Influence of Inoculum Density of *Fusarium oxysporum* f. sp. *cyclaminis* and Sodium Chloride on Cyclamen and the Development of Fusarium Wilt

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ABSTRACT

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The influence of soil densities of *Fusarium oxysporum* f. sp. *cyclaminis* on development of Fusarium wilt of cyclamen (*Cyclamen persicum*) was evaluated by adding increasing amounts of *F. oxysporum* f. sp. *cyclaminis*-colonized millet inoculum to potting mix planted to cyclamen. Additions of inoculum resulted in an increase in the CFU of *F. oxysporum* f. sp. *cyclaminis* per ml of potting mix and an increase in vascular discoloration of the corm of cyclamens after 10 weeks. A threshold of 5×10^4 CFU/ml of potting mix was needed to consistently cause vascular discoloration in the corms. Final fresh leaf weights declined to 30% of the leaf weights of the control when inoculum was added at 10^5 CFU/ml of potting mix. The effect of NaCl on Fusarium wilt was also examined, as anecdotal reports from cyclamen producers suggest that NaCl applications may improve plant growth. When NaCl was applied to potting mix at rates of 0.25 and 0.50 g/liter of potting mix, final fresh weights were greater and the area under the disease progress curve values were less than those of control plants. However, final disease severity was not affected. In the absence of the pathogen, leaf weights were greater when NaCl was added at 0.25 g/liter of potting mix. Disease development and the effectiveness of NaCl on disease were not affected by potting mix pH 5.1 to 7.2. Cyclamens grown in potting mix with a pH of 7.2 had chlorotic leaves, but with the addition of NaCl, the chlorosis was not observed. Leaf analyses showed that the addition of NaCl increased foliar levels of Na, Cl, and Mn, but decreased foliar levels of P, Ca, Mg, S, and B. Sodium chloride applied at 0.25 to 0.50 g/liter of potting mix had growth benefits, but disease suppression was marginal.

Additional keywords: mineral nutrition

Fusarium wilt of cyclamen is a destructive disease and limits the production of quality cyclamens (*Cyclamen persicum* Mill.). Plants can become infected anytime during the plant's life cycle. Symptoms include chlorosis, stunting, and wilting. The corm remains hard and develops a characteristic reddish-brown discoloration in the vascular tissue. Growers report that symptoms commonly appear on plants that are in flower and ready for shipment. In these situations, fungicides are used to salvage the crop, but often these treatments are ineffective and can increase the development of fungicide-resistant pathogen populations. In Connecticut, growers have lost over 50% of the crop due to Fusarium wilt. In Germany, cyclamen losses due to Fusarium wilt have been reported to be as high as 90% (27).

Fusarium wilt of cyclamen was first reported by Wollenweber and Reinking (39) in the 1930s, when the pathogen was named *Fusarium oxysporum* Schlechtend.:Fr f. sp. *aurantiacum* Wollenweb. &

Reink. In 1953, Gerlach (15) renamed the pathogen *Fusarium oxysporum* Schlechtend.:Fr f. sp. *cyclaminis* Gerlach. The disease has since been reported in Europe, North and South America, and Japan (28,35,37,40).

F. oxysporum f. sp. *cyclaminis* is spread on seed coats and in seed debris, transplants, infested potting mix, and planting pots (37). Fungus gnats, shore flies, and wind may also play a role in disseminating *Fusarium* inoculum in the greenhouse (5,30,31). Rattink (29) found inoculum densities as low as 10 conidia per ml could initiate disease development when seedling roots were dipped into conidial suspensions. However, in ebb-and-flow irrigation systems, disease was only observed when inoculum concentration was greater than 10^5 conidia per ml. There is no information available on the relationship between soil inoculum densities and Fusarium wilt of cyclamen.

Although cyclamen breeding programs have identified resistance to cyclamen wilt in wild species of cyclamen, no resistant cultivars are available (27). Disease management strategies include sanitation (37), roguing dead plants, and application of fungicides (5). Biological controls have also been investigated, with limited success (11,26,35). Chloride salts have been used to suppress Fusarium diseases on many plants, such as barley (14), celery

(33), corn (41), soybean (32), and wheat (4,20). Sodium chloride has been associated with suppression of root diseases on salt-tolerant plants like asparagus (9), beets (10), and palms (1). Because *C. persicum* presumably evolved in the arid climates of the Middle East (2), it may also have tolerance to NaCl. In the 1930s and 1940s, some cyclamen growers added NaCl to their fertilizer programs to enhance plant growth and quality (Jay Koths, University of Connecticut, *personal communication*). The objectives of this report were to study the effects of NaCl and densities of *F. oxysporum* f. sp. *cyclaminis* on the growth of cyclamen.

MATERIALS AND METHODS

Production of inoculum. A virulent isolate of *F. oxysporum* f. sp. *cyclaminis* was provided by Margery Daughtrey (Cornell University, Riverhead, NY). A monosporic culture was stored on silica gel (3) and used to produce all inocula. Because inoculation studies on celery with *Fusarium oxysporum* Schlechtend.:Fr f. sp. *apii* (R.R. Nelson & Sherb.) W.C. Snyder & H.N. Hans found that a soil-amended, colonized substrate gave a more consistent level of disease than root-dip inoculations with conidial suspensions (7), a colonized millet inoculum was used in these studies. One-liter flasks were filled with 100 g of millet seeds and 200 ml of H₂O and autoclaved for 1 h on consecutive days. Flasks were seeded with three agar plugs (4 mm diameter) removed from the outer margins of an *F. oxysporum* f. sp. *cyclaminis* colony. Cultures were incubated at room temperature and hand-shaken for 15 s daily for 14 days. The colonized seed was air-dried in autoclaved paper bags for 7 to 10 days. The dried colonized seed was ground in a Wiley mill, passed through a 40-mesh sieve, and stored in glass jars at 4°C. Twice-autoclaved, noncolonized ground millet was used as a control treatment.

Effect of inoculum rate. Millet inoculum was rotary incorporated into potting mix (Promix BX, Premier Brand, Inc., New Rochelle, NY) for 20 min using a cement mixer at rates 0.10, 0.25, 0.50, 1.0, or 2.0 g of millet per liter of potting mix. A nonamended control treatment was included. Samples of infested potting mix were assayed for the pathogen 2 weeks after amendment by serially diluting two 1-g samples of each potting mix treatment into sterile normal saline (0.9% wt/vol). One-milliliter aliquots of each dilution were placed on Komada's selective me-

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dium (23). Agar plates were incubated at 25°C in the dark for 5 days. The number of *F. oxysporum* colonies on each plate was counted, and the inoculum density was expressed as colony-forming units (CFU)/ml of dry potting mix. Cyclamen seedling plugs (Halios hybrid series, Hortus Group, Inc., Castroville, CA) were transplanted into 10-cm-diameter plastic pots (one plant per pot), each filled with 1 liter of potting mix that had been infested with different amounts of inoculum. There were 12 replicates per treatment. Plants were arranged on a greenhouse bench in a randomized complete block design with four blocks (three replicates per block). Plants were grown at a 15°C/18°C day/night cycle under sodium vapor lamps set for 12 h/12 h day/night photoperiods. Plants were irrigated with deionized water as needed and fertilized once a month with 100 ml of Hoagland's solution per pot (18).

Plants were rated weekly for disease symptoms based on the scale: 0 = no disease observed, 1 = slight stunting, 2 = slight stunting and chlorosis of leaves, 3 = <10% of the leaves showing chlorosis and/or 10% of the plant with wilt symptoms, 4 = <11 to 25% of the plant with wilt symptoms, 5 = 26 to 50% of the plant with wilt symptoms, and 6 = 51 to 100% of the plant with wilt symptoms or plant death. The area under the disease progress curve (AUDPC) was calculated using the equation: $AUDPC = \sum (Y_i + Y_{i+1})/2 * (t_{i+1} - t_i)$ where Y_i = the disease rating at time t_i .

Fig. 1. Effect of initial inoculum density of *Fusarium oxysporum* f. sp. *cyclaminis* on recovery of the pathogen from potting mix after 2 weeks ($\times 10^5$ CFU/ml potting mix) and on percent vascular discoloration in corms, fresh leaf weight, and number of flowers of cyclamens (Halios series) grown in the potting mix for 10 weeks. Values represent the means of 12 replicates. Error bars represent standard errors of the mean.

Flowers were counted and removed whenever disease severity was assessed.

Experiments were terminated when control plants reached marketable size (8 to 10 weeks). Fresh leaf weights were recorded, and leaves were dried for tissue analyses. The corm was sliced longitudinally and rated for the percentage of vascular discoloration. The experiment was repeated.

Effect of NaCl rate. Cyclamen seedlings were transplanted into 10-cm-diameter plastic pots (one plant per pot), each filled with 1 liter of potting mix. One week after transplanting, a granular application of NaCl was added at 0.25, 0.5, 1.0, 2.0, or 4.0 g/liter of potting mix. There were 12 replicates per treatment. Plants were arranged on a greenhouse bench in a randomized complete block design with four blocks (three replicates per block). Plants were irrigated with adequate deionized water to moisten the potting mix in the pot without causing leaching. One week later, pots were treated with extra deionized water to produce 25 to 30 ml of leachate. The electrical conductivity (EC) of the leachate was measured using a conductivity meter and expressed as dS/m. Plants were then grown and fertilized as described above.

Plants were rated for salt damage after 2, 3, 4, and 6 weeks using the scale: 1 = healthy plant, 2 = slight leaf yellowing, 3 = some plant stunting and leaf yellowing, 4 =

plant wilt with severe yellow leaves, and 5 = death of the plant. The salt damage severity was expressed as the area under the salt damage progress curve (ASDPC) where $ASDPC = \sum (Y_i + Y_{i+1})/2 * (t_{i+1} - t_i)$, where Y_i = the salt damage rating at time t_i . Flowers were counted and removed whenever disease severity was assessed. Plant roots including the corm were washed under tap water to remove potting mix, pressed between absorbent paper towels, and weighed.

Another series of experiments examined the effect of NaCl on Fusarium wilt of cyclamen. Cyclamen seedlings were placed into 1-liter plastic pots filled with potting mix infested with inoculum (0.5 g of colonized millet) or infested with sterile millet. One week after transplanting, each pot was treated with 0.25, 0.50, or 1.00 g of NaCl per liter of potting mix. Untreated pots served as controls. Growing conditions were as described above. Disease severity was recorded as described above. After 10 weeks, fresh leaf weights and vascular discoloration were recorded.

Effect of potting mix pH and NaCl.

The interaction of potting mix pH and NaCl amendments to the potting mix on the composition of foliar elements was examined. The potting mix used in this experiment had a pH of 6.0 to 6.5. To adjust the potting mix pH to be acidic or slightly alkaline, the potting mix was treated with 10% H_2SO_4 (3.1 ml/liter of potting mix) or hydrated lime (3.1 g/liter of potting mix), respectively. The treated and untreated potting mixes were moistened to 50% water content, rotary mixed for 15 min in a cement mixer, placed in separate plastic bags, and set on a greenhouse bench for 1 week to allow the potting mix pH to equilibrate. Potting mix pH was then measured on a 1:1 potting mix:water sample with a calibrated pH meter and determined to be 5.1 and 7.2. The acidic (pH 5.1), slightly acidic (pH 6.2), and slightly alkaline (pH 7.2) potting mixes were each divided in half. Half was infested with inoculum of *F. oxysporum* f. sp. *cyclaminis* (0.5 g of colonized millet) and half was infested with sterile millet. Cyclamen seedlings were placed into 1-liter plastic pots filled with each potting mix treatment. Half of the pots in each potting mix combination were treated with NaCl at 0.25 g/liter of potting mix, and the remaining half of the pots were left untreated. There were 12 replicates per treatment. Plants were arranged on a greenhouse bench in a randomized complete block design with four blocks (three replicates per block). Plants were grown and fertilized as described above. Plants were rated for disease severity as described. The experiment was terminated after 14 weeks. Total leaf area was determined by placing each leaf on a leaf area meter (Delta-T Devices, Pullman, WA) and summing the total leaf area per plant.

Fig. 2. Effect of NaCl on salt damage curve and growth of cyclamen (Halios series). Plants were rated for salt damage after 2, 3, 4, and 6 weeks using the scale: 1 = healthy plant, 2 = slight leaf yellowing, 3 = some plant stunting and leaf yellowing, 4 = plant wilt with severe yellow leaves, and 5 = death of the plant. The salt damage severity was expressed as the area under the salt damage progress curve (ASDPC) where $ASDPC = \sum (Y_i + Y_{i+1})/2 * (t_{i+1} - t_i)$, where Y_i = salt damage rating at time t_i . Values represent the means of 12 replicates. Error bars represent standard errors of the mean.

Tissue analyses. Dry leaf tissue from three replicate plants within each of the four treatment blocks in the NaCl experiments was bulked and ground to a powder using a Waring blender. Total nitrogen (N) was determined by digesting 0.25 g of dried tissue in H_2SO_4 and analyzing the digest colorimetrically using the Nessler reaction. Foliar levels of P, K, Na, Ca, Mg, S, Fe, Mn, Zn, Cu, and B were analyzed by microwaving 0.5 g of tissue in HCl and HNO_3 (CEM MDS 81D microwave, CEM Co., Matthews, NC) and quantified by inductively coupled plasma emission (ICP) spectroscopy (Thermal Jarrel ARL 3520 ICP-OES spectrophotometer, Fison Instruments, Deerborn, MI). Foliar levels of Cl were detected by titration of a filtered 1% (wt/vol) aqueous suspension of dried tissue using a chloridometer (Buchler Cottle Inc., Fort Lee, NJ). Concentrations are expressed as $\mu\text{Mol/g}$ of tissue.

Statistical analyses. Experiments were analyzed using factorial analysis of variance (ANOVA) for randomized block experiment (36). Regression analyses were performed where appropriate and best fit models were determined. Data on the percentage of vascular discoloration were transformed to square root of arcsine before analysis (36). All ANOVA, regressions, and mean separations using Tukey's test (36) were performed using Systat Statistical System V.5 (Evanston, IL).

RESULTS

Effects of *F. oxysporum* f. sp. *cyclaminis* on cyclamen. Inoculum of *F. oxysporum* f. sp. *cyclaminis* added at 0.0, 0.10, 0.25, 0.50, 1.00, or 2.00 g of millet per liter of potting mix resulted in recovery of 0.0, 0.18, 0.54, 0.62, 1.00, or 1.81×10^5 CFU of *F. oxysporum* f. sp. *cyclaminis* ($\times 10^5$ per ml of potting mix), respectively (Fig. 1). The relationship between the inoculum (X) and recovery of the pathogen

(Y) was linear ($Y = 0.15 + 0.85X$, $r^2 = 0.90$, $P < 0.001$). Cyclamens grown in infested potting mix did not consistently show vascular discoloration in the corm until 0.25 g of colonized millet per liter of potting mix (5.4×10^4 CFU/ml of potting mix) was added. Fresh leaf weight (Y) decreased linearly with an increase in inoculum density (X) ($Y = 30.0 - 3.9X$, $r^2 = 0.60$, $P = 0.04$). The number of flowers per plant (Y) decreased in a curvilinear pattern as inoculum (X) increased ($Y = 5.2 - 5.5X + 1.6X^2$, $r^2 = 0.50$, $P < 0.001$). Based on these experiments, inoculum densities of 0.50 g of colonized millet per liter of potting mix (approximately 6.2×10^4 CFU of *F. oxysporum* f. sp. *cyclaminis* per ml of potting mix) were used to provide a consistent level of disease pressure without overwhelming the plant.

Effect of NaCl on growth of cyclamen.

The EC of the potting mix leachates 1 week after the addition of 0.0, 0.25, 0.50, 1.00, 2.00, or 4.00 g of NaCl per liter of potting mix measured 1.1, 1.5, 3.0, 3.8, 8.7, or 19.0 dS/m, respectively. After 1 month, plant stunting and necrosis of the leaf margins became apparent on plants that had received 2.00 or 4.00 g of NaCl per liter of potting mix. Weekly ratings of salt damage resulted in AUDPC values (Y) that increased ($Y = 58.2 + 7.0X^2$, $r^2 = 0.65$, $P < 0.001$) as the rate of NaCl (X) increased (Fig. 2). No symptoms were observed on plants treated with 1.00 g of NaCl per liter of potting mix except for a delay in flowering (data not shown). The leaf weights of plants exposed to 0.25 and 0.50 g of NaCl per liter of potting mix were significantly greater than the leaf weights of plants not receiving any NaCl. Fresh and dry leaf weights were strongly correlated ($R = 0.91$, dfe = 70, $P < 0.001$)

at all rates of NaCl application. Root weights were not adversely affected at 0.25 and 0.50 g of NaCl per ml of potting mix, but rapidly decreased as the NaCl rate increased to 1.00 g/liter of potting mix. Flowering was delayed when plants were treated with 0.50 and 1.00 g of NaCl. The same number of flower buds was observed on these plants compared with nontreated plants over the duration of the experiments (data not shown). The higher rates of 2.00 or 4.00 g/liter of potting mix completely inhibited flower development.

Effect of NaCl on Fusarium wilt.

Foliar symptoms of chlorosis and wilt developed rapidly on plants grown in infested potting mix with no NaCl applied. Disease symptoms also developed on plants treated with NaCl, but they were less severe on plants that had been treated with 0.50 g of NaCl per liter of potting mix than on plants treated with 0.25 or 1.00 g per liter (Fig. 3). Plants treated with 0.25 and 0.50 g of NaCl per liter of potting mix grew faster than untreated plants.

Effect of potting mix pH and NaCl on Fusarium wilt. Fresh leaf weight was not affected by the pH of potting mix in pots not receiving NaCl amendments (Table 1). However, a few lower leaves of plants grown in potting mix at the highest pH were chlorotic, and the rest were not as green as plants grown at the lower pH. These symptoms did not develop when the potting mix at the highest pH was amended with NaCl. Plants grown in potting mix infested with sterile millet adjusted to pH 7.2 had more leaf area when treated with NaCl. Mean number of flowers was not affected by the treatments (data not shown). Sodium chloride amendments significantly decreased the AUDPC values for plants grown in potting mix with an

Fig. 3. Effect of NaCl amendments to potting mix on fresh leaf weights of cyclamen (Halios series) grown in potting mix infested with *Fusarium oxysporum* f. sp. *cyclaminis* (●) and noninfested potting mix (○), and on the percentage of vascular discoloration in the corms of cyclamens grown in infested soil (△). Values represent the means of 12 replicates. Error bars represent standard errors of the mean.

Table 1. Effects of NaCl and potting mix pH on the growth of cyclamen (Halios series) grown in potting mix infested or not infested with *Fusarium oxysporum* f. sp. *cyclaminis*

Initial pH ^t	NaCl ^u	Noninfested potting mix		Infested potting mix ^v	Final pH ^u
		Fresh leaf wt (g) ^w	Leaf area (cm ²) ^x	AUDPC ^y	
5.1	Control	17.1 ab ^z	231.2 b	277.1 ab	5.6 a
5.1	NaCl	18.9 ab	237.4 b	237.4 a	5.6 a
6.3	Control	15.9 a	214.6 ab	412.5 c	6.3 b
6.3	NaCl	20.1 b	260.7 b	299.2 a	6.4 b
7.2	Control	14.7 a	196.4 a	345.0 bc	7.4 c
7.2	NaCl	20.5 b	241.0 b	247.3 a	7.3 c

^t pH of potting mix 1 week after adjustment with H_2SO_4 and hydrated lime. Potting mix pH was determined on a 1:1 potting mix:water sample using a calibrated pH meter. Final pH was similarly determined 10 weeks later.

^u Sodium chloride applied as a granular application (0.25 g/liter potting mix).

^v Plants were grown in potting mix infested with ground millet colonized by *F. oxysporum* f. sp. *cyclaminis* (0.5 g inoculum per liter potting mix).

^w Fresh weight includes leaves and petioles only. All plants grown in infested potting mix had died by the end of the experiment.

^x Leaf area was determined with a leaf area meter (Delta-T Devices, Pullman, WA).

^y Area under the disease progress curve (AUDPC, days); disease ratings recorded weekly using the scale: 0 = no disease observed, 1 = slight stunting, 2 = slight stunting and chlorosis of leaves, 3 = <10% of leaves showing chlorosis and/or 10% of plant with wilt symptoms, 4 = <11 to 25% of plant with wilt symptoms, 5 = 26 to 50% of plant with wilt symptoms, and 6 = 51 to 100% of plant with wilt symptoms or plant death. Disease severity was calculated as the AUDPC using the equation: $AUDPC = \sum (Y_i + Y_{i+1})/2 * (t_i - t_{i+1})$ where Y_i = disease rating at time t_i .

^z Values represent the means of 12 replicate plants; values in columns followed by differing letters are significantly different according to Tukey's test at $P = 0.05$.

initial pH of 6.3 or 7.1, but not at a pH of 5.1. Final disease severity rating did not differ significantly among any of the treatments (data not shown).

Effect of NaCl on mineral composition of cyclamen leaves. Increasing the amount of NaCl added to the potting mix proportionately increased the leaf concentrations of Na and Cl. Leaf concentration of Mn increased as the NaCl rate increased to 0.5 g/liter of potting mix, but then decreased at the higher rate of 1.0 g/liter of potting mix (Table 2). Leaf concentrations of P, Ca, Mg, S, and B declined as the amount of NaCl added to the potting mix increased. Levels of leaf N, K, Fe, Zn, and Cu were not affected by the amount of NaCl applied (data not shown) and averaged 733, 1,035, 1.1, 0.6, and 0.1 $\mu\text{Mol/g}$, respectively.

The greater the pH of the potting mix, the higher the amount of foliar Mg (Table 3). Increasing the pH of the potting mix decreased leaf S, Mn, Fe, Zn, and B. As before, treatment with NaCl increased leaf Na and Cl while decreasing most other elements. Sodium chloride increased leaf concentrations of Mn in plants grown in potting mix of pH 7.3 only. Neither the pH of the potting mix nor NaCl affected leaf concentrations of N, K, or Cu.

DISCUSSION

Fusarium wilt of cyclamen is an economic constraint for most growers. Current management includes sanitation and fungicide drenches. This report examined the influence of inoculum, potting mix pH, and NaCl on the development of Fusarium wilt. Vascular discoloration was consistently observed in the corms of plants

when a threshold of 5.4×10^4 CFU of *F. oxysporum* f. sp. *cyclaminis* per ml of potting mix was reached. However, Rattink (29) found that cyclamens grown in an ebb-and-flow system remained disease-free until an inoculum concentration of at least 10^5 conidia per ml was present in the irrigation water. Rattink (29) suggested that if the irrigation water had been agitated, this inoculum threshold might have been lower. There are major differences between the current study and that of Rattink which could affect the threshold, such as the growing medium. In field soils, inoculum levels of 50 to 500 CFU/ml of soil have been reported to cause severe disease (12,16,34,38). The major propagules in field soil are the overwintering chlamydospores; whereas in the greenhouse, microconidia, macroconidia, and chlamydospores may be involved in disease. Rowe et al. (31) found that microconidia of *F. oxysporum* f. sp. *radicis-lycopersici* could be airborne in the greenhouse and reinfest steamed soil. Rekah et al. (30) also found that airborne conidia of *F. oxysporum* f. sp. *basilici* could spread Fusarium wilt among tomatoes and basil grown in greenhouses in Israel.

Public demand for high-quality cyclamens has motivated growers to find new solutions for suppression of Fusarium wilt. Growers currently use fungicide drenches for disease management. Cyclamen was hypothesized to be salt-tolerant because it originated in the arid Middle East (2). Visual evidence of salt damage to cyclamen in this study was not observed until plants had been exposed to more than 1 g of NaCl per liter of potting mix. The EC of the leachates from these pots averaged 3.8

dS/m. Using the categories of the USDA salinity laboratory (24), cyclamen would be considered moderately salt-sensitive to moderately salt-tolerant. The application of NaCl at 0.25 g/liter of potting mix promoted growth, but this growth benefit did not affect disease development. Therefore, NaCl application delayed the onset of symptoms but did not reduce the final disease. Sodium chloride improved growth and reduced disease on asparagus and beets (7,8,10), but the mechanism remains unclear. Sodium chloride may improve the photosynthetic efficiency of beets during periods of drought (6) and function in the replacement of K (25). There was no evidence of Na replacing K in this study on cyclamen. On asparagus, NaCl has been implicated in altering water potential of the ferns (13). The effect of water deficits on the growth of cyclamen was not evaluated in the current study, although heat and drought stresses are known to be conducive to outbreaks of Fusarium wilt of cyclamen (5). Under conditions of heat and drought stress, NaCl may lower the leaf water potential and increase host resistance.

It is known that Fusarium wilts in general are more severe in acid soil (22). Production guides for cyclamen recommend a soil pH of 6.0 to 6.5 (5). However, the current study found potting mix pH from 5.1 to 7.2 to have no significant effect on disease progress. Plant quality was also not adversely affected at the low pH of 5.1. Lower soil pH can increase the availability of micronutrients (19), as is evident in the foliar analyses of cyclamens. Foliar levels of N and K were not affected by increasing rates of NaCl, so the chlorotic leaves observed on plants grown at the higher pH

Table 2. Effect of NaCl rate on leaf composition of cyclamen (Halios series)

NaCl/liter potting mix ^y	$\mu\text{Mol/g tissue}$							
	P	CA	Mg	Na	Cl	S	Mn	B
0	116.2 ^z	233.5	189.2	288.5	52.2	195.4	0.7	9.7
0.25	93.3	223.3	171.5	736.2	162.4	145.2	0.7	8.4
0.50	86.7	205.9	141.6	905.8	215.1	121.2	0.9	7.5
1.00	82.2	159.4	122.9	1,073.4	277.6	117.0	0.6	5.2
Linear	0.02	0.03	0.001	0.001	0.001	0.001	0.05	0.001

^y Sodium chloride applied as a granular application to pots 1 week after planting.

^z Values represent the mean of four replicate samples (three plants were pooled into sample).

Table 3. Mineral composition of cyclamen leaves treated with NaCl at varying soil pH

Soil pH ^x	NaCl ^y	$\mu\text{Mol/g tissue}$									
		P	Mg	Na	Cl	S	Fe	Mn	Zn	B	Cu
5.1	-	94.9 ^a	172.3 a	237.2 a	35.5 a	198.0 a	1.7 a	2.1 a	0.4 b	8.5 a	6.6 b
5.1	NaCl	86.8 ab	175.8 a	790.6 b	149.3 c	182.5 a	1.2 b	2.0 a	0.4 b	8.9 a	7.4 b
6.3	-	98.2 a	223.1 ab	299.1 a	20.0 a	130.2 ab	1.1 b	1.2 b	0.5 a	7.5 ab	10.5 a
6.3	NaCl	84.7 ab	158.3 a	853.7 b	80.3 b	100.2 b	0.9 b	1.7 ab	0.4 b	7.5 ab	5.7 b
7.2	-	98.5 b	280.0 b	290.5 a	18.9 a	122.3 b	0.9 b	0.7 b	0.4 b	5.2 c	8.7 ab
7.2	NaCl	73.7 b	243.7 ab	812.2 b	67.7 b	110.8 b	0.8 b	1.0 b	0.3 c	4.8 c	4.2 c

^x pH of potting mix 1 week after adjustment with H_2SO_4 or hydrated lime. Potting mix pH was determined on a 1:1 potting mix:water sample using a calibrated pH meter. Final pH was similarly determined 10 weeks later.

^y Sodium chloride applied as a granular application (0.25 g/liter potting mix).

^z Values represent the means of 12 replicate plants; values in columns followed by differing letters are significantly different according to Tukey's test at $P = 0.05$.

may have been associated with a micronutrient deficiency. This deficiency was not observed on plants treated with NaCl, which resulted in plants with higher levels of Mn, Na, and Cl. An increase in foliar Mn and plant growth following chloride applications has been observed by other researchers (9,11,17,21).

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