IDENTIFYING TREES WITH TOLERANCE TO SOIL SALTS[1]

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ABSTRACT.--Urban trees can be injured by deicing salts in the form of salt spray or salts in the soil. Soil salts can be an important factor in causing injury and death of trees planted close to a roadway. Such damage in urban areas usually results from a specific ion effect rather than from an increase in osmotic potential. At Delaware we are looking for systematic techniques and reliable markers to identify trees with tolerance to soil salts.

THE PROBLEM

IN THE UNITED STATES about 12 million tons of deicing salts are applied to Northeastern highways alone each year. Experts predict no decrease in the use of salt in the next decade, despite several alternatives available, such as sand, limestone, and cinders (Dirr 1976; Struzesk 1971). The two principal deicing salts are sodium chloride (NaCl) and calcium chloride ($CaCl_2$). NaCl makes up about 95% of usage, and $CaCl_2$ about 5% (Dirr 1976).

Although application of salts is necessary for traffic safety, damage occurs to adjacent roadside trees and shrubs. This injury has been well-documented in several American (Dirr 1976; Demeritt 1973; Sucoff 1975; Hanes et al. 1970), Canadian (Hofstra et al. 1979), and European (Buschbom 1968) reports and reviews. Sucoff (1975) has reported specific cases of damage in Germany, New England, and Minnesota. Damage to white pine (Hall et al. 1972) and sugar maple (Baker 1965; Hall et al. 1973; Lacasse and Rich 1964; and Westing 1969) is especially well documented, but many other species haveshown injury (Button et al. 1977; Walton 1969).

Highway and street trees estimated to be worth millions of dollars are killed each year as a result of salt (Demeritt 1973). Damage can manifest itself in leaf or needle scorch, branch dieback, disfigurement, loss of vigor, growth reduction, and sometimes death.

Trees can be injured by salt spray (salt deposited on twigs, buds, and needles); by salt that leaches into the soil (soil salt); or by a combination of these two. Many scientists believe that at least along major highways, salt spray causes more damage than salt absorbed from the soil (Dirr 1976; Sucoff 1975). Along city streets or where trees are

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within 9 m of the road, however, soil salt may be equally damaging or more so (Foster and Blaine 1978; French 1959; Hanes et al. 1976). For example, Sucoff (1975) found that damage from soil salt in Minnesota is more serious in the city than on the highway. The probability of soil-salt damage usually is highest within 2.5 m of a salted street, in basins or depressions that collect runoff from salted streets, and next to intersections that demand high salt applications.

Langille (1976) found soil Na increased significantly to distances of 12 m from the edge of an interstate highway in Maine after only one salting season, and soil Cl increased to a distance of 61 m. The Na levels at 6.1 m from the highway edge were 14 ppm before salting and 113 ppm after salting. At the same distances, Cl rose from 22 ppm to 76 ppm. Both Na and Cl increased significantly in hemlock needle tissue at distances of up to 61 m from the highways. Hofstra et al. (1979) reported significant elevation of salt as far as 30 m from a highway in Ontario. Within this distance, they discovered that soil salt contributed to tree injury. Hughes et al. (1975) found that the soluble salt content of soils along Chicago freeways varied considerably, most having 500 to 2000 ppm salt, but a few showing concentrations of 20,000 to 50,000 ppm.

Hutchinson (1970) correlated the Na and Cl of roadside soils in Maine with the number of years they had received deicing salts. He suggested that salts carried-over and accumulated within the soils from one year to the next. Various roadside soils across the state at 0, 9.1 m and 18.2 m from the pavement showed average Na values of 281, 139, and 96 ppm respectively; chloride values were 116, 79, 54 ppm.

Salt spray runoff samples from a downtown Chicago Expressway in the winter of 1967 showed a Cl content of 11,000 to 25,000 ppm (Struzeski 1971). Button et al. (1977) showed that infiltration of such salty water could occur in winter, even when the soil was frozen to a depth of 10 cm.

Injury resulting from the presence of soil salts is caused by differences in osmotic potential between the tree and the soil solution; a specific ion effect associated with specific salt ions, such as Na and Cl; or a combination of these two effects (Dirr 1976). High osmotic pressure decreases the availability of soil water and changes the tree's ability to absorb water, causing moisture stress within the plant.

The specific-ion effect involves movement of ions such as Na and Cl into plant cells, where they adversely affect cell membrane stability and metabolism and, at high concentrations, are toxic and may kill the cells. This effect probably is moreharmfulto city trees than the osmotic effect (Button et al. 1977; Dirr 1976; Spotts et al. 1972).

Salt ions can also diminish the availability of other ions in the soil. Sodium often replaces calcium on the soil colloids and at the same time deflocculates the soil and destroys soil structure. The soil becomes compact, and oxygen levels and microorganism activity are reduced.

Symptoms caused by soil salt have been defined more precisely in deciduous than in coniferous tree species. Development of symptoms usually progressesthis way: reduced growth and marginal yellowing, browning of the leaves, premature fall coloration, and premature leaf drop (Holmes 1961; Holmes and Baker 1966; Sucoff 1975). Frequently only the leaves facing the road are affected. According to Sucoff (1975), this is the most specific symptom and the one most easily used for diagnosis. Leaf drop often precedes twig dieback, which can be followed by dieback of entire branches and finally by tree death. In many cases, damage develops progressively over a number of years with continued winter salting (Sucoff 1975). For diagnostic purposes, these visual symptoms should be combined with analysis of leaf Na and Cl and analysis of salt in soil by conductivity (measured in mmhos/cm) and "exchangeable sodium percentage" (ESP), the percentage of the total cation exchange capacity occupied by Na.

GENETIC SOLUTIONS TO THE PROBLEM

Genetic Evaluation

One solution to the problem is to select and use salt-tolerant trees. Salt tolerance varies considerably among species and to a lesser extent within species (Demeritt 1973; Dochinger and Townsend 1979). Dirr (1976) emphasizes that the aim of any evaluation program should be to identify plants with partial resistance rather than total immunity, because no plants are wholly immune to salt injury. Generally, trees tolerant to soil-salt accumulation are able to adapt to salt because they have the ability to: (1) absorb and conserve water under salt stress, (2) exclude salt ion uptake, or (3) physiologically tolerate the presence of the salt ion.

Tables ranking species for salt tolerance have been developed by many authors (Blaser 1976; Carpenter 1970; Dirr 1976; Hanes et al. 1970; Monk and Wiebe 1961; Monk and Peterson 1962; Pellett 1972; Shortle and Rich 1970; and Sucoff 1975). Many of these rankings are based on insufficient data, and comparisons lack systematic experimental bases (Dirr 1976). As a result, authors vary in the relative tolerance they give to a species. As Dirr (1974) points out, good experimental techniques are necessary to compare species, progenies, or clones, and the evaluation must include consideration of salts, concentrations, application methods (soil versus aerial application), and both osmotic and specific ion effects. For example, tolerance to salt spray does not imply or necessarily correlate with tolerance to soil salt, or vice versa. Many criteria, not just visual injury, should be used in evaluating the response of trees to salt.

Studies at the Delaware Lab

Realizing the need for more thorough experimental work, we have carried out a series of studies designed to compare important or potentially useful urban species for tolerance to salt-spray and soil salt.

Our first study showed differences among three red maple progenies in response to salt (Dochinger and Townsend 1979). Our second study involved the comparison of six frequently planted urban tree species for which little information on tolerance to soil salt was available. The six species were white flowering dogwood (Cornus florida L.), American sycamore (Platanus occidentalis L.), pin oak (Quercus palustris Muenchh.), eastern white pine (Pinus strobus L.), Japanese pagoda tree (Sophora japonica L.) and ginkgo (Ginkgo biloba L.). A seventh species, honeylocust (Gleditsia triacanthos L.), was included in the study as a "standard" salt-tolerant species. Seedlings from the seven species were subjected to 0, 2000, 4500, and 7000 ppm NaCl in a hydroponics system for 5 weeks. To measure the total response to salt, we estimated foliar injury and measured reduction in height growth and dry matter production, and changes in Na, Cl, and essential elements.

Ginkgo seedlings did not grow well, even in the nutrient solution without NaCl, because pustules formed on the roots; their data therefore were not used in the analysis. Results from the other species indicated the importance of using several parameters to identify trees tolerant to salt. Dogwood and sycamore showed the greatest amount of foliar injury, high levels of leaf and stem Cl, and significant reductions in height growth and dry matter production. Pin oak and white pine were somewhat intermediate in their responses. Pin oak showed a high degree of foliar damage (similar to that of dogwood and sycamore) and high stem Na and Cl levels, but height growth and dry matter production were not affected. White pine showed low foliar symptoms and no reduction of height growth, but its dry weight production was reduced. Japanese pagoda tree and honeylocust showed the least foliar symptoms and no reduction in height or dry weight. The low foliar symptoms in the pagoda tree occurred espite high leaf Cl levels. Apparently low salt damage in this species is due to a physiological tolerance to high ion levels rather than to ion exclusion.

Changes in concentrations of essential nutritional elements (N,P,K, Ca, Mg,Mn,Fe,B,Cu,Zn,Mo) occurred in response to salt, but generally these changes did not indicate salt sensitivity. For example, the salt-tolerant honeylocust showedmore decreases in elemental concentrations than did the salt-sensitive dogwood. The only elemental changes that appeared to be related to salt-tolerance were those in manganese and copper. The concentration of both of these elements increased in the leaves and stems of the salt sensitive species but remained stable in the tolerant species.

In another study we grew these species in either a silt loam soil or in a mix of peat:perlite:sand rather than in a hydroponics solution. Preliminary analysis of data indicates that response to salt and degree of salt tolerance is similar in soil and in a hydroponics medium. Screening of genotypes in the hydroponics solution therefore may be a reliable indication of their relative tolerance in soil.

Selection and Breeding

Selection and breeding for salt tolerant clones, progenies, and cultivars can be concentrated on families and genera that already possess a reasonable level of salt tolerance (Dirr 1976). For commercially valuable species that are somewhat salt sensitive, however, any genetic increase in salt tolerance can be justified. The salt-tolerance in all groups can be improved by screening populations, full-sib and half-sib families, and clones and then crossing the best biotypes. Release of clones or genetically identified, superior progenies is the ultimate goal.

The efficiency of any evaluation or selection and breeding program for salt tolerance depends on finding resistance mechanisms (Mass and Hoffman 1977). Dirr (1976) has evidence that the degree of salt tolerance in many woody plants depends on their ability to exclude Cl, and possibly Na, from entering cells. This ability is also a factor in salt tolerance of some agronomic species. For example, restricted uptake of Cl into leaves and stems of salt tolerant soybean cultivars is controlled by a single dominant gene (Abel 1969). In citrus, restriction of Cl movement into leaves is controlled by several genes acting quantitatively (Shannon 1979). Other genotypes may not exclude the ions but may tolerate the presence of such ions or may be more efficient in adjusting to the osmotic effects of salt. Unfortunately, no reliable and rapid screening technique for salt tolerance is known, either in trees or in agronomic crops (Shannon 1979).

Many factors must be taken into account in identifying trees with salt tolerance. Salt tolerance of agronomic genotypes partially depends on their stage of development (age) and partially on humidity, temperature, light, soil fertility, cultural practices, and presence of other stresses such as air pollution (Shannon 1979). These factors are probably important with trees, and therefore should be investigated.

Any evaluation or breeding program should be followed by field-testing of trees found to have salt tolerance in the greenhouse and laboratory. Trees should be planted where salt is a primary problem, such as city streets, highways, and freeway interchanges. Vigor, survival, and resistance to salt can be observed at periodic intervals after planting.

Research Needs

Identifying trees tolerant to soil salt first necessitates the development and use ofsystematic experimental procedures to compare different genotypes under the same conditions. Second, we must search for reliable markers for resistance, including physiological, biochemical , and morphological characteristics, that will enable us to distinguish a salt-resistant genotype from a salt-sensitive one of the same species. Third, we should determine the extent of juvenile - mature correlations of salt tolerance in order to measure the change, if any, in relative salt tolerance from the seedling stage of development to maturity. Fourth, we must learn about the interaction with soil salt of other abiotic and biotic stresses such as air pollution, drought, soil compaction, fungi, bacteria, and viruses. This composite of stresses can be studied by comparing trees under relatively controlled conditions in the growth chamber and greenhouse. These comparisons should then be followed by the ultimate test, performance and survival along the street or highway.

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