

Sodium Chloride Resistance in Selected Cultivars of *Hedera helix*

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Abstract. Two experiments were conducted to determine the relative resistance of 33 selected cultivars of English ivy (*Hedera helix* L.) to soil- and shoot-applied NaCl. In the soil-applied NaCl experiment, ramets of the 33 cultivars were irrigated with a fertilizer + 0.25-N NaCl solution for 55 days. 'Harrison', 'Hibernica', 'Thorndale', 'Wilson', and 'Woerner' exhibited the least amount of visible shoot damage. Dry weights of all cultivars were much lower in the salt treatment. In the shoot-applied NaCl experiment, plants were sprayed daily with a 0.25-N NaCl solution for 48 days. The young leaves and stems of all cultivars were severely injured by the salt spray, while the mature leaves and stems and the dormant buds were only slightly injured. Reduction in dry weight varied between cultivars. Two subsequent experiments focused on resistance to soil-applied NaCl. Ramets of the NaCl-resistant 'Harrison', 'Hibernica', and 'Thorndale', and the NaCl-sensitive 'Baltica', 'Cathedral Wall', and 'Wingertsberg' were irrigated with a fertilizer + 0.25-N NaCl solution for 48 days. Whole-plant Cl content for all six cultivars was in the range of 30,000 ppm. Ramets of 'Thorndale' and 'Cathedral Wall' were irrigated with a fertilizer + 0.25-N NaCl solution for 30 days with replicate plants harvested at 5-day intervals. 'Cathedral Wall' accumulated more Cl at a faster rate than 'Thorndale'. Mean whole-plant Cl concentration peaked at 97,000 ppm for 'Cathedral Wall' and 40,000 ppm for 'Thorndale'. Salt resistance may be partly based on slower uptake of Cl.

English ivy is an evergreen vine native to Europe and western Asia, having more than 400 known variants (S.M. Sulgrove, personal communication). *Hedera helix* is one of the most valuable plants for ground and wall cover. It can grow in sun and shade and in a wide range of soils. Variants of this species may be grown in U.S. Dept. of Agriculture (USDA) zones 4-9 (Flint, 1983). *Hedera helix* presently is being used to plant traffic medians and roadside areas. In northern areas of the United States, NaCl in the form of rock salt is extensively used to melt ice on roadways in winter. Salt may come in contact with a roadside plant in two ways: 1) salt-contaminated runoff may drain into nearby plantings, thus inundating the root

system; or 2) traffic-generated salt spray may drift from the roadway onto the leaves and stems. There is abundant evidence that rock salt is injurious to roadside vegetation (Hanes et al., 1970; Sucoff, 1975; Westing, 1969). One of the easiest ways to prevent salt damage is to use plants known to be salt-resistant.

Dirr (1975) studied the effects of soil- and shoot-applied salts on one variant of *H. helix*. He reported that *H. helix* is fairly resistant to soil-applied NaCl, but is severely damaged by shoot-applied NaCl. He determined that the damage was due specifically to Cl⁻ ion toxicity and not to Na⁺ ion toxicity or the osmotic effect of the salt. Brawley and Mathes (1990) compared five cultivars of *H. helix*, but found only a small range of salt resistance among these cultivars.

The purpose of this study was to determine whether there is a range of NaCl resistance in this species and to help elucidate the mechanism of resistance if it existed. First, 33 selected cultivars of *H. helix* were screened for resistance to soil- and shoot-applied NaCl. Because these cultivars varied greatly in resistance to soil-applied NaCl but varied little in resistance to shoot-applied NaCl, the remainder of this study focused on the mechanism of soil-applied NaCl resistance. The amount and the rate by which Cl is accumulated was compared for a small set of salt-

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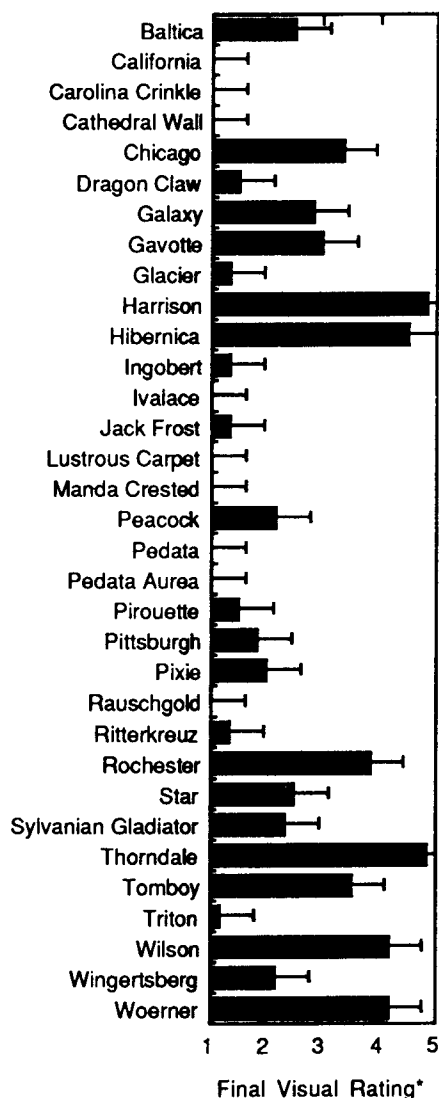


Fig. 1. Comparison of shoot condition of 33 cultivars of *Hedera helix* in response to soil-applied salt (0.25 N NaCl). *Final visual rating: 1 = shoot 96% to 100% necrotic; 5 = shoot 0% to 5% necrotic. Each error bar represents LSD 0.05 of 0.62 visual rating units.

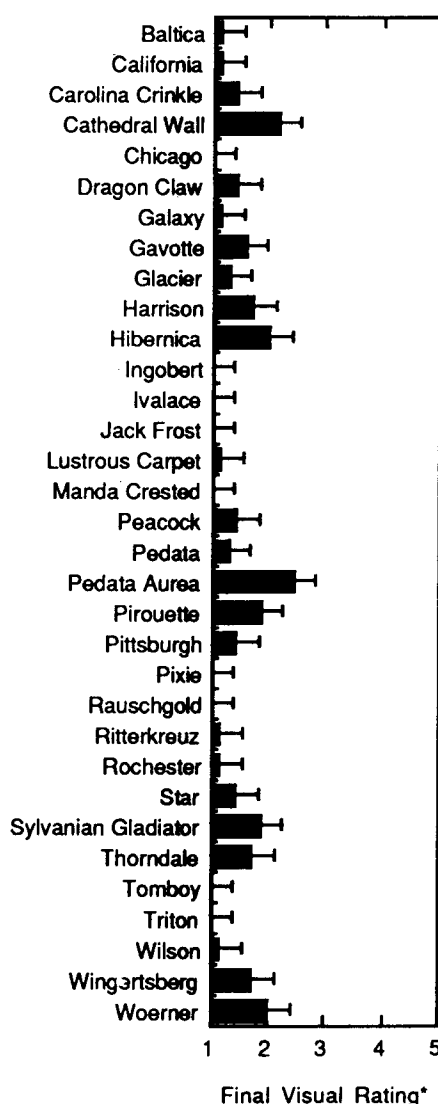


Fig. 2. Comparison of young shoot condition of 33 cultivars of *Hedera helix* in response to shoot-applied salt (0.25 N NaCl). *Final visual rating: 1 = stems and leaves 100% necrotic; 5 = stems healthy, leaves 0% to 5% necrotic. Each error bar represents LSD 0.05 of 0.39 visual rating units.

resistant and salt-sensitive cultivars. A plant that takes up large amounts of Cl can become saturated to the point of toxicity and death. Furthermore, a plant that accumulates Cl too quickly may not have time to adapt, osmotically or otherwise, before toxic levels are reached. Studying the mechanism of salt resistance in *H. helix* may lead to a better understanding of salt stress and may determine ways to manage this problem in this and other species.

Plant material. Thirty-three cultivars of *H. helix* selected for this study represent the wide morphological diversity within the species. The American Ivy Society plant identification number is provided for each clone. The cultivars were: 'Baltica' (83-63), 'California' (88-264), 'Carolina Crinkle' (88-267), 'Cathedral Wall' (79-149), 'Chicago' (88-269), 'Dragon Claw' (88-198), 'Galaxy' (81-120), 'Gavotte' (88-206), 'Glacier' (88-208), 'Harrison' (79-330), 'Hibernica' (85-55, syn. *H. hibernica* Kirchn.), 'Ingobert' (81-72),

'Ivalace' (88-215), 'Jack Frost' (79-292), 'Lustrous Carpet' (79-268), 'Manda Crested' (88-221), 'Peacock' (88-230), 'Pedata' (88-231), 'Pedata Aurea' (79-4), 'Pirouette' (83-183), 'Pittsburgh' (79-221), 'Pixie' (88-233), 'Rauschgold' (81-195), 'Ritterkreuz' (81-199), 'Rochester' (88-236), 'Star' (88-243), 'Sylvanian Gladiator' (79-170), 'Thorndale' (88-247), 'Tomboy' (88-249), 'Triton' (79-24), 'Wilson' (80-70), 'Wingertsberg' (81-194), and 'Woerner' (79-428). These cultivars are known or are thought to be cold-hardy to at least USDA zone 7 (Sulgrove, 1988). Ramets of the 33 cultivars of shoot length 20 to 60 cm were grown in 0.4-liter plastic pots in a 1 peat : 1 perlite (v/v) mixture amended with 1.14 kg triple superphosphate/m³, 3.5 kg calcium nitrate/m³, and 0.60 kg dolomitic limestone/m³. Plants were irrigated with a solution of Peter's Peat-Lite Special fertilizer (20.0N-4.2P-16.6K) with trace elements at a rate of 300 ppm N. The

plants were grown in a greenhouse at 20C day/16C night under 18 h daylength maintained by supplemental HID illumination at a height of 1.75 m.

Soil-applied salt (Expt. 1). Potted plants were placed onto a lath-covered greenhouse bench, and the shoots were supported by wire. Every 2 to 3 days, all pots were leached with two 150-ml overhead applications of tap-water followed by a 300-ml application of fertilizer solution of the formulation noted (control) or a 300-ml application of fertilizer solution plus NaCl. To reduce osmotic shock, the NaCl concentration of the salt treatment was gradually increased to 0.25 N in three steps over the first week of the experiment. Electrical conductivities (EC) of the irrigation solutions of the control and salt treatment were 0.1 and 3.1 S·m⁻¹, respectively. All solutions were delivered to the pots via a drip irrigation system. The experiment was designed as a factorial arrangement of 33 cultivars and two treatments with six replicates in a complete randomized block (CRB) design. The soil-applied experiment was terminated after 55 days.

Condition of the shoot of each plant was evaluated visually. Based on the damage, a pretransformed five-step scale was developed to assign a final visual rating (FVR) to each plant, where: 1 = shoot dead or nearly so, 96% to 100% necrotic; 2 = shoot severely damaged, 66% to 95% necrotic; 3 = shoot moderately damaged, 36% to 65% necrotic; 4 = shoot lightly damaged, 6% to 35% necrotic; 5 = shoot healthy or nearly so, 0% to 5% necrotic. Plants were harvested, washed, then dried at 60C for 3 days and weighed. Relative growth (RG) for all cultivars was determined where RG = dry weight (DW) of plant in salt treatment/DW of plant in the control.

Shoot-applied salt (Expt. 2). The bottom and sides of a greenhouse bench were lined with a sheet of polyethylene. A second sheet of polyethylene was stretched over the top of the bench and slits were made in it. A potted plant was slipped through each slit so that only the shoot protruded above. The slits then were sealed with plastic adhesive tape. The upper plastic sheet prevented any salt from coming in contact with the soil mix in the pots. Plants were bottom-irrigated by periodically flooding the bench to a depth of 2 cm with fertilizer solution of the same formulation as above. Plants were sprayed daily with either distilled, deionized water (control), or 0.25 N NaCl using a pressurized hand sprayer at a pressure of 280 to 420 kPa until liquid was dripping off the foliage. The experiment was designed as a factorial arrangement of 33 cultivars and two salt treatments with seven replicates in a randomized split-block (RSB) design. Plants were grown under the same temperature and light regimes as mentioned above. The experiment was terminated after 48 days because little change in plant condition occurred during the final 3 weeks.

Condition of the shoots then was visually evaluated. There was a differential response to the salt spray between the older (the prox-

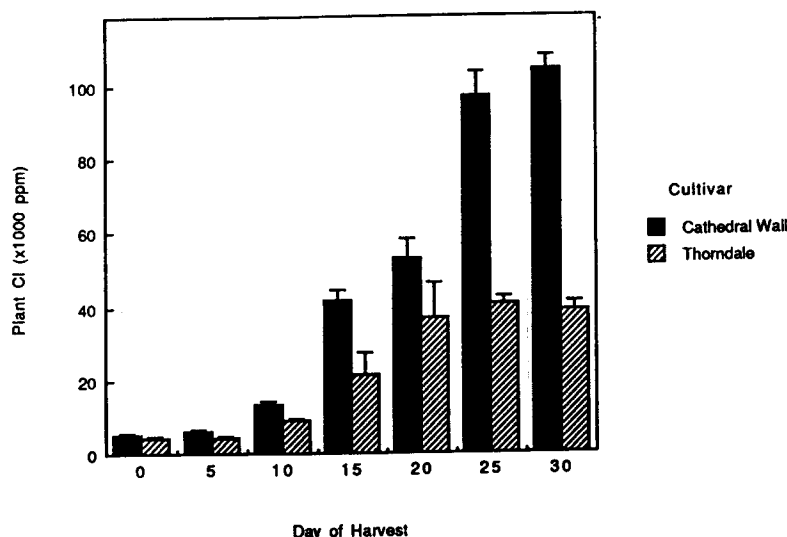


Fig. 3. Comparison of rate of chloride accumulation by *Hedera helix* cultivars Cathedral Wall and Thorndale in response to soil-applied salt (0.25 N NaCl). Bars represent SE.

imal 1/2 to 2/3) and the younger (the distal 1/2 to 1/3) portions of the shoot. Therefore, the portions were evaluated separately. Based on the nature of the damage, a pretrans-formed five-step scale was used to assign a FVR where: 1 = stems and leaves 100% necrotic; 2 = stems healthy and leaves 91% to 100% necrotic; 3 = stems healthy and leaves 41% to 90% necrotic; 4 = stems healthy and leaves 6% to 40% necrotic; 5 = stems healthy and leaves 0% to 5% necrotic. Plants were harvested, washed, then dried at 60C for 3 days and weighed. Relative growth was determined as described above.

Comparison of six cultivars of varying soil salt resistance for whole-plant accumulation of Cl (Expt. 3). Ramets of the NaCl-resistant 'Harrison', 'Hibernica', and 'Thorndale', and the NaCl-sensitive 'Baltica', 'Cathedral Wall', and 'Wingertsberg' of 40 to 60 cm initial shoot length were irrigated for 48 days with either fertilizer solution or fertilizer + 0.25 N NaCl solution. The experiment was designed as a factorial arrangement of six cultivars and two salt concentrations with 10 replicates in a complete randomized (CR) design. The irrigation solution formulation, irrigation schedule, irrigation method, temperature, and daylength regimes were the same as above.

Plants were evaluated with the five-step scale used for the soil-applied salt experiment. Plants were then harvested, washed, and rinsed with two 10-sec rinses in tap water and one 10-sec rinse in deionized distilled water. Plants then were dried at 65C for 3 days. Dried plant samples were ground in a mill equipped with a 40-mesh screen. A 0.15-g dry sample was mixed into 40 ml of 0.125 N HNO₃ for 15 min and allowed to settle for 1 h. Ten milliliters of 0.5 N KOH was added to raise the pH of the mixture to 1.5. A 10-ml aliquot of extract was mixed with 10 ml 1.0 N KNO₃ and used for Cl analysis. Direct potentiometric measurement of Cl was performed using an ion meter (model 130; Corning Glass Works, Medfield, Mass.) equipped with a combination Cl electrode

(model 9617BN; Orion Research, Boston) and a set of standards.

Comparison of two cultivars for rate of accumulation of Cl (Expt. 4). Ramets of 'Cathedral Wall' and 'Thorndale' were irrigated every 2 to 3 days for 30 days with a fertilizer + 0.25 N NaCl solution. A set of plants of each cultivar was harvested at 5-day intervals and analyzed for Cl content as described above. The experiment was designed as a factorial arrangement with two cultivars and seven harvest dates with six replicates in a CR design. The NaCl-amended irrigation solution formulation, irrigation schedule, irrigation method, temperature regimes, and daylength were as described above.

Statistical analysis. Analysis of variance (ANOVA) was performed on the experimental data. For Expts. 1 and 2, Fisher's least significant difference (LSD) test was used to compare cultivars. For Expts. 3 and 4, Tukey's studentized range (HSD) test, as well as linear contrasts, were used to compare cultivars within each treatment. Comparisons of means were conducted at $P = 0.05$. Statistical analysis was performed using the general linear models procedure of SAS, version 5.16 (SAS Institute, Cary, N.C.).

'Harrison', 'Thorndale', 'Hibernica', 'Wilson', and 'Woerner' exhibited the least phytotoxicity to soil-applied NaCl (Fig. 1). 'California', 'Carolina Crinkle', 'Cathedral Wall', 'Ivalace', 'Lustrous Carpet', 'Manda Crested', 'Pedata', 'Pedata Aurea', and 'Rauschgold' exhibited the most. Dirr (1975) reported that a variant of *H. helix* was resistant to the osmotic effect and Na⁺ of soil-applied NaCl but was sensitive to Cl⁻. Therefore, the five cultivars that sustained the least visible damage are not only resistant to the osmotic effect and Na⁺ toxicity, but also to Cl⁻ ion toxicity. Dry weight of plants of all 33 cultivars in the soil-applied NaCl treatment was 15% to 30% of the control (detailed data not shown). Cultivars that performed marginally better than the rest include 'Peacock', 'Pixie', and 'Carolina

Crinkle'. When evaluating the performance of ornamentals in response to stress, however, appearance of the plant may take priority over rate of growth (Bernstein et al., 1972). Therefore, when screening for superior salt resistance, as in the case of *H. helix*, cultivar selection should be based primarily on appearance and secondarily on growth rate.

The old growth of most cultivars suffered little or no visible damage from shoot-applied NaCl (data not shown). In contrast, the actively growing apices and the young stems and leaves of all cultivars were severely damaged by salt spray (Fig. 2). Following the death of the shoot meristems, the dormant axillary buds commenced active growth, but the resulting young shoots also were killed by the salt spray. Growth of most cultivars was adversely affected (35% to 60% of control on a dry-weight basis) by the daily application of salt spray, although effects were generally not as severe as in the soil-applied salt experiment, presumably due to the shorter duration of treatment. Growth was least affected by shoot-applied NaCl in 'Peacock', 'Pirouette', 'Jack Frost', and 'Sylvanian Gladiator', and most affected in 'Rochester', 'Glacier', and 'Cathedral Wall'.

Simini (1984) proposed that NaCl-contaminated water is unlikely to penetrate a leaf via the stomates, but rather through the leaf's epicuticular wax and cuticle. More epicuticular wax is deposited on a leaf's surface over time (Skoss, 1955) and leaf cuticle thickens with age (Leopold and Kriedemann, 1975). As a result, older leaves (and stems) repel polar liquids, like water, better than younger ones. Thus, older shoot material is more resistant to foliar-applied NaCl than is younger material probably because of its ability to exclude salt from sensitive sites within the shoot.

Salt may be a problem in two landscape situations. Salt spray in coastal areas may affect growth year around, damaging and killing new growth as it arises; *H. helix* in such a situation would perform poorly. In areas adjacent to roadways and sidewalks that receive de-icing salts in winter, plants of *H. helix* may be exposed to both soil- and shoot-applied salt generally only during the dormant season. In this situation, there may be significant interaction between salt exposure and cold hardiness in this species, because NaCl can reduce cold hardiness in plants (Levitt, 1980; Sucoff and Hong, 1976). However, evidence indicates this only happens when NaCl is present inside the tissues of the plant. For soil-applied NaCl, cultivars demonstrating resistance to soil-applied NaCl at room temperature may not show good resistance during winter, if plants accumulate NaCl in winter. However, because salt uptake by roots is greatly reduced during the winter (Walton, 1969), the problem of reduced hardiness may not be significant. For shoot-applied NaCl, minor damage would be expected because only small amounts of NaCl would penetrate the shoot since most, if not all, of the shoot is mature growth with thick cuticles and waxes on its surfaces. Only more research will determine if this is the case.

Clearly, time of salt application and the prevailing temperature need to be taken into consideration when evaluating NaCl resistance. In areas that receive large amounts of salt-contaminated run-off from a nearby road, a cold-hardy *H. helix* cultivar that has been shown to be resistant to soil-applied NaCl might be grown successfully.

In Expt. 3, plants of 'Hibernica', 'Thorndale', and 'Baltica' displayed the least amount of damage (FVR of 3.6, 3.8, and 3.4, respectively) from soil-applied NaCl. 'Cathedral Wall' and 'Wingertsberg' sustained major shoot damage (FVR of 1 and 1.9, respectively). There was a significant difference in shoot damage between 'Cathedral Wall' and the three resistant cultivars. However, all plants to which salt was applied accumulated large amounts of Cl ($30,000 \pm 2200$ ppm on a dry-weight basis).

Plants of 'Cathedral Wall' accumulated roughly the same amount of Cl in 24 days (all plants of this cultivar were dead by day 24) as the resistant cultivars in 48 days. Assuming an end to Cl accumulation at death, plants of 'Cathedral Wall' accumulate Cl about twice as fast as the resistant cultivars. 'Cathedral Wall' may accumulate Cl so fast that it may not have time to adapt to high levels of Cl.

All plants of Cl-sensitive 'Cathedral Wall' were dead by day 15, while only 20% of the plants of the more salt-resistant 'Thorndale' were dead at the conclusion of the experiment on day 30. During the experiment, 'Thorndale' had accumulated much less Cl than 'Cathedral Wall' (Fig. 3). 'Cathedral Wall' not only took up Cl faster than 'Thorndale', but also accumulated Cl to extremely high levels (up to 116,000 ppm or 11.6% in some plants). This amount is much higher than the 30,000 to 40,000 ppm level reported by Dirr (1975). In addition, this level of Cl for 'Cathedral Wall' was much higher than that found in Expt. 3. This difference might have been due to leaching of Cl from the necrotic plant tissues continued overhead irrigation with tap water to remove excess salts from the media in Expt. 3. Leaching of Cl occurs faster from necrotic regions of needles in *Pinus strobus* than from living tissue, resulting in lower Cl content for necrotic tissue (Hofstra and Hall, 1971; Hall et al., 1972).

The results of Expts. 3 and 4 suggest that Cl resistance of 'Thorndale' may be based on a Cl⁻ ion exclusion mechanism and/or an ability to sequester Cl away from sensitive sites. However, no evidence of either mechanism at the supercellular level was found using X-ray microanalysis (Headley, 1990). Therefore, the data suggest 'Thorndale' has one or more of the following: 1) a slower Cl⁻ ion uptake/transport mechanism; 2) its physiological processes tolerate higher levels of Cl; 3) it can safely localize Cl in subcellular parts (such as in the vacuole of the cell).

Results from this study indicate that *H. helix* exhibits differences in sensitivity to salt between young and mature shoots and may be used in locations where plants are exposed to salt spray only during the dormant

season. With careful cultivar selection, *Hedera helix* may be used successfully in landscape situations where salt is a problem.

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