non-Cl salts	0.006	—	—	<0.001	—	—	0.001	—	—

[a] Treatments N = N-form [$(NH_4)_2SO_4$ or $Ca(NO_3)_2$], M = micronutrients added as a slow release formulation, S = K or Ca salts.

[b] Values represent the means of four replicates.

[c] ns = $P > 0.10$.

Black root rot suppression with $(NH_4)_2SO_4$, compared to $Ca(NO_3)_2$, is in contrast to reports that root diseases of other crops caused by presumably multinucleate *Rhizoctonia* spp., *Pythium* spp. and *Fusarium* spp. were suppressed by NO_3-N and enhanced by NH_4-N (1,16,28). The lack of agreement between these reports and the current study may be because earlier work on these diseases were conducted on seedlings of annual plants, thus, the possibility of phytotoxicity caused by the ammonium would be more likely to occur than with one year old strawberry crowns. Our results may also differ because in our study black root rot was caused by a disease complex dominated primarily by *R. fragariae* and lesion nematodes. The inclusion of the migratory endoparasite, *P. penetrans,* into this complex may be the reason for the varying reaction of the disease to fertilizers, but this has not been documented. Although there was no trend between the ameliorating effects of $(NH_4)_2SO_4$ versus $Ca(NO_3)_2$ with nematode densities in the roots, nematode densities are commonly higher in roots of healthy than in diseased

Table 4. Effect of different fertilizer combinations on mineral composition of strawberry in Windsor, CT in 1993.

Treatments[a]			N	µMol per/g tissue										
N	M	S	mMol	P	K	Ca	Mg	Cl	S	Fe	Mn	B	Zn	Cu
$(NH_4)_2SO_4$	-	KCl	1.2[b]	88	334	285	178	76	53	15	6	2	0.3	0.13
$(NH_4)_2SO_4$	-	$CaCl_2$	1.0	78	267	280	178	91	48	12	3	2	0.3	0.11
$(NH_4)_2SO_4$	-	K_2SO_4	1.1	74	270	266	175	14	53	9	3	2	0.3	0.11
$(NH_4)_2SO_4$	-	$CaSO_4$	1.1	82	268	301	189	26	52	10	4	2	0.3	0.11
$(NH_4)_2SO_4$	+	KCl	1.0	76	290	285	170	65	53	11	5	2	0.3	0.13
$(NH_4)_2SO_4$	+	$CaCl_2$	1.1	79	269	316	199	87	52	10	6	2	0.3	0.12
$(NH_4)_2SO_4$	+	K_2SO_4	1.0	80	263	282	195	46	53	10	3	2	0.3	0.12
$(NH_4)_2SO_4$	+	$CaSO_4$	1.1	83	345	253	177	35	53	8	3	2	0.3	0.11
$Ca(NO_3)_2$	-	KCl	1.1	76	285	315	174	55	50	10	3	2	0.3	0.11
$Ca(NO_3)_2$	-	$CaCl_2$	0.9	74	244	314	189	23	47	12	3	2	0.3	0.11
$Ca(NO_3)_2$	-	K_2SO_4	1.0	76	290	291	186	43	51	11	2	2	0.3	0.12
$Ca(NO_3)_2$	-	$CaSO_4$	1.0	68	251	318	176	10	48	15	3	2	0.3	0.12
$Ca(NO_3)_2$	+	KCl	1.0	74	255	306	187	67	51	10	3	2	0.3	0.11
$Ca(NO_3)_2$	+	$CaCl_2$	1.1	81	279	300	187	45	52	8	3	2	0.3	0.13
$Ca(NO_3)_2$	+	K_2SO_4	1.0	67	239	319	211	59	49	9	2	2	0.3	0.11
$Ca(NO_3)_2$	+	$CaSO_4$	0.9	44	248	295	185	22	49	8	2	2	0.2	0.10

Analysis of variance (P)

	N	P	K	Ca	Mg	Cl	S	Fe	Mn	B	Zn	Cu
N-form (N)	0.003	0.002	0.034	0.028	ns[c]	ns	0.036	ns	0.010	ns	ns	ns
Salt (S)	ns	ns	ns	ns	ns	0.037	ns	ns	ns	ns	ns	ns

All other interactions were not significant.

[a] Treatments N = N-form [$(NH_4)_2SO_4$ or $Ca(NO_3)_2$], M = micronutrients added as a slow release formulation, S = K or Ca salts.
[b] Values represent the means of four replicates.

plants at the end of the season. The role of nitrogen fertilizers on the dynamics of nematode populations deserves study.

We saw in both sites that suppression of strawberry black root rot was associated with the amount of N and Mn in the leaf, and these levels were greatest in the $(NH_4)_2SO_4$ treatment. Ammonium fertilization is reported to increase N and Mn availability more so than other nutrients (9,16,17).

The increased nitrogen level in plants treated with $(NH_4)_2SO_4$ is believed due to the more rapid assimilation of ammonium ions into amino acids than what would occur with nitrates (16). Nitrates must be absorbed and enzymatically reduced prior to being incorporated into metabolites. In addition, the potential for greater leaching of NO_3^- compared to NH_4^+ from the root zone may have lowered the available N in the $Ca(NO_3)_2^-$treated plants. Levels between 1.4-2.0 mMol/g leaf (2.2–2.8%) are considered sufficient following renovation (25). We sampled 1 to 2 months after renovation and found between 1.4–1.7 mMol/g N (2.2–2.4% N) in Hamden and 0.9–1.2 mMol/g N (1.3–1.7% N) in Windsor. Greater leaching of N in the more sandy soils at Windsor may explain why these plants had less N and other nutrients than at Hamden. Nevertheless, at each site greater yield and less disease were associated with plants with higher N levels in the leaf.

Manganese has been reported to be associated with suppression of *Rhizoctonia* diseases of cereals (14,26), cotton (33), and legumes (35). Strawberry leaves are reported to contain between 1.0 and 4.0 µMol/g of Mn (25), and in the current study, we found levels of *up to* 6.0–7.0 µMol/g of Mn. The higher levels of Mn were associated with plants that had less black root rot than in plants which had levels of 2.0–3.0 µMoles of Mn. Increased Mn availability can result from the acidification of the rhizosphere and from Mn-transforming microbes, of which both are increased by ammonium nutrition (17). It is not known if Mn had a direct role in strawberry disease resistance or is merely present as a result of these factors. In other plants, Mn has been shown to be associated in host defense mechanisms through its role as an activator of enzymes in phenol metabolism (17).

The salts that contained Cl were associated with disease suppression in Windsor, but the reduction was not significant in Hamden. Chloride has been implicated in suppression of other soilborne diseases (7,8,13,14,31,32,39), and may also affect disease by influencing the resistance of the host. Chlorides act as nitrification inhibitors which prevent the conversion of ammonium to nitrate, thus, stabilizing ammonium and increasing N and Mn availability (17). Given the observation that disease was suppressed in plants containing higher levels of N and Mn, it may not be surprising that Cl-containing salts tended to suppress black root rot.

In summary, it should be stressed that although $(NH_4)_2SO_4$ was superior to $Ca(NO_3)_2$ in two sites on different soil types, the pathogen components of the black root rot complex may shift to different proportions as reported in areas outside of the Northeastern U.S. (40), and these fertilizers may have different effects. Our findings, however, provide persuasive evidence that black root rot severity can be manipulated through strawberry nutrition.

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