Effect of Photoperiod, Temperature, and Relative Humidity on Chloride Uptake of Plants Exposed to Salt Spray

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ABSTRACT

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Eleven plant species that vary widely in growth rate, habitat adaptation, leaf structure, and morphology were exposed to airborne salt spray dosages commonly found within 600 m of the New Jersey seacoast. After salting, the plants were exposed to various conditions of temperature, relative humidity, and photoperiod. Foliar chloride content of salted and unsalted plants was measured. Most of the species tested absorbed more chloride when exposed to shorter photoperiods, lower temperatures, and higher relative humidities. High relative humidity is believed to alter the physical and chemical properties of both the salt particles and plant tissues. Increased light and temperature may induce structural changes in the cuticle and epicuticular waxes of leaves, thereby decreasing their permeability.

Additional key words: climatic factors, cuticular wax, salt aerosol, sodium chloride.

Evaporative salt-water cooling towers, which were developed recently to dissipate thermal pollution from energy-generating plants, produce saline spray drift (15,27). The question of environmental impact of spray from these cooling towers arises, therefore, from the known detrimental effects of airborne salt on vegetation (5,17,28). Plants growing in coastal areas or along roadways salted for deicing purposes often display foliar injury attributable to wind-driven salt (4,9,10,12,13,16,19,22,24,32). Plant injury caused by airborne salt-water spray in nature has been simulated under controlled conditions (14,18,25,31). However, there have been few detailed studies of the effects of environmental variables on the amount of salt absorbed into leaves (3,14). An understanding of these effects would enable selection of species with desirable characteristics or the use of techniques that alter the foliar absorption of chloride making susceptible plants less susceptible to salt-spray injury.

The purpose of this study was to determine the effect of day length, temperature, and relative humidity (RH) on chloride uptake by leaves of plant species with widely differing salt-spray tolerance.

MATERIALS AND METHODS

Cultural methods. Plant species representative of those commonly found in agricultural, roadside, and forest habitats were grown in the greenhouse. Seeds of bean (*Phaseolus vulgaris* 'Topcrop') and tomato (*Lycopersicon esculentum* L. 'Rutgers') were sown in vermiculite and seedlings were transferred to sterilized topsoil (7.6-cm-diameter pots) after the primary leaves had emerged. Bean seedlings were allowed to grow until the primary leaves were approximately one-quarter expanded (7–10 days old). Tomato seedlings were grown until 7–10 fully expanded leaves had emerged (21–30 days).

Two-year-old container-grown stock seedlings of white pine (*Pinus strobus*), Douglas fir (*Pseudotsuga menziesii*), mountain laurel (*Kalmia latifolia*), Norway spruce (*Picea abies*), red maple (*Acer rubrum*), arborvitae (*Thuja occidentalis*), holly (*Ilex opaca*), hybrid poplar (*Populus maximowiczii* × *P. trichocarpa*), and dogwood (*Cornus florida*) were purchased from a nursery, transferred to sterilized soil in 3.8-L plastic greenhouse containers, and allowed to grow until the leaves from a flush of new growth were fully expanded. All plants, herbaceous and woody, were selected for uniformity.

Salt treatment. A sedimentation chamber was constructed of a 1 × 1 × 1.5-m-high wooden frame covered with polyethylene (Fig. 1) (31). A resealable flap allowed access to the chamber. Salt spray was generated by delivering a synthetic seawater solution from a spinning-disk humidifier below the chamber. The synthetic seawater had the following composition (per liter): NaCl, 24.5 g; $MgCl_2$, 5.2 g; Na_2SO_4, 4.1 g; $CaCl_2$, 1.2 g; KCl, 0.7 g; $NaHCO_3$, 0.2 g; and KBr, 0.1 g (1). Salt particles were forced upward in a 1-m-high, 10-cm-diameter polyvinyl chloride pipe and outward into the chamber through holes near the top. The salt particles then settled to the bottom of the chamber. Plants (in groups of 10 replicates) were placed on the floor of the chamber and exposed to the airborne salt mist. Salt output was determined by placing open petri plates at the bottom of the chamber and measuring the amount of salt collected in the plates. Salt dosage was expressed as micrograms of chloride per unit area ($\mu g\ Cl^-/cm^2$).

Experimental plants were placed in the sedimentation chamber and exposed to salt spray at the rate of 20–25 $\mu g\ Cl^-/cm^2/hr$ for 6 hr. This level is similar to deposition rates commonly found in seashore areas and those expected near salt-water cooling towers (27). The plants were then placed in one of three controlled environment chambers (Scherer-Gillett model CEL 37-14) set at various combinations of temperature, photoperiod, and RH.

Five salted and five unsalted plants from each treatment were placed in each chamber for 72 hr. Leaves were then harvested and analyzed for chloride content. All experiments were repeated once.

Effect of photoperiod. White pine, Douglas fir, mountain laurel, dogwood, and Norway spruce plants were placed in each of the three growth chambers set at 8, 12, or 16 hr of daylight (60 hlx) at constant temperature (21 ± 2 C) and RH (80 ± 5%).

Effect of temperature. Poplar, arborvitae, holly, bean, and tomato plants were placed in each of three growth chambers set at 10, 21, or 32 ± 2 C at a constant photoperiod (12 hr) and RH (80 ± 5%).

Effect of RH and temperature. Tomato, holly, bean, and arborvitae plants were placed in each of three growth chambers set at 10, 21, or 32 ± 2 C and low (50 ± 5%) or high (80 ± 5%) RH and constant photoperiod (12 hr).

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Chloride analysis of plant tissues. After salt treatment and 72 hr in the controlled environment chamber, the plants were set on the greenhouse bench for 24 hr. Leaves were harvested, rinsed three times in distilled deionized H_2O, and dried in a forced-air oven at 75 C for 48 hr. The dried tissue was ground in a Wiley mill (Arthur H. Thomas, Philadelphia, PA 19106) fitted with a 20-mesh screen. Samples (100 mg) of tissue were allowed to soak in deionized water for 2 hr. The suspensions were then filtered through Whatman No. 4 filter paper, and the filtrates were diluted to 50 ml and analyzed for chloride by using a Buchler-Cotlove Chloridometer (6). Chloride content was expressed as percent of dry weight.

RESULTS

Chloride uptake by leaves, expressed as percent of control, was highest at the shortest (8 hr) photoperiod (Fig. 2) in all species except Douglas fir and decreased as the day length increased. Chloride uptake was highest at the lowest (10 C) temperature and decreased as the temperature increased in all species (Fig. 3). High humidity favored chloride uptake in most species at low temperatures (Fig. 4). Humidity appeared to have less effect on foliar absorption as the temperature increased. Holly reacted differently from the other species (Fig. 4d) in that more chloride was absorbed by plants exposed to low rather than high RH at 10 C.

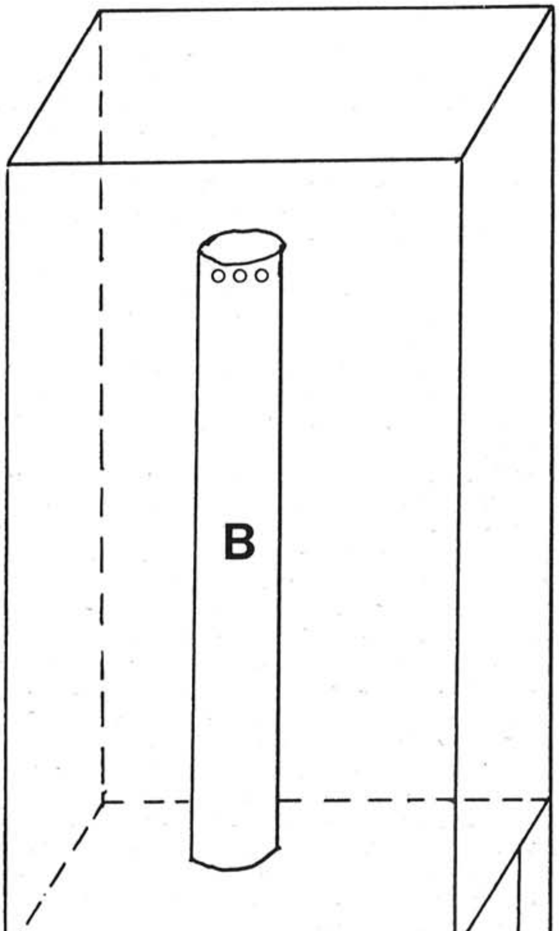

Fig. 1. Experimental salt mist sedimentation chamber with **A,** a spinning-disk humidifier and **B,** polyvinyl chloride pipe delivery column.

DISCUSSION

The increased foliar salt content during short-day conditions observed in this study may be due to decreased epicuticular wax production. Skoss (23) reported that ivy plants (*Hedera helix*) grown in direct sunlight are wetted less easily than those grown in shade. More wax and cutin are produced on sun leaves than on shade leaves. Increasing light intensity also induces greater leaf epicuticular wax deposition in *Brassica oleracea* (2,29).

In contrast to its effect on epicuticular wax, short day length may tend to decrease absorption by leaves. Sargent and Blackman (21) observed greater absorption of growth regulators, 2,4-D, and chloride by leaf disks of *P. vulgaris* in light than in darkness. Thorne (26) also reported decreased uptake by the foliage of

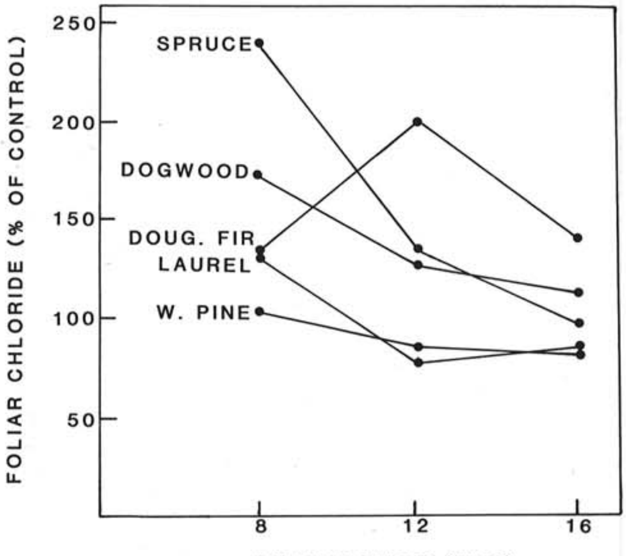

Fig. 2. Mean foliar chloride content of plants of five species exposed to synthetic seawater mist and to three photoperiods for 72 hr. Data are expressed as percent of chloride content of untreated control plants. Points on the graph represent the means of two experiments (10 replicates in each experiment).

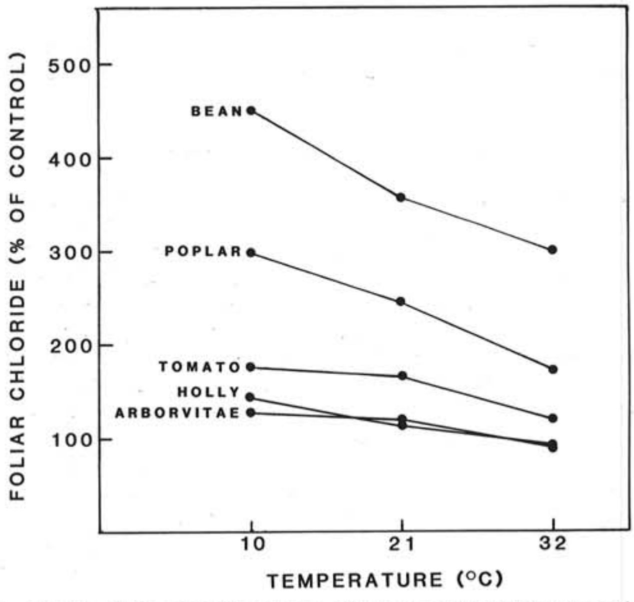

Fig. 3. Mean foliar chloride content of plants of five species exposed to synthetic seawater mist and subsequently to three temperature regimes for 72 hr. Data are expressed as percent of chloride content of untreated control plants. Points on the graph represent the means of two experiments (10 replicates in each experiment).

Brassica napus and *P. vulgaris* when the leaves were shaded. Both studies were performed in the laboratory on excised plant parts with a wetting agent added to the solution applied to the leaves. Absorption under these artificial conditions may vary greatly from that in field situations with intact plants. Douglas fir was the only species that absorbed less chloride when exposed during the 8-hr photoperiod than during the 12- or 16-hr photoperiod. The Douglas fir plants were stunted and chlorotic, conditions that could have altered leaf morphology (ie, wax and cuticle deposition) and resulted in differences in chloride absorption.

The increased foliar chloride absorption at the lower temperatures observed in this study may also be due to differences in cuticular and epicuticular wax production and structure. Greater wax production and more glaucous surfaces on leaves of tobacco plants grown at higher temperatures (23–30 C) have been associated with decreased wettability (23). Decreased wettability at higher temperatures may also be due to changes in the morphological structure of epicuticular waxes as observed by Whitecross and Armstrong (29) on *B. napus* leaves. Leaf epicuticular wax of plants grown at 15 C consisted of vertical rodlets; much of the cuticle was left exposed. On leaves of plants grown at 21 C, the upright rodlets were replaced by flat platelets lying parallel to the cuticular surface. These platelets developed into solid overlapping sheets at 27 C and coverage commonly exceeded 70% of the total surface area of the cuticle. Baker (2) observed similar results on leaves of *B. oleracea*. Holloway (11) also reported that a higher percentage of alkanes in epicuticular wax is associated with decreased wettability. Wilkerson and Kasperbauer (30) reported that epicuticular wax of tobacco contains significantly more alkanes when grown at longer and warmer (16 hr, 28 C) than at shorter and cooler (8 hr, 18 C) photoperiods and temperatures. Increased total wax and alkane percentage, resulting in decreased wettability of the leaf surface, could explain the lower chloride absorption by the leaves of plants grown at the shorter photoperiods and higher temperatures used in this study.

The effect of RH on chloride absorption into leaves depends upon the species and the ambient temperature. Salted leaves of bean, tomato, and arborvitae plants exposed to high RH at low temperatures absorbed significantly more chloride than those exposed to low RH. Logan (14) showed that high RH (75%) significantly increases chloride uptake in leaves of *Pinus strobus* and *P. thunbergii*. Grattan et al (8) obtained similar results with pepper, soybean, and tomato. Logan demonstrated that the salt remained in a solid form below 75% RH, but was solubilized when the RH was raised above 75%. In addition, Crafts (7) suggested that under high humidity conditions, cuticular pores become filled to capacity with moisture, extending the water continuum of the leaf as far as the surface. This causes the surface layers to become permeable to both polar and nonpolar substances (20). We found that the differences between RH treatments decreased as the temperature was increased. The salt particles probably remained in the solid form longer at the higher temperatures, regardless of RH, causing ion absorption to be more difficult. Holly is the only species that behaved differently, absorbing less chloride at 10 C under high- than under low-RH conditions. The differences may be due to different mechanisms of wax formation for holly than for the other species.

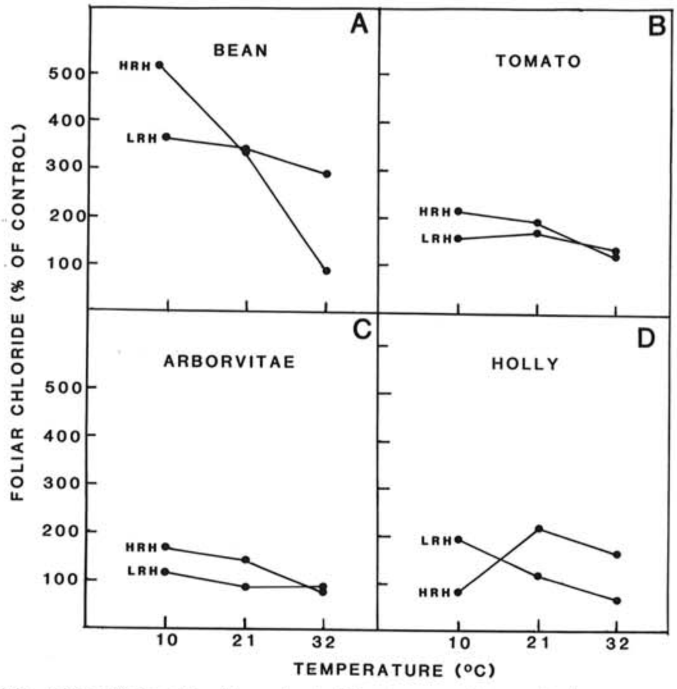

Fig. 4. Mean foliar chloride content of plants exposed to synthetic seawater mist expressed as percent of control of **A,** bean, **B,** tomato, **C,** arborvitae, and **D,** holly exposed to high (80 ± 5%) or low (50 ± 5%) relative humidity and three temperature regimes. Points on the graph represent the means of two experiments (10 replicates in each experiment).

Preliminary studies recently completed in this laboratory appear to support the role of epicuticular waxes as barriers to foliar chloride uptake. More intensive studies of cuticle and wax formation and structure are needed to confirm these data.

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