Influence of Chloride and Nitrogen Form on Rhizoctonia Root and Crown Rot of Table Beets

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ABSTRACT

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The effect of NaCl combined with $\text{Ca}(\text{NO}_3)_2$ or $(\text{NH}_4)_2\text{SO}_4$ was examined on table beets (*Beta vulgaris*) in the presence and absence of *Rhizoctonia solani* (anastomosis group 2-2), the cause of Rhizoctonia root and crown rot. Transplants of cvs. Detroit Dark Red and Early Wonder grown in the greenhouse in infested soils and fertilized with $\text{Ca}(\text{NO}_3)_2$ (10 mmol of N) were 32% larger in dry weight than plants treated with $(\text{NH}_4)_2\text{SO}_4$ (10 mmol of N). In noninfested soils, a 17% increase in dry weights was observed for plants treated with $\text{Ca}(\text{NO}_3)_2$ compared to plants that were fed $(\text{NH}_4)_2\text{SO}_4$. When NaCl (0.17 mmol) was applied, the mean dry weights increased 40% in noninfested soil and 12% in infested soil compared to plants that received no NaCl. No significant interaction occurred between N fertilizer and NaCl in greenhouse trials. However, in field soils infested with *R. solani*, NaCl (560 kg/ha) combined with $(\text{NH}_4)_2\text{SO}_4$ (112 kg of N per ha) produced 26 to 47% more root yield than when $(\text{NH}_4)_2\text{SO}_4$ was used alone. In the absence of NaCl, $\text{Ca}(\text{NO}_3)_2$ suppressed disease more than $(\text{NH}_4)_2\text{SO}_4$, but adding NaCl to $\text{Ca}(\text{NO}_3)_2$ did not increase yield more than $\text{Ca}(\text{NO}_3)_2$ alone. The Cl salts KCl, CaCl_2 , and MgCl_2 did not significantly differ from NaCl in their ability to increase the dry weight of beets grown in infested soils. Leaf and root analyses revealed that $(\text{NH}_4)_2\text{SO}_4$ applications increased N, P, S, and Mn in tissue more than $\text{Ca}(\text{NO}_3)_2$ applications. Applying NaCl increased tissue levels of Na, Cl, and Mn more than in plants that were not fed NaCl. All of the Cl salts had the effect of increasing concentrations of Cl and Mn in the plant. There was no evidence that the Na ion was disease suppressive. Chloride, however, may be of use in disease management of Rhizoctonia root and crown rot of table beets.

Rhizoctonia solani Kühn, the anamorph of *Thanatephorus cucumeris* (A.B. Frank) Donk, has become a destructive pathogen of table beets (*Beta vulgaris* L.) in the northeastern United States (1,25). Beet plants can be infected at any time during the production cycle, and all tissues are susceptible to *R. solani*. Symptoms of damping-off, root and crown rot, dry rot cankers, and a foliage blight known as pocket rot syndrome all are caused by *R. solani* (1, 25,33). Control of *R. solani* on table beets has been extremely difficult because no highly resistant cultivars are available, and effective chemicals have not been cleared for use on table beets. The threat to beet production also increased with the discovery that the teleomorph, *T. cucumeris*, is contributing wind-blown inoculum in the form of basidiospores (2).

Although it is well documented that the nutritional status of a plant can influence its susceptibility to disease (4,11,12,19), manipulating fertilizers as a strategy for managing disease has not gained wide ac-

ceptance. This may be due to a lack of understanding of which fertilizers are suppressive to disease and to inconsistent responses from year to year. The failure of certain fertilizers to affect disease also may be due to a lack of understanding of how fertilizers affect the uptake and distribution of other elements that may be more crucial in disease suppression.

B. vulgaris is very tolerant of saline conditions (33), and single applications of NaCl improve growth and yield in both sugar and table beets (6,15). Hammer and Beene (15) found that when using muck soils in Michigan adding NaCl with KCl stimulated growth and yield of beets and Swiss chard. Durrant et al. (6) found NaCl increased leaf area and sugar beet yield and was most effective during periods of drought. In New York State, applications of NaCl at 560 kg/ha once were recommended in beet production to enhance growth and suppress weeds (G. Abawi, *personal communication*).

Greenhouse studies have shown that beet seedlings were more susceptible to disease by *R. solani* when treated with $\text{NH}_4\text{-N}$ as opposed to $\text{NO}_3\text{-N}$ (4). However, conditions in the field may differ enough to question whether these N fertilizers would differ in their effect on Rhizoctonia root and crown rot of table beets.

A combination of chloride salts with different forms of nitrogen has proven sup-

pressive to root diseases on asparagus (7), celery (29), and several grain crops (18). The combined effects of chloride and N form on *R. solani* on beets needs to be examined. The objective of this paper was to compare the combined effects of NaCl and $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ on growth, disease, and mineral composition of table beets. A second objective was to compare different sources of chloride salts.

MATERIALS AND METHODS

Greenhouse studies. A highly pathogenic isolate of *R. solani* (anastomosis group 2-2) was obtained from the USDA Sugar Beet Laboratory, Michigan State University, East Lansing. Millet inoculum was prepared by autoclaving 100 g of Japanese millet with 100 ml of distilled H_2O in 1-liter flasks for 1 h on two consecutive days. Flasks were seeded with three agar plugs colonized by *R. solani* and shaken twice a week to promote rapid and uniform colonization. After 3 weeks, the colonized millet was shaken into sterile paper bags, dried at room temperature, and ground to pass through a 0.5-mm sieve.

Seeds of table beet cvs. Detroit Dark Red and Early Wonder (Hart Seed Co., Wethersfield, CT) were sown in 36-cell plastic trays filled with ProMix BX (Premier Brand, New Rochelle, NY). After 4 weeks, seedlings were thinned to one plant per cell and transplanted into 10-cm square plastic pots filled with 2 parts ProMix BX potting mix and 1 part sand. The mix had the following properties: pH = 6.5, bulk density = 0.7 g/liter, $\text{NO}_3\text{-N}$ = 3.0 $\mu\text{g/g}$, $\text{NH}_4\text{-N}$ = 0.0 $\mu\text{g/g}$, $\text{PO}_4\text{-P}$ = 100 $\mu\text{g/g}$, exchangeable K^+ = 6.0 meq/100 g, exchangeable Ca^{+2} = 8.0 meq/100 g, exchangeable Mg^{+2} = 2.5 meq/100 g, and exchangeable Cl^- = 0.8 meq/100 g. The soil in half the pots was infested previously with 0.2 g of the millet inoculum per liter of soil mix. Uncolonized autoclaved millet that was similarly prepared was mixed into soil that filled the remaining pots to serve as noninfested controls.

One plant was transplanted into each pot, and the fertilizer treatments were applied immediately. Hoagland's solution (17) was modified where the N form was altered accordingly. The base stock had 2 mmol of MgSO_4 , 1 mmol of K_2HPO_4 , and 1 ml of the Hoagland's trace elements per liter of H_2O . To this, $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ was added to yield 10 mmol of N. Each N stock was divided in two, and half was treated with NaCl to yield 0.17 mmol of NaCl

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(1%, wt/vol). Pots received 100 ml of each fertilizer treatment once a week and were watered with deionized water to keep soil moist. Therefore, 16 treatments (two cultivars by two N forms by two NaCl treatments by two inoculum treatments) were arranged randomly on a greenhouse

bench under high-intensity sodium-vapor lights. The experiment was conducted two times, with five or six replicates per treatment. The experiment also was repeated twice, with six replicates in sand culture that had been infested with and without the millet inoculum.

Another series of experiments was designed to examine the effect of different sources of Cl on growth and disease. Plants of both of the cultivars mentioned above were transplanted into sand in 10-cm pots and treated with one of five Cl salt treatments. The base stock solution mentioned above was amended with $(\text{NH}_4)_2\text{SO}_4$ at 10 mmol and treated with NaCl, KCl, CaCl_2 , or MgCl_2 at rates that yielded 0.17 mmol of Cl. A fifth treatment contained no Cl and served as a no Cl control. Therefore, 20 treatments (two cultivars by five Cl treatments by two inoculum treatments) were arranged randomly under the sodium-vapor lights on greenhouse benches. These experiments were repeated twice, with five and six replicates, respectively.

Greenhouse experiments were terminated after 6 to 8 weeks. Plants were rated for disease using a 1 to 5 scale: 1 = no disease, 2 = slight stunting, 3 = stunting with slight wilt, 4 = severe stunting and/or severe wilt, and 5 = plant collapse, near death, or dead. *R. solani* was reisolated by placing surface-disinfested pieces of diseased petioles on potato dextrose agar. Plants were cut at the soil line, and the fresh and dry weights were recorded. Roots and tops of beets grown in sand were washed in deionized water, oven-dried, and saved for tissue analyses, described below.

Field studies. A 100-m² section of a field that had been cropped to rye for 6 years was plowed during the spring of 1995. One-half of the field was treated with 100 g of the millet inoculum described above; the other half received sterile millet. Both sections were roto-tilled to

Table 1. The influence of N form combined with NaCl on disease ratings and dry weights of two beet cultivars grown in noninfested soil or soil infested with *Rhizoctonia solani* (anastomosis group 2-2)

Treatment ^a	Experiment I		Experiment II	
	Disease rating ^b	Dry weight (g)	Disease rating	Dry weight (g)
Noninfested soil				
$(\text{NH}_4)_2\text{SO}_4$	...	0.59 ^c	...	1.01
$(\text{NH}_4)_2\text{SO}_4$ + NaCl	...	1.12	...	1.22
$\text{Ca}(\text{NO}_3)_2$	...	1.31	...	1.08
$\text{Ca}(\text{NO}_3)_2$ + NaCl	...	1.53	...	1.44
Infested soil				
$(\text{NH}_4)_2\text{SO}_4$	3.6	0.23	3.1	0.76
$(\text{NH}_4)_2\text{SO}_4$ + NaCl	2.5	0.39	2.6	0.81
$\text{Ca}(\text{NO}_3)_2$	2.1	0.54	1.8	1.11
$\text{Ca}(\text{NO}_3)_2$ + NaCl	2.0	0.67	2.1	1.09
ANOVA (<i>P</i>) ^d				
Source				
N form	0.009	0.002	0.006	0.006
NaCl	0.04	0.015	0.04	0.007
<i>Rhizoctonia</i>	...	<0.001	...	<0.001
Cultivar ^e	ns ^f	ns	ns	ns

^a Treatments included $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ at 10 mmol of N and NaCl at 0.17 mmol; infested soil contained 0.2 g of millet colonized by *R. solani*.

^b Plants grown in infested soils were rated for disease using a 1 to 5 scale: 1 = no disease, 2 = slight stunting, 3 = stunting with slight wilt, 4 = severe stunting and/or severe wilt, and 5 = plant collapse, near death, or dead.

^c Values in experiment I contained five replicates, and values in experiment II contained six replicates.

^d ANOVA = analysis of variance. All interactions were not significant.

^e Values from cvs. Detroit Dark Red and Early Wonder were combined.

^f ns = not significant at *P* > 0.10.

Table 2. Mineral composition of beet leaves treated with ammonium sulfate or calcium nitrate combined with or without NaCl

Treatment ^a	mmol/g tissue			μmol/g tissue									
	N	P	K	Ca	Mg	Na	Cl	S	Fe	Mn	Zn	Cu	B
Leaves													
$(\text{NH}_4)_2\text{SO}_4$	1.8 ^b	0.42	2.02	276	391	300	70	203	1.7	8.5	2.9	0.68	6.8
$(\text{NH}_4)_2\text{SO}_4$ + NaCl	1.7	0.40	1.46	232	323	1,815	250	156	1.7	13.1	2.6	0.82	6.4
$\text{Ca}(\text{NO}_3)_2$	1.6	0.34	2.17	259	362	321	100	147	1.0	6.9	2.4	0.68	5.4
$\text{Ca}(\text{NO}_3)_2$ + NaCl	1.4	0.31	1.60	244	325	2,169	2,888	112	1.5	9.2	2.6	0.65	5.8
Roots													
$(\text{NH}_4)_2\text{SO}_4$	1.2	0.12	1.03	209	416	71	64	89	6.3	8.9	4.8	0.16	5.7
$(\text{NH}_4)_2\text{SO}_4$ + NaCl	1.3	0.11	0.63	196	420	538	393	62	8.2	13.4	5.0	0.19	4.7
$\text{Ca}(\text{NO}_3)_2$	1.3	0.11	0.91	223	463	82	67	84	7.1	5.7	3.9	0.13	4.4
$\text{Ca}(\text{NO}_3)_2$ + NaCl	1.5	0.11	0.70	202	439	624	368	56	11.8	5.3	3.5	0.15	4.3
ANOVA for leaves ^c													
Source													
N form	0.001	0.01	ns ^d	ns	ns	ns	ns	0.038		0.032			ns
NaCl	0.006	ns	0.002	ns	ns	0.001	0.05	ns		0.016			ns
Cultivar ^e	ns	ns	ns	0.047	0.001	ns	ns	ns		ns			0.017
ANOVA for roots ^f													
Source													
N form	ns	0.045	ns	ns	ns	ns	ns			0.005			ns
NaCl	ns	ns	0.002	ns	ns	0.001	0.05			0.048			ns
Cultivar ^e	0.048	ns	ns	0.047	0.001	ns	ns			ns			0.017

^a Treatments included $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ at 10 mmol of N and NaCl at 0.17 mmol.

^b Values represent bulked samples from two separate experiments that contained five and six replicates, respectively.

^c ANOVA = analysis of variance. All interactions were not significant at *P* = 0.05.

^d ns = not significant at *P* > 0.10.

^e The values from cvs. Detroit Dark Red and Early Wonder were combined.

^f All interactions were not significant at *P* = 0.05.

a depth of 15 cm. Rows 12.2 m long and spaced 0.6 m apart were seeded with cv. Early Wonder seeds, with 2.5 cm between seedlings. After seedling emergence, rows were thinned to 7.5 cm spacing. All rows received a seasonal total of 112 kg of N, 140 kg of P₂O₅, 224 kg of K₂O, and 60 Kg of CaSO₄ per ha.

Sections of row 1 m long that had uniform seedling emergence were selected as plots (0.6 m²). The treatments included (NH₄)₂SO₄ or Ca(NO₃)₂ applied at equal rates of N, and NaCl was applied at 560 kg/ha, with an equal number of untreated rows serving as controls. Thus, eight treatments (two N forms by two NaCl treatment by two inoculum treatments) were arranged in a split-plot design, with inoculum treatment as the major plot and N form and NaCl treatments as the subplots; there were four replicate plots.

At the time the beet seedlings were thinned, 70% of the total fertilizers, including the N forms and NaCl treatments, was banded along side the row. The remaining 30% was applied 4 weeks later. Two months after planting, a fully expanded leaf from each plant in each replicate plot was sampled, bulked, and allowed to air-dry. Plants were rated using the scale described above. The number of marketable beets with their tops were harvested and weighed. Beets less than 3 cm in diameter were not weighed, but these were rare. Most beets had diameters greater than 6 cm. The experiment was repeated by establishing the same design 3 weeks later in a plot adjacent to the first design.

The second experiment differed from the first in that seedlings were germinated first in the greenhouse in potting soil and transplanted at 7.5 cm spacing and treated with the fertilizer. This was done to insure a uniform stand of seedlings at the time fertilizers were applied. The second experiment also did not include plants grown in noninfested soil.

Tissue analyses. Dried leaf and root tissues from healthy plants were ground to powder in a mortar with a pestle. Total N was determined by digesting 0.25 g of tissue in H₂SO₄ and was colorimetrically analyzed by the Nestler reaction. P, K, Na, Ca, Mg, S, Fe, Mn, Zn, Cu, and B were analyzed by microwaving 0.5 g of tissue in HCl and HNO₃ in a CEM MDS 81D microwave (CEM Co., Matthews, NC) and using inductively coupled plasma-emission (ICP) spectroscopy on an ARL 3520 ICP-OES spectrophotometer (Fison Instruments, Deerborn, MI). Free chlorides were detected by agitating 0.2 g of tissue in 20 ml of deionized water and injecting a diluted and filtered sample into a Dionex 2010i ion detector (Dionex Corp. Sunnyvale, CA). Mineral concentrations of N, P, and K are expressed as millimoles per gram of tissue, and all remaining elements are expressed as micromoles per gram of tissue.

Statistics. A factorial analysis of variance was used in greenhouse studies to detect treatment interactions on dry weights and nutrient concentrations. Disease ratings were analyzed by the Kruskal-Wallis rank test. Orthogonal contrasts were employed to test post-hoc comparisons. Field studies were analyzed by a split-plot analysis of variance.

RESULTS

Effect of N form and NaCl on growth, disease, and mineral composition. The inoculum density of 0.2 g of colonized millet inoculum per liter of soil produced significant reductions in the dry weights of both cultivars compared to healthy controls (Table 1). Cv. Early Wonder appeared to be slightly more tolerant than Detroit Dark Red, but the cultivars did not significantly differ in dry weights, so their values were averaged. No significant interactions between N form and NaCl were detected. Plants grown in noninfested and infested soil were 17 and 32% larger, respectively, when treated with Ca(NO₃)₂ than when treated with (NH₄)₂SO₄. NaCl also increased dry weight by 40% in noninfested soil and by 12% in infested soil compared to no NaCl.

Overall, Early Wonder had less Ca, Mg, and B in leaves and less N, Ca, Mg, and B in roots than Detroit Dark Red, but none of the other elements differed between the cultivars (data not shown). Therefore, the values were averaged across cultivars (Table 2). Roots contained lower levels of minerals than did leaves, with the exception of Mg, Fe, and Zn, which were higher. No interaction occurred between the cultivars, N form, or NaCl. Beets treated with (NH₄)₂SO₄ had more N, P, S, and Mn than plants treated with Ca(NO₃)₂. Compared to controls, adding NaCl in the fertilizers increased N, Na, Cl, and Mn and decreased K. The treatments affected the mineral concentrations in roots similar to the effect on concentrations in the leaves, in that no interactions between the main effect treatments occurred (Table 2). Compared to treatment with Ca(NO₃)₂, roots treated with (NH₄)₂SO₄ had more P and Mn. Adding NaCl under both N forms increased Na, Cl, and Mn and decreased K levels compared to no NaCl.

Effect of different chloride salts on growth, disease, and mineral composition. All of the Cl salts increased the dry weight of beet plants. The effect was clearly dependent on the presence or absence of Cl rather than on any Cl source, because neither

Table 3. The influence of different chloride salts on beets grown in noninfested soil or soil infested with *Rhizoctonia solani* (anastomosis group 2-2)

Chloride salt ^a	Experiment I		Experiment II		
	Disease rating ^b	Dry weight (g)	Disease rating	Fresh weight (g)	Dry weight (g)
Noninfested soil					
No Cl	...	1.14 ^c	...	12.1	1.49
NaCl	...	1.30	...	16.4	1.53
KCl	...	1.34	...	15.8	1.60
CaCl ₂	...	1.43	...	14.7	1.48
MgCl ₂	...	1.50	...	15.7	1.64
Infested soil					
No Cl	3.4	1.12	2.9	9.0	1.00
NaCl	2.1	1.27	1.8	15.2	1.34
KCl	2.0	1.08	2.0	13.5	1.31
CaCl ₂	2.4	1.18	2.2	14.7	1.48
MgCl ₂	2.1	1.32	2.3	11.3	1.21
ANOVA ^d					
Source (P)					
Cl salt	0.04	0.015	0.04	<0.001	ns
<i>Rhizoctonia</i>	...	0.010	...	0.003	0.006
Cultivar ^e	ns ^f	ns	...	...	...
Orthogonal contrasts (P)					
NaCl vs. control	...	0.059	...	...	0.001
KCl vs. control	...	ns	...	...	0.001
CaCl ₂ vs. control	...	0.036	...	...	0.001
MgCl ₂ vs. control	...	0.001	...	...	0.012
NaCl vs. other salts	...	ns	...	...	ns
KCl vs. NaCl	...	ns	...	...	ns
CaCl ₂ vs. NaCl	...	ns	...	...	ns
MgCl ₂ vs. NaCl	...	ns	...	...	ns

^a Treatments included Cl salt (0.17 mmol of Cl); infested soil contained 0.2 g of millet colonized by *R. solani*.

^b Plants were rated for disease using a 1 to 5 scale: 1 = no disease, 2 = slight stunting, 3 = stunting with slight wilt, 4 = severe stunting and/or severe wilt, and 5 = plant collapse, near death, or dead.

^c Values in both experiments contained five replicates.

^d ANOVA = analysis of variance. All interactions were not significant.

^e The values from cvs. Detroit Dark Red and Early Wonder were combined.

^f ns = not significant at *P* > 0.10.

Table 4. Mineral composition of beet roots treated with different chloride salts (experiment I)

Treatment ^a	mmol/g tissue			μmol/g tissue									
	N	P	K	Ca	Mg	Na	Cl	S	Fe	Mn	Zn	Cu	B
No Cl	1.2 ^b	0.42	1.52	278	392	250	70	203	1.7	8.5	2.9	0.08	6.7
NaCl	1.3	0.36	1.43	379	508	1,431	163	259	1.6	18.0	3.5	0.11	6.0
KCl	0.9	0.27	2.60	246	587	577	156	167	1.4	13.1	2.6	0.10	5.3
CaCl ₂	1.3	0.25	1.12	795	469	559	150	192	1.6	17.4	4.1	0.12	6.5
MgCl ₂	1.4	0.28	1.07	347	1,058	486	143	159	1.4	16.0	2.9	0.10	6.1
ANOVA (P) ^c													
Source													
Chloride source		0.013	0.015	0.001	0.087	0.091	0.002			0.005			
Cultivar ^d		ns ^e	ns	ns	ns	ns	ns			ns			
Orthogonal contrasts													
NaCl vs. control		ns	ns	0.077	ns	0.001	0.001			0.001			
KCl vs. control		0.007	0.004	ns	ns	ns	0.001			0.022			
CaCl ₂ vs. control		0.003	ns	0.001	ns	ns	0.001			0.003			
MgCl ₂ vs. control		0.007	ns	ns	0.049	ns	0.001			0.003			
NaCl vs. other salts		0.015	0.022	ns	ns	ns	ns			0.083			
KCl vs. NaCl		0.047	0.003	0.035	ns	ns	ns			ns			
CaCl ₂ vs. NaCl		0.015	ns	0.001	ns	ns	ns			ns			
MgCl ₂ vs. NaCl		0.047	ns	ns	0.086	ns	ns			ns			

^a Treatments included Cl salt (0.17 mmol of Cl); infested soil contained 0.2 g of millet colonized by *R. solani*.

^b Values in both experiments contained five replicates.

^c ANOVA = analysis of variance.

^d The values from cvs. Detroit Dark Red and Early Wonder were combined.

^e ns = not significant at $P > 0.10$.

Table 5. Root yield of table beets treated with ammonium sulfate or calcium nitrate with or without NaCl and grown in noninfested soil or soil infested with *Rhizoctonia solani* (anastomosis group 2-2)

Treatment ^a	Experiment I		Experiment II	
	Disease rating ^b	Yield (kg/m row)	Disease rating	Yield (kg/m row)
Noninfested soil				
(NH ₄) ₂ SO ₄	1.2	2.25 ^c	... ^d	...
(NH ₄) ₂ SO ₄ + NaCl	1.0	2.35	...	...
Ca(NO ₃) ₂	1.0	2.06	...	...
Ca(NO ₃) ₂ + NaCl	1.0	2.15	...	...
Infested soil				
(NH ₄) ₂ SO ₄	3.1	0.60	3.8	0.53
(NH ₄) ₂ SO ₄ + NaCl	2.8	0.81	2.7	1.00
Ca(NO ₃) ₂	1.5	0.98	2.0	0.87
Ca(NO ₃) ₂ + NaCl	1.7	0.95	2.5	0.97
ANOVA (P) ^e				
Source				
N form	0.04	ns ^f	0.06	ns
NaCl	ns	ns	ns	ns
N form × NaCl	...	0.086	...	0.050
<i>Rhizoctonia</i>	...	<0.001	...	...
N form × NaCl × <i>Rhizoctonia</i>	...	0.093	...	...

^a Treatments included (NH₄)₂SO₄ or Ca(NO₃)₂ at 112 kg of N per ha and NaCl at 560 kg/ha; infested soil contained 0.2 g of millet colonized by *R. solani*.

^b Plants were rated for disease using a 1 to 5 scale: 1 = no disease, 2 = slight stunting, 3 = stunting with slight wilt, 4 = severe stunting and/or severe wilt, and 5 = plant collapse, near death, or dead.

^c Values in both experiments contained four replicates.

^d Plants in noninfested soil were not harvested.

^e ANOVA = analysis of variance.

^f ns = not significant at $P > 0.10$.

salt was superior or inferior to NaCl (Table 3). In the experimental repetition, the Cl salt treatments had similar effects, except that dry weights were not significantly different from controls, but the fresh plant weights increased. Once again, the source of the Cl did not affect plant weight.

The mineral composition of these plants was affected accordingly, in that the ac-

companying cation of the Cl salt usually was found in higher levels than in other treatments (Table 4). The amounts of S were less in plants treated with CaCl₂ and MgCl₂. The one similar effect on mineral composition among all Cl salts was an increase in Cl and Mn per gram of tissue.

Field trials. The fertilizer used did not affect yield in the absence of *Rhizoctonia*

root and crown root (Table 5). However, in infested soils, there was an interaction between (NH₄)₂SO₄ and NaCl that increased yields more than when NaCl was absent and more than when NaCl was combined with Ca(NO₃)₂. When the experiment was repeated in infested soils, the same interaction was observed. Mineral analyses of the sampled leaves at harvest revealed that treatment with (NH₄)₂SO₄ tended to increase Mn but decreased K (Table 6). NaCl increased Na and Cl in leaves, whereas Mn was only slightly increased compared to no NaCl.

DISCUSSION

In both greenhouse and field experiments, the yield of table beets increased with use of Ca(NO₃)₂ more than with (NH₄)₂SO₄, and the differences in yield tended to be greater in the presence of *R. solani* than in noninfested soils. Sodium chloride also had a growth-enhancing effect that tended to be greater under the (NH₄)₂SO₄ regime than under the Ca(NO₃)₂ regime. In both field studies, the inclusion of NaCl with (NH₄)₂SO₄ increased yield by 26 and 41%, respectively, but only was marginal when NaCl was combined with Ca(NO₃)₂.

The current study supports past reports that seedling diseases caused by *R. solani* are less severe with NO₃-N than with NH₄-N nutrition (19). In general, NH₄-N nutrition is more harmful to young seedlings than is NO₃-N, because small plants lack the available carbohydrates to convert the toxic NH₄⁺ into amino acids (26). However, Rush and Winter (27) observed that the incidence of *Rhizoctonia* crown and root rot of sugar beet was greater after rotation crops that left high levels of resi-

Table 6. Mineral composition of field-grown beet leaves treated with ammonium sulfate or calcium nitrate combined with or without NaCl

Treatment ^a	mmol/g tissue			μmol/g tissue									
	N	P	K	Ca	Mg	Na	Cl	S	Fe	Mn	Zn	Cu	B
(NH ₄) ₂ SO ₄	2.8 ^b	0.12	1.99	356	917	326	87	170	4.4	1.3	0.6	0.14	4.7
(NH ₄) ₂ SO ₄ + NaCl	2.7	0.13	1.95	385	971	429	159	203	4.8	1.9	0.7	0.20	4.8
Ca(NO ₃) ₂	2.7	0.11	1.67	386	969	848	67	166	6.9	1.1	0.6	0.17	4.9
Ca(NO ₃) ₂ + NaCl	2.7	0.15	1.73	414	912	653	196	225	5.4	1.3	0.7	0.23	6.2
ANOVA (P) ^c													
Source													
N form	0.013			0.004		ns ^d		0.09					
NaCl	ns			0.050		0.002		0.08					

^a Treatments included (NH₄)₂SO₄ or Ca(NO₃)₂ at 112 kg of N per ha and NaCl at 560 kg/ha.

^b Values represent bulked samples from two blocks in each experiment.

^c ANOVA = analysis of variance. All interactions were not significant at $P < 0.10$.

^d ns = not significant at $P > 0.10$.

dual soil NO₃-N compared to crops that left low NO₃-N levels. Late-season nitrate reduced sugar production in sugar beet roots and favored disease (21,34). It is difficult to compare these observations to the current one because NH₄-N was not compared to NO₃-N. Also, late-season NO₃-N levels may not be of great concern to table beet growers, because sugar production is less important than for sugar beets.

NaCl was beneficial to beet growth and suppressed Rhizoctonia root and crown rot. The original studies on NaCl use with sugar beets concentrated on the ability of Na to replace K in metabolic functions (13, 23). The current study also showed that applications of NaCl resulted in a decrease in K leaf concentrations, possibly due to replacement. The phenomenon of Na/K replacement may be specific to *B. vulgaris*, because K replacement is not observed with other saline-tolerant plants, such as celery and asparagus (9,29). However, there was insufficient evidence to consider Na as a major ion in disease suppression, because greenhouse trials found that NaCl was not superior to CaCl₂, KCl, or MgCl₂ in suppressing disease. Past studies on sugar beets touted the value of Na in growth and water relations and ignored the contributions of Cl (3,6,13). On wheat, yellow rust caused by *Puccinia striiformis* was less severe when NaCl was combined with NaNO₃ than when NaNO₃ was applied alone (28), implicating Cl as the determining ion in disease suppression. An interesting area for future work would be to determine the role of different Na and Cl sources in Rhizoctonia diseases of beets in K-deficient soils.

Unlike Na, Cl has received much attention as an element that enhances growth and suppresses disease (14,22). Cl concentrations increased 6- and 25-fold for leaves and roots, respectively, and reached levels comparable to K and Ca, a phenomenon not uncommon in many plants (9,14,16, 29,35). There are many possible mechanisms, not mutually exclusive, that may explain the disease-suppressive effects of Cl and influence host resistance.

Cl inhibits soil nitrification and tends to keep soil N in NH₄-N form, which can

affect microbial populations in the rhizosphere and trace-element availability (18). In fact, Cl applications have been used to enhance sugar beet quality by reducing the availability of residual NO₃-N levels (21, 24). Chloride also lowers plant water potential, which may increase the ability of the plant to maintain turgor when water absorption by roots has been compromised by pathogens (5,9). Another possible mechanism could be a reduction in the amount of organic acids released as exudates from roots that are fed Cl (8,30). These alterations in exudates could deprive root pathogens of the substrates they need prior to pathogenesis. Cl applications also increase the availability of Mn (10,12,14,16,20), and there is convincing evidence in the current study showing that Mn levels and disease suppression are increased when Cl is applied. The greenhouse studies with different Cl salts found that, along with increased plant weights and Cl levels, the concentrations of Mn were increased.

In the combination studies with N form/Cl, the largest increase in Mn was found when NaCl was combined with (NH₄)₂SO₄, and this combination frequently resulted in the greatest increase in growth in greenhouse studies and the largest increase in yield in the field compared to (NH₄)₂SO₄ alone. The inclusion of NaCl with Ca(NO₃)₂ was less beneficial to growth, yield, and Mn levels. This may be because NO₃-N and Cl ions compete for absorption sites on plant roots (14). The disease-suppressive effects of Ca(NO₃)₂ compared to (NH₄)₂SO₄ may operate by mechanisms other than those associated with increased Mn availability, such as increasing Ca levels in cell walls.

Much attention has been given to the effect that Cl has on Mn availability, because Mn also has been implicated in disease suppression (10–12,14,20,31). Cl can chemically reduce Mn oxides in soil (32), and evidence for asparagus has shown that Mn-reducing bacteria are associated more with asparagus roots treated with NaCl than with nontreated roots (10). Manganese is an activator for enzymes that function in phenol metabolism (20). A current hypothesis holds

that root cells containing ample Mn may be able to produce antifungal barriers, such as lignin, faster than cells containing lower levels of Mn (20).

The response of other table beet diseases to Cl salts is unknown. High salt levels in soil may aggravate other beet diseases, such as Pythium root rot caused by *Pythium ultimum*. Nevertheless, the use of Cl salts should receive further consideration in the management of Rhizoctonia root and crown rot of table beets.

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