DEVELOPING TREE VARIETIES FOR URBAN SOIL STRESSES[1]

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ABSTRACT.- The importance to trees of several types of soil stress (poor aeration, moisture deficiency, toxic metals, and low fertility) in the urban environment is briefly reviewed, and the possibilities for developing cultivars that are tolerant to each of these stresses are discussed. Five criteria are listed by which the practicality and potential success of meeting improvement goals can be assessed. In light of these criteria, tolerance to soil moisture deficiency and tolerance to low fertility are the most promising improvement goals. However, tolerance to soil moisture deficiency is difficult to evaluate in trees, and the need for tolerance to low fertility in urban areas has not yet been conclusively demonstrated.

COMPANIES THAT MANUFACTURE fertilizer spikes, nutrient capsules, nutrient injection systems, and other products for fertilizing trees do a thriving business with arborists and homeowners. When these treatments are used they frequently result in some increase in the health of the tree, suggesting that the tree was under some degree of stress before treatment. Stresses caused by poor nutrition and other soil characteristics are known to reduce the resistance of plants to diseases (Schoeneweiss 1973). A tree that is stressed--i.e., one that will respond with renewed vigor to a change in its environment--is not fully adapted to the conditions under which it is living and is a candidate for genetic improvement.

Soils in urban environments tend to have several characteristics that mav cause poor survival or growth of trees. They are often low in fertility because of a loss of organic matter or disruptionof the soil profile. Deicing salts and heavy metals arising from vehicular

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[1] Metro. Tree Impr. Alliance (METRIA) Proc. 3:57-69, 1980.

traffic and industrial processes may be present and may cause chemical toxicities, Soil compaction or the presence of pavement over the roots are almost ubiquitous in urban areas and contribute to anaerobic conditions by either reducing pore space in the soil or limiting gas exchange with the atmosphere. Re-grading around existing trees may result in the same problem by increasing the distance between tree roots and the atmosphere. Finally, urban planting sites are frequently drought-prone because of reduced infiltration of moisture, a condition which is often exacerbated by elevated leaf-surface temperatures and transpiration.

To improve the health of trees in urban habitats, we can modify the environments or we can improve adaptation to the environments by planting better varieties. Either approach may be the more practical in any particular situation, although it is always desirable to both plant the best varieties available and provide good cultural care to the trees. In the following pages, I want to focus on the genetic approach by discussing the potential for developing tree varieties that are tolerant to several soil stresses common in urban areas.

POOR SOIL AERATION

Of all soil stresses in urban areas, the most common may be poor aeration. Under anaerobic conditions, roots exhibit a decrease in water and nutrient absorption, tree vigor is reduced, the incidence of diseases may be increased, and the plant may eventually die. Causes of poor aeration include overlying pavement, the occasional addition of soil above the roots of existing trees, and soil compaction by pedestrians and vehicles (Patterson 1976, Yelenosky 1963). Patterson (1976) emphasized the importance of soil compaction in urban areas by proposing that soil bulk density is the best single indicator of soil conditions in areas of intense use.

Flooding also causes poor aeration in the soil. Although flooding is not common in urban areas, Yelenosky (1963) found that species differences in response to flooding were very similar to species differences in general performance in urban areas. As may be expected, species that inhabit bottomland sites are generally more tolerant of flooding than species that inhabit upland sites (Gill 1970). Considering the importance of poor soil aeration in urban habitats, it is probably no coincidence that most of the species of <u>large</u> trees commonly planted along streets are native to bottomlands: pin oak, willow oak, honeylocust, green ash, red maple, silver maple, some of the lindens, sycamore or plane tree, sweetgum, and American elm.

Nothing is known about intraspecific variation in trees in tolerance to poor soil aeration, although evidence of genetic variation in rates of root respiration (Allen 1969) suggests that it may exist. It would probably be possible, but difficult, to develop varieties with superior tolerance to this trait. Yelenosky (1963) indicated considerable difficulty in arriving at consistent differences among species using different methods to effect anaerobic soil conditions. Presumably, it would be even more difficult to evaluate differences within species. Rankings reported by different authors for differences among species in flooding tolerance tend to be somewhat inconsistent, also, since response may vary with season of flooding, duration of flooding, and age of tree (Gill 1970). Breeding for this trait could perhaps be a fruitful and useful activity, but first a method must be developed by which response to poor aeration can be measured quickly and with consistent results.

SOIL MOISTURE DEFICIENCY

Several features of urban areas contribute to slightly higher temperatures compared to surrounding countryside (Andresen 1976) and to increased transpiration by trees. Runoff from paved surfaces presumably diminishes the amount of moisture that reaches the soil, although Patterson (1976) observed that soil beneath pavements is usually quite moist. Roberts (1976) proposed that insufficient moisture is one of the most common stresses on urban trees. Certainly, symptoms of drought injury, particularly leaf scorch, are common in late summer on some tree species in urban areas. Drought stress has been implicated as a predisposing factor in ash dieback (Tobiessen and Buchsbaum 1976) and other tree diseases (Parker 1969).

There is considerable evidence of genetic variation in drought resistance within native tree species. As expected, trees native to relatively dry habitats are generally more drought resistant than trees native to moist habitats (Bilan *et al.* 1977, Meuli and Shirley 1937, Townsend and Roberts 1973, and others). Habeck (1958) found that northern white-cedars from upland habitats had more plastic (adaptable?) root systems under varying soil moisture regimes than those from lowland habitats, although nothing was determined about drought resistance per se. Thus, it may be possible to develop drought resistant varieties in at least some tree species. Paradoxically, there may already exist races of some species that are relatively tolerant of both flood and drought. Those species of eastern hardwoods whose ranges extend farthest into the Great Plains, where selection for drought resistance may be expected (Bey 1974, Meuli and Shirley 1937), are all inhabitants of bottomlands: green ash, hackberry, bur oak, eastern cottonwood, American elm, and boxelder. Each of these species has been classed as relatively tolerant of flooding (Bell 1974, Hall and Smith 1955), although this character, also, could vary from one part of the distribution to another.

Even if the genetic potential exists for developing drought-resistant varieties, there are practical difficulties in evaluating genetic variation in drought resistance. In particular, the relative response of seedlings to imposed drought can be influenced by differences in characteristics that may change with age or cultural practices. These include rooting depth, root/shoot ratio, leaf surface area, and root regenerating potential after transplanting. Bey (1974) found that seedlings of black walnut from relatively dry and moist provenances differed in time to wilting under imposed drought. However, these differences in apparent drought resistance were not correlated in the expected manner with survival and growth of the same provenances on a "droughty" upland site.

Kozlowski (1976) suggested breeding for small stomata, few stomata, stomata that close early during drought, abundant leaf waxes, or dwarfing rootstocks. These characteristics contribute to drought resistance and may not change appreciably with age or cultural conditions. In lieu of developing varieties specially selected for drought resistance, some improvement in resistance can probably be obtained by simply using provenances from relatively dry sites or regions in ecologically variable species such as red maple (Townsend and Roberts 1973) or geographically dispersed species such as green ash (Meuli and Shirley 1937) and sugar maple (Kriebel 1963).

TOXIC METALS

Elevated concentrations of certain heavy metals (lead, zinc, cadmium, and nickel) have been found in plant and soil samples taken from densely populated areas and transportation corridors (Lagerwerff and

Specht 1970, Motto et al. 1970, Smith 1973). Among these elements, lead (from gasoline combustion) usually appears in greatest concentrations, particularly near heavy traffic. All are toxic to plants (Foy et al. 1978).

Research on herbaceous plants (Antonovics et al. 1971) suggests that it would be possible to develop heavy-metal tolerant varieties of trees. Ecotypes tolerant of lead, zinc, or cadmium have frequently evolved in grasses and forbs that colonize mine tailings (Gregory and Bradshaw 1965 Hogan and Courtin 1977, Jowett 1964, McNeilly 1968, Simon 1977). However, on sites other than these, actual phytotoxic effects caused by ambient heavy-metal concentrations have been more difficult to demonstrate. Most metals are precipitated or bound in soils, thus reducing their availability to plants (Foy et al. 1978). Reports of elevated concentrations of heavy metals in soils along roadsides do not usually distinguish between "total" and "available" levels, nor do we know what effects these elevated concentrations have on plants (Smith 1975). Similarly, concentrations of heavy metals in plants growing in urban areas may be exaggerated by failure to remove particulate deposits on external surfaces (Motto et al. 1970, Smith 1973). However, Rolfe (1974) found that lead concentrations inside trees growing near heavily traveled roads had increased over several decades.

Persuasive reports of actual toxicity to roadside plants by heavy metals are rare. One of the best ways to demonstrate phytotoxicity in situ, where it is difficult to isolate a particular cause of plant response, is to show that the plants have evolved tolerance to the toxin to which they are believed to have been exposed. This was done by Wu and Antonovics (1976), who demonstrated that English plantain (Plantago lanceolata) had evolved a lead tolerant population immediately adjacent (0.5 meters) to Main Street in Durham, North Carolina. However, at distances as short as 4 meters from the road, the plantains exhibited the normal low level of tolerance, indicating that lead toxicity at that distance from the source of pollution was not severe enough to be effective in selection. Four meters is, of course, easily spanned by the shoot and root systems of trees, and many urban trees are not planted that close to the road. Thus, whatever significance one wishes to place on this single report, the importance of heavy metal toxicities to large woody plants in urban environments is still open to question. The present state of knowledge does not warrant any investment in developing heavy-metal tolerant tree varieties for urban areas. Future revelations could change this, of course.

LOW FERTILITY

There is little information available on the nutritional status of urban soils compared with that of the native soils on which our common shade trees evolved. However, it is probable that urban soils are generally less fertile with respect to certain macronutrients, particularly nitrogen. Poorer fertility than the trees are accustomed to will contribute to nutrient stress. Whether or not foliar symptoms of deficiency are present, nutrient stress may contribute to disease and insect susceptibility--which can further detract from tree health.

Research on forest trees indicates that genetic variation in response to fertility levels is very common in tree species. Clones or families in several species have been shown to vary in response to nitrogen levels (Curlin 1967, Roberds et al. 1976), phosphorus levels (Mason and Pelham 1976) or some combination of these and other nutrients (Jahromi et al. 1976, Pritchett and Goddard 1967, Steinbeck 1971). Genetic variation in response to fertility appears to be more or less a local phenomenon in natural populations. While we expect to find cold-tolerant trees in the North, and drought-tolerant trees in dry regions, the geographic occurrence of tolerance to infertility in native trees is much less predictable. Fairly large differences in response are sometimes found even among trees growing near one another in a single wild population.

If it can be definitely shown that poor fertility is a chronic and widespread stress in urban trees, the development of tolerant varieties would be one of the most useful contributions that geneticists can make in urban tree improvement. Since stress tolerance and fast growth may actually be incompatible improvement objectives (Grime and Hunt 1975, Parsons 1968), urban tree breeders may find it easier to employ tolerance of infertility than forest tree breeders. The best measure of tolerance to infertility is probably relative growth at low vs. high nutrient levels, on the presumption that a minima increase in growth with increasing fertility indicates minimal stress at low fertility (Steiner and McCormick 1979). The fact that maximum growth response is not of particular concern in urban trees could be a definite advantage in developing varieties that are better adapted to urban habitats (Zobel and Kellison 1978).

Some nutrient disorders of shade trees arise not from any failing in the urban environment per se, but from our attempts to plant some species on soils very different from those to which the trees are accustomed. For example, pin oak and several other species develop iron deficiency (Neely 1976) and some maples develop manganese deficiency (Kielbaso and Ottman 1976, Smith and Mitchell 1977) when these species are planted on alkaline soils. These particular deficiencies are frequent enough in shade trees that developing varieties specifically for resistance to them may be justifiable. Berrang and Steiner (1980) were successful in identifying pin oak families that were nearly as tolerant of iron chlorosis as two other oak species that are often used in lieu of pin oak on calcareous soils. Wallace and Lunt (1960) reported some evidence that sweetgum may also vary in resistance to iron chlorosis.

DISCUSSION AND SUMMARY

The practicality of developing cultivars with improved genetic response to urban stresses must be evaluated for each situation according to the following criteria:

1. Need -- Obviously, the stress must be an important one and the species widely planted.
2. Genetic potential -- Tolerant variants must be present in the species, and the amount of variation must be great enough to be of practical significance.
3. Feasibility -- It must be possible to identify tolerant variants without prolonged and elaborate procedures for testing and evaluation.
4. Cultivar stability -- Variants must exhibit stability in tolerance over a range of environments to avoid the necessity of developing different cultivars for different sets of conditions.
5. Ease of propagation -- If tolerant genotypes are not easily cloned, then seed propagation is necessary and long-term breeding may be required to obtain a cultivar that reproduces true to type.

The importance of these criteria may be illustrated by our experience at Penn State in trying to develop a chlorosis-resistant pin oak cultivar. In this case, Criteria 1-3 were passed with flying colors. Pin oak is one of the most popular street tree species, and iron chlorosis is definitely a common problem. As mentioned above, there is a substantial amount of genetic variation in the species for resistance to chlorosis; and this variation is fairly easy to evaluate if the proper experimental conditions are used (Berrang and Steiner 1980). Since these criteria are the ones that tree breeders pay the most attention to, the prospects for developing an improved cultivar of this species appear excellent at first glance.

However, Criteria 4 and 5 present some difficulties that force us to be cautious (though not necessarily pessimistic) about the future success of this project. In the first place, we were able to evaluate chlorosis resistance only under a limited set of conditions. Many environmental factors are known to influence the severity of iron chlorosis, so we could not guarantee the superiority of a cultivar without rather extensive testing at many locations over many years. Would consumers plant a pin oak cultivar that was only possibly resistant on untried sites? --probably not. Secondly, we compared resistance among sets of progenies, yet the data also suggested considerable differences among individual trees. We can neither evaluate the resistance of individual genotypes, nor propagate superior ones, because of our inability to readily duplicate genotypes of pin oak with rooted cuttings. Developing varieties of pin oak that breed true for resistance could take decades. We can reproduce the families that proved to be superior, but would consumers accept seed-propagated trees that have only an average high level of resistance? Perhaps not, considering the importance and value of the individual tree in the urban landscape.

As illustrated by this example with pin oak, the potential of any improvement effort cannot be fully assessed until the effort has already begun and some of the necessary information has been obtained. Obviously, much depends on the biology and genetics of each species studied. However, our current knowledge suggests that developing adapted cultivars would generally be more practical for some types of soil stress than for others. This is summarized below by considering each of the stresses in light of the criteria that must be met in an improvement program. "Ease of propagation" is omitted, since this depends entirely on characteristics of individual species.

The need for tolerance to toxic metals in the urban environment has yet to be shown to be important, so this improvement goal should presently receive low priority. However, if there were a need, other criteria would appear to be favorable: evidence from herbaceous plants indicates that the genetic potential for tolerance is present in many species, reliable methods are available for testing and evaluation, and tolerance to toxic metals has proven to be relatively stable over a range of environments.

Improved tolerance to poor soil aeration would probably be desirable in some species. However, the genetic potential for developing tolerant cultivars is unknown, and reasonably fast and reliable methods for testing and evaluating response to this stress have yet to be developed. The stability of tolerance to this stress must also be considered unknown, but we do know that species differences in tolerance appear to change with the seasonal timing and duration of poor soil aeration.

The performance of many species in urban environments would probably be helped by better tolerance to soil moisture deficiency. Variation in drought resistance is known to be present in many species. We still do not know enough about methods of testing and evaluating response to drought to be confident that results obtained with seedlings will be applicable to older trees. However, selecting for specific drought-avoidance adaptations could overcome this problem. Some drought-avoidance adaptations are very stable from one environment to the next. Thus, some effort toward developing drought-resistant cultivars is justified.

There is likely a need for tolerance to low fertility in many species planted in urban areas ,although this has not been proven. The genetic potential for improved response to low fertility levels is known to be present in many species, and methods of testing and evaluation are relatively simple. The stability of tolerance to low fertility must be determined on a case-by-case basis since much depends on the chemistry and physiology of the nutrient in question and the genetics of the species. This could prove to be a productive area for research, but it is first necessary that more be learned about the urban soil environment so that specific breeding goals can be identified.

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