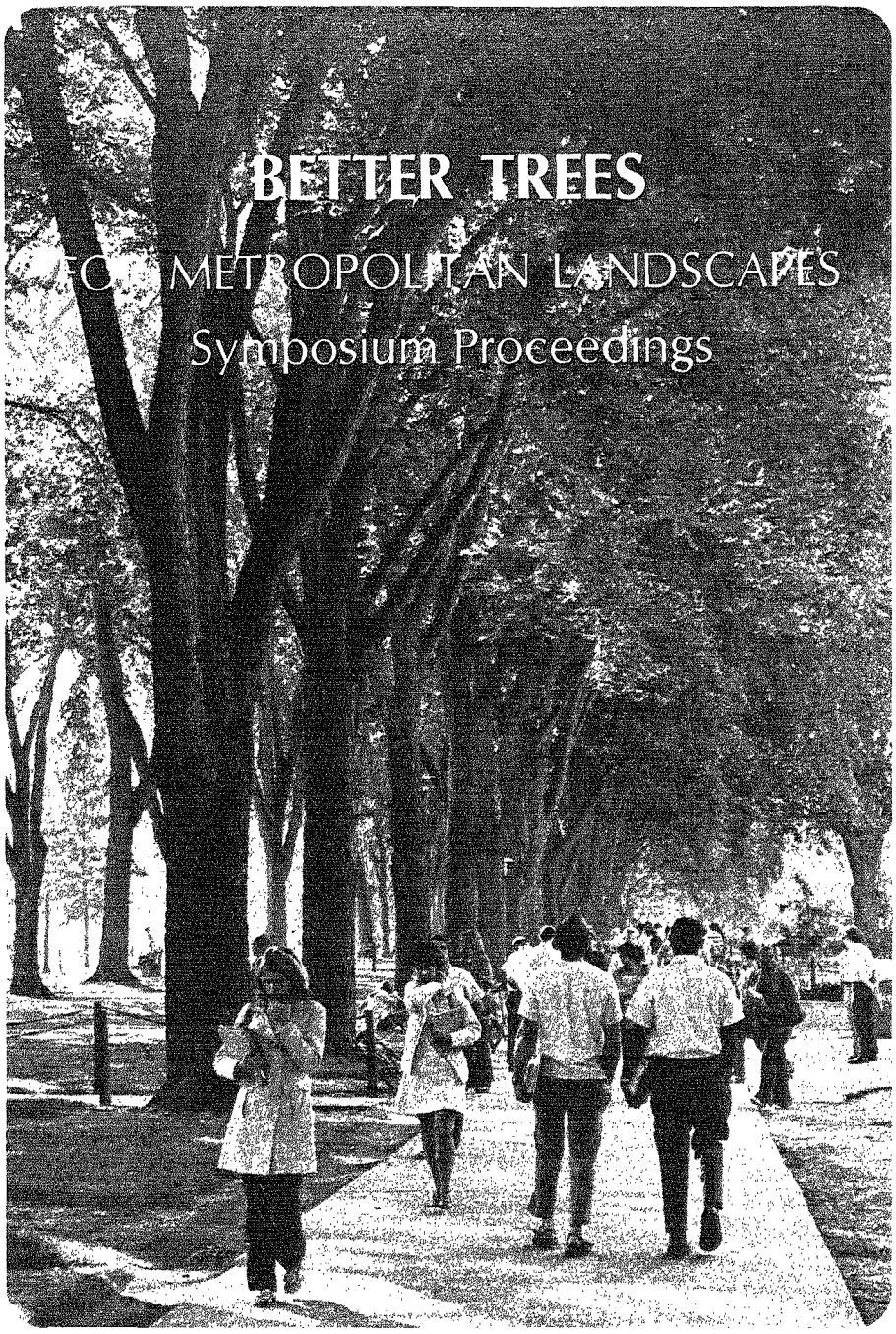


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BETTER TREES

FOR METROPOLITAN LANDSCAPES

Edited by

Frank S. Santamour, Jr.
Henry D. Gerhold
Silas Little

Proceedings of the Symposium held on 4-6 November 1975, at the U.S. National Arboretum, Washington, D.C.

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BREEDING AND SELECTING BETTER TREES FOR METROPOLITAN LANDSCAPES

by FRANK S. SANTAMOUR, JR., *Research Geneticist, U.S. National Arboretum, Washington, D.C.*

ABSTRACT. The development of superior trees for planting in metropolitan areas is in its infancy. Although many of the techniques and methods of plant breeding for other crops can be adapted to this endeavor, there are certain special features that influence the successful production of better trees for people. Some of the problems and prospects of developing better trees are discussed—with emphasis on diversity within and among species, the consequences of clonal uniformity, adaptability (to climatic conditions, pests, stresses, and successful nursery culture), "personality", and reliability of plant materials.

THE DEVELOPMENT OF SUPERIOR shade and landscape trees for metropolitan areas represents a challenge that is not matched by any other type of plant breeding. Crop geneticists and petunia breeders work with plants that have a short generation time and in which the cultural factors are normally kept near optimum. Forest geneticists may deal with long-lived trees, which are normally grown under near-natural growing conditions, and little effort is expended in their culture.

However, forestry planting and rotations are such that only 20 percent of the trees initially planted may suffice for a successful final harvest. In contrast, the urban tree has a high unit cost and value, both at the time of planting and, increasingly, year after year. Thus, 100 percent survival is *expected* under the prevailing adverse conditions. Better metropolitan trees must also be amenable to the production practices of commercial nurseries and must be subjected to long-term testing. Furthermore, the selected trees are frequently planted in environments alien to tree growth, where cultural care after planting may be minimal.

Research to develop superior trees for use in populated areas is in its infancy. Even at this stage, there are problems in terminology. The trees are described as "shade", "amenity", "ornamental", "street", "landscape", or "environmental"; and their use is intended for "urban", "metropolitan", or "megalopolitan" areas. Basically we should be working on "trees for people".

In discussing in a general way, some of the problems and prospects in the development of superior "trees for people", there is no royal road to follow and few, if any, absolutes as guideposts. However,

if we understand and appreciate the tree qualities that must be considered, better trees are sure to follow.

DIVERSITY

It is perhaps significant that the current surge of scientific interest in developing superior metropolitan trees coincides with a low point in the diversity of tree materials being grown by the nurserymen. Economic, biological, and ecological factors are forcing nurserymen to stop growing species or cultivars that have limited sales potential, that have proved marginally adaptable to urban situations, or that require liberal applications of pesticides to insure their well-being.

In addition to these factors, many of the old-timers or plantsmen, whose love of plants was reflected in the breadth of their nursery listings, are passing out of the picture. More and more, nurseries are assuming a corporate structure; and the plants, like loaves of bread, are merely the produce of the venture. Of course, it makes good economic sense to produce a limited number of high-quality products. The tree geneticist can be a driving force in the quest for quality trees. But there are other considerations.

What we need, desperately, is increased diversity. The metropolitan environment provides a unique blend of sites and settings for the utilization of the widest possible range of tree and shrub materials. We have more than enough genera and species to provide the range of form, color, and texture necessary for optimum development of any metropolitan area. The landscape architect must be provided with the raw materials to do his job.

Look at the collections of trees in our major arboreta or botanic gardens. Why are so few of these species currently in the commercial nursery trade? The problems are economic, biological, and ecological. But they are not insurmountable. In fact, there are many cases where an improvement in a single, simple characteristic might change the status of an otherwise undesirable tree.

With more than 100 genera and hundreds of species capable of successful culture in temperate United States, it will be the scientists' job to survey this array of plant material and determine what type of selection and breeding program could produce desirable and useful trees.

One of the benefits of increased diversity of genera and species is that the nurseryman and the tree grower are insured against major losses that might be caused by new pest outbreaks, climatic disturbances, or man-made changes in the environment. The chances of having the right tree in the right place are increased immeasurably. Other benefits accrue to the tree user who looks at, drives by, stands under, or listens to the trees as an integral part of his world.

Another aspect of diversity is genetic diversity *within* a species. As we continue to seek and promote the reliability and uniformity of clones and cultivars, this diversity is being diminished. Seedling populations of trees provide us with thousands of different genotypes, but some nurseries may now offer only seven genotypes (cultivars), or three, or one. It is a common argument that the maintenance of genetic diversity *within* a species is a safeguard against possible disaster when new pests or new pest strains become abundant. Certainly the entire range of genetic diversity within *Castanea dentata* did not save the American chestnut from chestnut blight. The American elm-Dutch elm disease situation offers only slightly more promise. Intraspecific genetic diversity must be maintained in breeding programs and gene banks, but to try to maintain all of this diversity on the city streets would defeat the purpose of breeding and selecting superior genotypes.

UNIFORMITY

There is no doubt that the current trend of selecting and using cultivars will will continue in the nursery trade. It makes good sense. When a genotype has been proved superior in pest resistance, stress tolerance, and general adaptability,

it would be unwise not to exploit this superiority. Each cultivar becomes a standard of performance and reliability. The municipal arborist, the landscape architect, and the homeowner will choose a particular cultivar because of its uniformity in desirable characteristics.

Cultivars or clones may also be uniform in undesirable traits. Even after long-term testing, hidden flaws may become apparent under new conditions. What degree of diversity we need and should strive for will certainly be one of the key arguments among scientists.

As generally conceived, cultivars are clones. That is, they represent identical genotypes that are reproduced vegetatively. Plants grown from cuttings certainly fit this concept. However—and the point may be academic—how can we consider, as a clone, the plants that are reproduced by budding or grafting on rootstocks of seedling origin? Is the root system of such little importance in the life of the tree that we can ignore this source of variation? Generally, of course, the influence of *average* rootstocks on the above-ground characteristics of a grafted tree are not sufficient to dramatically alter the phenotype. But there are nematodes, salty and compacted soils, and soil-borne pathogens that may play an important role in the tree's survival.

Thus, there is also a need for the selection and propagation of superior and uniform rootstocks. The degree of uniformity needed might not be clonal, but only enough to insure the tolerance or resistance levels for optimum survival. For instance, it might be that seedlings of a particular elm *species* could serve as Verticillium-resistant rootstocks for the grafting of superior and disease-resistant scions. Still, few nurserymen or scientists would care to take potluck on the source of the seedling rootstock. Again, a certain degree of uniformity and reliability is desirable and necessary.

We might also desire uniformity in graft compatibility, but our inadequate knowledge of the factors influencing the stock-scion relationship make this desire more of a wish. We have been rather lucky, I think, that few cases of latent graft failure have caused problems in the nursery or on the street. The skill and experience of the nurseryman has been the key to success in this area, and until some scientific data are available, the situation will remain the same.

Seedling Cultivars

A cultivar, according to the Code (*International Code of Nomenclature of Cultivated Plants*, 1969), does not have to be a clone, nor must it be vegetatively propagated. The only requirements are ". . . an assemblage of cultivated plants which is clearly distinguished by any characters (morphological, physiological, cytological, chemical, or others), and which when reproduced (sexually or asexually), retains its distinguishing characters" (Article 10).

Vegetative propagation by cutting, grafting, or budding requires special facilities and skill, time, and money. There are also certain important genera or species (oaks, some maples) that cannot be economically reproduced by cuttings or grafting.

Quite possibly the ultimate achievement in shade-tree improvement will come when we can grow superior trees from seed. The way is open for the use of controlled crosses and seed orchards in the production of superior cultivars. Both intra- and interspecific combinations are possible. It might also be possible to utilize natural or induced apomixis (asexual seed production) for the rapid increase of desirable genotypes. Seedling cultivars can provide the needed uniformity in survival characteristics (and, we hope, in growth characters), while allowing a modest degree of intra-cultivar genetic diversity.

ADAPTABILITY

Progress in metropolitan tree improvement will proceed by a series of successive approximations to certain ideals, but

the conditions that influence the tree's performance are highly variable in time and space. Here are some topics that must be taken into account if a new cultivar is to be widely accepted.

Provenance

Climatic adaptability is obviously an important characteristic, and winter- or cold-hardiness is the most frequently cited criterion. Data given in most tree lists on the northernmost "Hardiness Zone" are based on *species* performance. A nurseryman growing red maple seedlings of local origin in Tennessee may advertise his product as being hardy to Zone 3 (say, St. Paul, Minnesota). While it is true that *Acer rubrum* has a native range encompassing Zone 3, and even parts of Zone 2, there is no guarantee, and little likelihood, that the Tennessee maples will be completely adapted to the colder climates.

One of the most neglected aspects of tree adaptability in the nursery trade is the matter of provenance, or geographic origin of the genetic material. Our native tree species frequently occupy a wide latitudinal and elevational range. Particular populations grow where they do because they are acclimated to the natural environment. Movement of this germ plasm too far north, or south, may result in less than optimum growth and survival.

For non-native species, there is frequently much less information available. We may know the native *range* of the species but not the precise locality of origin of our seed or of a tree in an arboretum. Judgments as to potential hardiness are sometimes based on the coldest zone in which a tree of a particular species exists. Many mistakes have been made by using this criterion of hardiness.

Without belaboring the point further, let me say that the provenance of a tree may well determine its utility. As the selling range of nurseries is increased, and coast-to-coast (in North America) is not unusual, cultivars of unknown origin may be spread throughout the country. Application of adequate long-term testing results could help avoid some of the bad consequences of this practice.

Before leaving this topic, I should point out that provenance is important not only to hardiness. The movement of plant materials far south of their native or adapted range may cause less dramatic problems, but they are real ones. The long hot summers and drought are only two of the many environmental survival factors that must be considered. In addition, flowering, fruiting, and autumnal leaf coloration may be altered significantly.

For the future, the scientist must be aware of provenance in the selection of parent material and in his choice of test sites. Furthermore, he should endeavor to spread this concern for provenance to nurserymen, arborists, and the public.

Pest Resistance

If a neophyte researcher were to consult the various references listing the diseases and insect pests of shade trees, he might consider it just short of miraculous that there are any elms or poplars that have survived the biological blitz. On the other hand, he would note that relatively few pests appear to plague certain tree species that are relatively rare in cultivation. It is axiomatic that the number of pests associated with a crop increases with more extensive culture—and intensive observation. There are major pests, minor pests, and unknown pests. What pests are important and how much resistance do we need?

In some genera, the ranking of priorities may be relatively easy. For elms, resistance to Dutch elm disease, phloem necrosis, and Verticillium wilt are in a reasonable order. Among elm insects, the elm leaf beetle would probably be considered the most destructive. Surely, if cultivars were developed with resistance to all the above pests, and possessed reasonable growth habits, they could find ready acceptance in the nursery trade. Nectria canker might still be a problem,

and leaf spots, and wetwood, and borers, and cankerworms, and aphids. Where do we stop?

The elms, as noted above, are a special case. Consultation of standard references will show a large number of genera and species with only a few serious pests, or none at all. Wouldn't it make good sense to work with these genera and species?

Maximum improvement of our metropolitan environments will come when we seek to improve *all* genera and species that are available to us. The need for diversity is urgent and important.

Pests that are *limiting* factors in the successful culture of a tree are the obvious first choices for resistance breeding and selection. Inoculation with the most virulent or aggressive strains of the pathogen or long-term exposure to natural, or enhanced, insect populations will be necessary to achieve significant improvement. All tree geneticists, pathologists, and entomologists realize the problems; but each may have strong personal opinions on the relative importance of certain pests and the degree of resistance required. There are no *absolute* answers to these questions.

The diversity of opinions and approaches, of genes and selective factors, of techniques and criteria, plus intensive and extensive testing, should provide pest-resistant trees for tomorrow.

Stress Tolerance

There is no doubt that certain man-made stresses imposed on trees in metropolitan environments are major factors in tree growth and survival. Any reduction below optimum growing conditions may make the tree more susceptible to insect, disease, and nematode pests that might otherwise not be problems.

We are fortunate that we can duplicate —under laboratory or controlled field conditions—most of these stress situations. Tolerance of salty and compacted soil is amenable to field and greenhouse experimentation. The effects of gaseous air pollutants may be tested in special chambers. The response of trees to certain sources of artificial illumination can be determined. Furthermore, the response of trees to injuries caused by automobiles and other mechanical agents can be assessed by observing healing patterns of pruning cuts or deliberate trunk wounds during the testing period.

Screening procedures against stress factors may be applied to populations or individual selections and at different stages in the improvement program. For instance, tests of salt tolerance were conducted on seedlings of progenies resulting from crossing *Platanus occidentalis* and *P. orientalis* at the National Arboretum. Individuals exhibiting resistance to sycamore anthracnose disease in field tests were selected from those progenies that had demonstrated the highest salt tolerance. After further observations on anthracnose, selected clones may then be subjected to salt testing once more before final selections are made. Or the clones may be screened for ozone or sulfur dioxide tolerance.

Stress conditions are seldom the limiting factors to the successful culture of a tree. The limiting factor in *Platanus* is anthracnose. The only reason salt-tolerance testing preceded other tests was that we had an abundance of seed, more than we could possibly use in producting trees for long-term field tests.

Where the number of seed or seedlings is small, stress-tolerance testing should be postponed until after resistance to major pests has been determined. If there are no major pests, the entire improvement program may consist of stress testing.

While we can work with stress factors singly, the trees on the streets are subjected to these conditions in combination with each other, and with biological and climatic factors. We cannot hope to duplicate, or even account for, all of the variable conditions. Thus, the best products of our laboratory and field studies must be tested on the street. The more ruthless we are in our screening and se-

lection procedures, the better the chances are for the survival and use of our improved trees.

Nursery Practices

The builder of the better mousetrap may have had a well-worn path beaten to his door, but the builder of a better chestnut *(Castanea)* tree has not been so fortunate. The new blight-resistant chestnut hybrids developed by the Connecticut Agricultural Experiment Station have not aroused much interest in the nursery industry. There may be several reasons for this apathy, but certainly one of the major deterrents to widespread acceptance of these chestnuts has been the lack of successful mass-propagation techniques. Obviously, propagation of these hybrids by seed is nearly impossible. Chestnuts do not root well from cuttings, and grafting is only slightly more effective. So the superior genotypes, developed after more than 40 years of breeding and testing, stand as reminders that good intentions and success in breeding are not enough.

The oaks are also difficult to propagate. Little breeding effort has been expended on this genus, and the few selected species cultivars may be exhibiting signs of latent graft incompatibility.

The cheapest and most efficient method of tree production is by seed. If an improved seed-propagated cultivar can be increased by seed giving reliable and uniform germination, there would be little doubt about its wide acceptance and use. We should remember, however, that such a cultivar should also be uniform in desirable traits relating to survival and growth. Tree species that are heavy and consistent seed producers will be best adapted to this method of propagation.

The next most effective and least costly method of propagation is the rooting of cuttings. The development of rooting hormones and mist systems now allow cutting propagation of many species and genera that were difficult or impossible to root in the past. Still, there are many species in which rooting success is economically marginal, and much remains to be learned. The geneticist must be the experimental propagator of such material. Juvenility may be the key to success in many species, and initial propagation soon after the first selection cycle may be important. Further propagations may be made from sprouts after the propagations have been cut back. Perhaps there are not many nurseries that maintain stock blocks that are handled on a cut-and-sprout basis; but if the scientist can demonstrate that *some* method of rooting is successful, the chances of his material being mass-produced are increased.

There is also another advantage to the scientist-as-propagator scheme. When plants are sent to nurserymen or others for evaluation, all parties are sure that the genotype is pure—from root tip to apical meristem. Thus, the possibilities of cultivar contamination by rootstock sprouts are eliminated and more accurate appraisals of the tree's value are assured.

There are, perhaps, not many scientists who are skilled in budding or grafting, or who have a skilled person available to do it for them. If the superior selections are of sufficient interest or potential, it is possible that a nurseryman would be willing to assist in tests of propagation.

Some trees require extensive "training" in the nursery in order to develop the kind of trunk and crown that makes a salable tree. The increase of container-growing in nurseries may impose other restrictions on the characteristics desired for mass production. The ease of transplanting, although not necessarily the province of the nurseryman, will certainly be a factor in decisions on what the nursery produces.

There are few, if any, trees that cannot be propagated and planted successfully if enough time, money, and effort are expended. However, if the nurseryman and the scientist are to get the greatest number of the best possible trees to the largest number of people in the shortest

possible time, serious attention must be given to the biology and economics of mass production.

PERSONALITY

We have thus far been considering the traits necessary for survival and utility. A living, green tree is a thing of beauty. But man is a seeker of novelty and variety and the cosmetic industry is a prosperous one.

Most of the cultivars presently in the nursery trade were chosen for their personality, the traits that differentiate them from the norm. Weeping, fastigiate, columnar, globe, and vase-shaped forms are not only pleasing to the eye, but have distinct utilitarian functions. Autumnal leaf coloration is urban man's reminder that winter is on the way. Permanent leaf coloration may jar the sensibilities of certain beholders, but such non-green-leaved trees do have their place. Flowers are desirable, to be sure, in as wide a range of sizes and colors as Nature and the breeder can conspire to develop. Fruit and seed are important too, but more for their absence than presence.

A tree can be ornamental as well as functional. As the architects of the trees of the future, geneticists should not overlook the embellishments that distinguish the Rheims Cathedral from the New York Trade Center.

RELIABILITY

The key to reliability is testing, testing, and more testing. A recent publication gave 100 years as a reasonable period in which to develop and test a new tree cultivar. None of us would argue that this time span might be desirable, and some of us might even wish to volunteer for the final evaluation phase in 2075. Conversely, few of us are so naive or lacking in ego that we do not expect to make some significant contributions in 1/10 or 1/5 of a century.

What we must do, as best we can, is to compress 100 years of testing into a fraction of that period. Deliberate and controlled tests of pest resistance and tolerance of environmental stress factors should be made as early as possible. Similar tests at a later date can be carried out at the same time as field (or street) tests for "general" survival. Trials of propagation and culture are necessary to insure wide use.

There is not, and may never be, an ideal tree. We can establish "ideal" criteria, but we must be practical enough to realize that we should not postpone the introduction of a superior tree until the ideal is reached. Conversely, we should not hasten to issue a new tree if it is likely that an ever better tree will be forthcoming in a few years' time.

There may be times when, because of inner desires or outside pressures, we may release a cultivar that is not the ultimate ideal, or which has not been tested as strenuously as we would have wished. We shall all do this at one time or another. However, if the cultivar is superior in some traits, and is the best we can hope to offer in the next decade, such release may be justified.

Trees usually outlive their breeders. By careful attention to the goals of improvement, and thorough testing in spite of many difficulties, the trees we leave behind us should be a source of esthetic pleasure and scientific interest for generation to come.

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A MUNICIPAL ARBORIST SELECTS TREES FOR STREET PLANTING

by EDGAR G. REX, *Executive Secretary, New Jersey Federation of Shade Tree Commissions, Cook College, Rutgers University, New Brunswick, N.J.*

ABSTRACT. Past experience and published guides provide a basis for present-day selections of trees for planting along municipal streets. Selections that the shade-tree commission of a New Jersey municipality might make, and the reasons therefore, are described briefly.

I SHALL IMPERSONATE the president of a shade-tree commission in a municipality of central New Jersey. This municipality has 35 miles of streets, a tree-planting extent of 70 miles when both sides of each street are included. A recent census of street trees showed that the municipality had about 5,000 trees. Because of Shade-Tree Commission does not directly employ any men, it contracts for all its labor, including that for planting. The Shade-Tree Commission operates on an annual appropriation of $15,000, of which $5,000 are allocated to the purchase and planting of trees. Uncommitted balances of current appropriations revert on December 31 to the municipal treasury.

SELECTION OF TREES

Controlling Factors

There are several factors that we have to consider in selecting trees for replacement of removed trees or for establishment of trees in locations not previously planted.

First, trees planted in strips adjacent to street curbs ("lawn strips") should develop crowns that, at least when pruned, provide clearance to a height of 14 feet for vehicular traffic.

Second, selected trees should require little or no protective spraying. Hence, species susceptible to appreciable damage by insects—*Gleditsia* (mimosa and fall webworms) or *Tilia* (resurging populations of Japanese beetle)—are not included.

Third, trees should be adapted to the spaces provided in varying widths of lawn strips. The guide for New Jersey selections is the outline on pages 28-31 of TREES FOR NEW JERSEY, second revision.

Fourth, only about half of the funds available for establishing new trees can be used in the purchase of trees. The other half is needed for planting costs.

Actual Selections

With the above factors in mind, the Commission compiled the following list of trees to be purchased:

GROUP A—FOR LAWN STRIPS LESS THAN 30 INCHES WIDE

Number	*Species or cultivar, height or caliper, and type of stock*	*Cost*
15	*Acer campestre,* 6 to 8 feet tall, B-R (bare roots)	$150
10	*Oxydendrum arboreum,* 5 to 6 feet tall, B&B (balled and burlapped)	180
5	*Cornus florida* f. *rubra,* 4 to 5 feet tall, B&B	60
5	*Aesculus splendens,* 2 to 2½ inch caliper, B&B	300

GROUP B—FOR LAWN STRIPS 2½ TO 4 FEET WIDE

20	*Acer platanoides* 'Erectum', 8 to 10 feet tall, B-R	200
10	*Ostrya virginiana,* 6 to 8 feet tall, B-R	85
10	*Aesculus* X *carnea* 'Briotii', 5 to 6 feet tall, B-R	200
10	*Nyssa sylvatica,* 6 to 7 feet tall, B&B	460
10	*Prunus sargentii,* 6 to 8 feet tall, B-R	77
10	*Prunus yedoensis,* 6 to 8 feet tall, B-R	80

GROUP C—FOR LAWN STRIPS MORE THAN 4 FEET WIDE

25	*Acer rubrum* 'October Glory', 6 to 8 feet tall, B-R	250
25	*Acer saccharum* 'Green Mountain', 6 to 8 feet tall, B-R	250
10	*Quercus acutissima,* 6 to 8 feet tall, B-R	75
10	*Quercus rubra,* 6 to 8 feet tall, B-R	75

In the above list we have 35 trees in group A, 70 in group B, and 70 in group C—a total of 175 trees. The total cost is $2,442, which is within the limit of our budget.

Comments on Selections

In compiling the list, the Commission noted some comments on each selection. These may be of interest to you:

Acer campestre.—A small tree that requires 7 years in the nursery before it is salable. It develops into a fine small tree that suffers little from insect damage and has attractive yellow fall foliage.

Oxydendrum arboreum.—A unique tree that has very decorative ericaceous blossoms. In the fall the peach-leaf-like foliage turns blood-red, forming a conspicuous picture in the landscape. Though the tree is slow-growing, over a period of 25 years it will make a good showing.

Cornus florida f. *rubra.*—A specialty tree for individual places that need horticultural embellishment. Its pink flowers are very decorative and last for a period of 2 to 3 weeks.

Aesculus splendens.—A masterpiece for showmanship. Its panicles of deep red color that appear in late May make this tree a distinction in the municipality.

Acer platanoides 'Erectum'.—This is a cultivar propagated from the famous tree in the Mt. Hope cemetery, Rochester, N.Y. It has unique branching habits that fit it well for sites with overhead wires. Its conformation is so distinctive that it cannot be mistaken for any other cultivar of Norway maple.

Ostrya virginiana.—A tree noted for its very decorative hop-like fruits, which cover the tree in normal seasons. Its slow growth in diameter is advantageous for sites of limited area within the range of the species.

Aesculus X *carnea* 'Briotii'.—A tree of larger proportions than *A. splendens,* but having the same attractive flowers and producing them in the same profusion.

Nyssa sylvatica.—A species distinctive in leaf character and exquisite in fall coloration. A row of blackgums (also called sourgums) in typical fall color will not be forgotten, and trees of both sexes are equally attractive.

Prunus sargentii and *Prunus yedoensis.*—Species that have made the Tidal Basin in Washington a picture of renown. They do well as street trees and are included in our list for diversity.

Acer rubrum 'October Glory'.—A nurseryman's selection for bright fall coloration. Its uniformity in fall coloration differs from the species, which has a mixture of both coloration and timing of leaf coloration.

Acer saccharum 'Green Mountain'.—Another nurseryman's selection. Its uniformity of conformation and glossiness of foliage make this cultivar a selection preferred over typical trees of the species.

Quercus acutissima.—A relatively new species in street-tree plantings. It holds its foliage throughout the winter months, a factor that may be objectionable. The species is readily established, and its growth rate is good.

Quercus rubra.—The standard of oaks for street-tree plantings. Once established, it can be considered a pivotal tree among street trees. The species is comparatively free of insect and disease problems, and its growth rate is excellent.

The foregoing selections of trees are for one community. Each shade-tree commission in each of the various New Jersey municipalities must weigh the advantages and disadvantages of the several species or cultivars recommended in TREES FOR NEW JERSEY STREETS, and then make selections that fit local conditions.

AVAILABILITY OF SELECTIONS

In some years shade-tree commissions will select tree species or cultivars that they consider highly desirable, but then find that some of their selections are not available in the supplying nurseries. To overcome that problem without forfeiting appropriated money, an escrow contract can be negotiated. This contract sets aside a specific amount of money chargeable to the current appropriation until the contracting nursery produces and delivers the desired trees, possibly 2 to 5 years later. A model for such escrow contracts has been published by the New Jersey Federation of Shade Tree Commissions *(Rex 1966).*

CONCLUSION

Shade-tree commissions can draw on accumulated experience and published guides, such as I mentioned, in selecting suitable trees for specific conditions. Research in progress or in prospect will, we hope, provide cultivars superior to those we have to use today in selecting trees for planting along the streets of our municipalities.

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ESTHETIC CONSIDERATIONS IN THE SELECTION AND USE OF TREES IN THE URBAN ENVIRONMENT

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ABSTRACT. The relationship between the physical qualities of trees and esthetics is clarified first by exploring the theory of esthetics; second by a brief overview of the impact of line, form, color, and texture of trees in three categories of compositional scale; and third by the presentation of a digest of esthetic qualities to which people respond on an emotional or intuitive level. The important contributions of the esthetic qualities of trees to various urban situations are outlined. It is suggested that plant scientists should consider the genetic traits that contribute to esthetics as seriously as they do the traits affecting cultural and physiological problems.

THE TITLE OF THIS paper suggests that there is more to consider than physiological and cultural requirements of trees in the urban environment. It suggests the need for an understanding of the esthetic potentials of trees as well.

To gain such an understanding I have divided this paper into three parts. First I will attempt to establish an understanding of the theory of esthetics. The second part is a brief overview of the esthetic qualities of trees. Third, I will suggest where the esthetics of trees can make important contributions toward converting man-made urban areas into a more pleasant environment.

PHILOSOPHY OF ESTHETICS

Most discussions of esthetics lapse into vague terms, confusion, and disagreement. Estheticians, theorists, critics, philosophers, and artists have long been ensnared in their efforts to find apt, expressive, and critical terms to define, to judge, and to describe the effects of beauty on man. Newton in his book THE MEANING OF BEAUTY (*1950*) stated that, except within the vaguest limits, beauty cannot be described and therefore cannot be defined. It cannot be measured in quality or quantity; yet it is, to man, a recognizable element.

People have come to use the term as if it had physical substance. For this reason, beauty is often considered something you can add to that which is considered ugly. This idea is a misconception. Beauty does not have substance or body in a tangible sense. Rather it has to do with a relationship between an observer and the object observed. Therefore this inquiry into esthetics must examine these two phenomena: the viewing process and the subject being viewed.

The viewing process is concerned with the visual perception of the scene, which causes a personal reaction on the part of the viewer. Two viewers observing the same object or scene will react differently, developing divergent mental images and conflicting value judgments. An individual's perception and assessment of beauty depends not only on the physical properties of the object and its surrounding environment, but also on the human variables of the individual—his experience, his education, his needs and purposes, his prejudices, and his social environment. Although individual value judgments will vary from one another, the degree and extent of these differences will change in time as these human variables change.

It would then seem that the old adage "beauty is in the eye of the beholder" implies that no two people will agree that an object or scene is beautiful. This is not true. It cannot be assumed that, just because individuals vary in how they see an object or scene, it is impossible to create compositions that to all viewers have beauty. The research conducted by Coughlin and Goldstein *(1970)* indicates that there is significant agreement among people on the attractiveness of various scenes and that environmental attractiveness can be determined and analyzed. The study does not mean to imply that each individual will have equally strong feelings about the beauty of an object or scene. It is impossible to have a fixed standard or uniform response because there is no common fund of the human variables.

As a consequence of these variables, the esthetics of a design cannot be predicted precisely; yet it is possible to have general agreement. This is because the scene or object has several common factors that contribute to the pleasure and intensity of emotion of most observers.

PHYSICAL QUALITIES AFFECTING ESTHETICS

Emotional responses to objects or scenes are based on the physical qualities of the object. The latter can be separated into (1) line and form, (2) color, and (3) texture. Every object has these physical qualities. They are the raw materials of esthetics and beauty. In fact, they are the only elements that can be manipulated by the designer to create satisfying and beautiful compositions.

Since these physical properties are the basis of judging esthetics and beauty, it might seem logical to assume that the viewer analytically evaluates each physical quality. This is not the case. Only the most critical and trained observer analyzes and reasons good or bad on the basis of each physical quality isolated from the other.

The average viewer casually views an object or scene and reacts to the composite effect of the physical qualities, not just to one component. The process of viewing and reacting to what is seen is both an unconscious and conscious act.

The unconscious phase involves feeling —an involuntary response of pleasure or disgust on first observation. The reaction is based on our sensory perception through sight, touch, hearing, smell and taste. The unconscious phase is followed by the conscious response. At this point the viewer starts to compare with past experience. His judgment will be conditioned by familiarity, prejudices, knowledge, and background.

It should be understood that unconscious (feeling) and conscious (thinking)

are familiar terms that permit the concept of viewing to be established. However, they should not be regarded as separate and distinct functions that operate independently. Within the human mind, the two phases merge into a single process that cannot be divided.

Therefore in establishing the theory and philosophy of esthetics, it should be recognized that esthetic values are appreciated through the senses of sight, sound, smell, and touch, but that beauty itself is dependent upon the physical properties of line and form, color, and texture of objects. For this reason, it is necessary to examine these physical qualities as they relate to trees.

The basic structure of a tree, its pattern of lines, the contour outline of its form, and its basic habit of growth are discussed to provide a basis for determining which types are suitable in the urban setting.

Line and Form

Characteristics.—Line and form are particularly important because these qualities are the most predictable and the most permanent regardless of season. Line is essentially an expression of form, form is an expression of line. They are separated here for discussion purposes only. Among trees, lines are straight or curved, vertical or horizontal or oblique. The trunk and main branches determine the line and mass of a tree, the shadow patterns both internally and externally, and the character and personality of the tree.

Form is the mass or volume of a tree that expresses itself in all three directions of space. The extremes of form—ranging from rigidly erect to weeping—provide a wide palette of materials from which to choose. It is the form of a tree that is responsible for the feeling and emotional appeal that is conveyed to the viewer.

Classification.—Lines can be classed as horizontal, vertical, or oblique, and forms of trees as columnar, rounded, vase-shaped or broad-rounded, pyramidal, irregular, or weeping. Horizontal lines emphasize extent and are restful; vertical lines are severe and provide a feeling of height; oblique lines suggest movement. Columnar forms of trees have either rounded or pointed tops and provide contrast. Rounded forms are pleasing and usually have dense crowns. Vase-shaped forms branch high so there is usable ground space below, are compatible with most plant forms, and blend well with architecture. Pyramidal forms accent the spire top, provide strong contrast, are difficult to harmonize with other plants, but are effective as specimen plants. Irregular forms provide both interest and contrast to architectural masses because of variable outline. Weeping forms are unnatural to some people, but are unique, lead attention to the ground area, and are effective against hard lines of architecture.

Color

Characteristics.—Flowers, fruit, twigs, bark, and foliage are the sources of color in trees. Because flower and fruit colors are seasonal and of short duration, they cannot be considered as primary design elements. Twig color becomes a major factor during winter months if deciduous materials are being used. But leaf color in both subtropical and temperate plant regions is an important consideration.

Foliage, although predominately green, can be classified according to its varying shades. In both subtropical and temperate plants, the following greens are common: gray-green, red-green, yellow-green, blue-green, black-green, and emerald green (true spectrum green). In some cases these are subtle variations of green and in others, they are obvious derivations from spectrum green. Regardless of the degree of variation, they are still considered green colors. In most situations the use of color in the landscape should be built around these variations of green.

All colors in the landscape are subject to one further modification that affects a person's experience of the color. This is

the variation between true local color and the color perceived as a result of atmospheric interferences between the light source (the sun) and the object. The earth's atmosphere varies the effects of color with every hour. At sunrise and sunset there is a violent disturbance of local color. For example the sun turns to crimson, the sky to gold, and clouds to rose and lilac. The chromatic interference resulting from atmospheric causes produces significant changes in color. Therefore color is more difficult to grasp intuitively as compared to form, which is not subject to atmospheric variations.

Nevertheless, color compositions should be based on the predominant foliage color of green and its derivations. To do otherwise would be counter to nature's own use of color. Nature is timid in her use of warm colors (red, yellow, orange), which are limited to small amounts such as flowers and berries. Our use of color should not attempt to rearrange this balance of color harmony.

This leads us to horticultural introductions in which unnatural colors have been developed—garish reds, jarring variegations, and vivid blue, to name a few. These abnormal colors should not be the goal of breeding and selection. They do not fit into the urban landscape—a landscape which is already overpoweringly artificial. Such foliage colors assume a prominence that is not warranted and further underscore man's separation from nature.

Classification.—The varying shades of green can be broken down into seven classes:

1. Dark green appears somber but combines well with architecture.
2. Light green is effective in expanding apparent size of space and lightening low-light areas.
3. Gray-green is also effective in expanding apparent size of space, combines well with vivid colors of buildings, but conveys a cold feeling.
4. Blue-green combines well with other foliage colors, suggests coolness and calmness.
5. Red-green offers a spark of vitality and feeling of warmth to an area, but reduces its apparent size.
6. Yellow-green blends well with other colors, brightens shadowy areas, and offers a cheerful effect.
7. Black-green seems somber and formal, but combines well with other foliage colors and with architecture.

Texture

Characteristics.—Texture in trees is judged on the basis of visual qualities instead of tactile experience. It is the arrangement and the character of the component parts that results in a texture effect.

Plant textures vary according to the distance from which the plant is viewed. In the near view, texture is the result of size and spacing of leaves and twigs, shape and surface quality of leaves, and length and stiffness of petioles. In the far view, texture depends on the same qualities listed in the near view. However, as the individual detail is lost, texture results from the light and shadow of the plant or plant masses.

Too often texture is overlooked in the selection and use of trees, probably because it is a variable quality subject to modification by season, age, climate, and atmosphere. It should not be ignored, particularly in the urban landscape. Effectively used, it can exploit and heighten the character and visual impact of the tree.

Texture can be used to establish a harmony throughout the urban space by repeating the texture of the surrounding elements in the space, or it can be used to create variety and accent. Texture can also be used to modify distance and the size of the space. For example, fine textures recede, thereby increasing the apparent size of the space. Coarse textures are visually dominant, resulting in a reduction in the apparent size of the space.

Classification.—Texture can be divided into five classes: fine, medium-fine, medium, medium-coarse, and coarse. Fine

textures are delicate and airy, provide a refined appearance, complement smooth surfaces, and soften and blend with harsh lines of architectural masses. Coarse textures blend well with rugged, heavy materials, are dominant and effective even when viewed from a distance, but tend to dwarf areas. All other classes are gradational between these two extremes.

Design Context

To aid in the use of these qualities as a tool for judging and selecting trees, it is now necessary to discuss the use of line, form, color, and texture from a design context. Such a discussion requires an understanding of the visual impact of these qualities on the basis of static and kinetic observation and scale. The potential visual strength and visual impact of each esthetic quality on urban space varies according to the movement of the observer and the distance between the object and the observer.

The landscape may be viewed from points or locations that allow static or stationary perception. In this case the designer can exercise great control over the impact of line, form, color, and texture since it will always be seen from one direction and from an unvarying distance. Which physical quality emerges as the strongest depends on the designer.

Most often the landscape is experienced while the observer is in motion. The speed of this motion becomes a critical factor in evaluating visual impact of the physical qualities. If the observer is moving through the landscape in a vehicle, the high rate of speed precludes the opportunity for careful and detailed observation of the physical qualities. In this situation form has the greatest impact, followed by line and color, and texture is the weakest. This ranking varies substantially when considered on the basis of the observer's motion resulting from walking at a rate of 2 to 3 miles per hour. In this case the distances between the observer and that which is being observed will determine which of the three physical qualities will have the greatest impact.

The basis for judging visual impact is dependent upon the compositional scale of the design. In any design there are three compositional scales: foreground, middle-ground, and background. As we discuss each of these compositional scales, we must also consider the physical qualities on each scale.

The foreground space is that close to the viewer. Closeness allows the details of building materials and trees to be seen. At this scale, the intricate structure of line in twig and branching produces strong asculptural pattern in space and a three-dimensional filagree pattern against architectural structures. Form is important only when the total tree can be perceived by the viewer. Such small trees must have an interesting silhouette and sculptural shape. The color of bark, twigs, foliage, flowers, and fruit have strong impact, as does texture. Both must be carefully planned and patterned to avoid overuse and jarring results.

The middle-ground scale is the transition between the close-up detailing of the foreground and the overall general composition of the background. All of the physical qualities come into play, but form will have greater strength. For example, the line of branches begins to merge into form; color details are lost except for the foliage contrasts of the various shades of green; and texture is a general effect of foliage and structure rather than details of leaf and twig. The added distance between the viewer and the tree permits easier perception of the total tree, further enhancing the importance of form. Therefore tree forms can be selected to contrast with surrounding architecture, to offset architecture as a foil, or to complement it by repeating the dominant forms, masses, or lines.

Background is the basic structure and framework of the composition and is a greater distance from the viewer. Although it will already be structured by surrounding urban elements—buildings, roads, signs, walls, etc.—the trees should mold, define, and reinforce the volume of space contained within the composition.

In this situation, line is evident only as a contour outline of the tree's form or as the result of several trees combined as a mass. Color has minimal impact except for the general impression of green without the subtle variations noted earlier. Texture, however, is somewhat more important because it is perceived as light and shadow effects resulting from line, color, and form. But once again form asserts itself over all the other physical qualities. Tree forms in the background should be presented with clarity, boldness, and strength—and yet always with simplicity.

It should be noted that, at certain times of the day or year, a normally weaker element can assume temporary strength to the point where it dominates the scene. For example, seasonal floral displays or spectacular fall color, either of which could overpower form at any scale.

EMOTIONAL QUALITIES AFFECTING ESTHETICS

There are other esthetic qualities associated with trees that result from line, form, color, and texture, but are conveyed and perceived more on the emotional level than on the rational and analytical evaluation of the physical qualities. The following is a digest of these qualities. They can be utilized in any urban situation; it is only a matter of determining which is appropriate. But in each case it is a combination of the physical qualities of the tree and the element of compositional scale that produce the esthetically desirable effects.

Space identification results from trees being used to establish a feeling or sense of place, possession, and movement. *Sense of place* is an encounter between the individual and place that is dramatic, simple, and impressive—space in which a person is emotionally secure. *Sense of possession* involves shade, shelter, and visual quality of space in order for people to use it and take possession of it. *Sense of movement* results from space defined by trees to outline a corridor of movement that eliminates confusion and indecision on the part of the user.

Enclosure and space definition is the shaping of outdoor spaces by utilizing trees. Enclosures created by trees are rarely total and complete. Trees function more on the basis of suggestion rather than by providing complete visual stops. In the near view, tree trunks provide a colonnade that defines space and implies containment, yet the gaps between trunks reveal what is beyond. In the far view the combination of trunks and foliage tend to merge, suggesting a total and complete enclosure.

The details of line and form, color, and texture of the trees used for enclosure have importance at a distance of 40 feet or less. Beyond 40 feet the composite effect of the total mass assumes importance.

Visual control orientation, focus, and sense of direction are attributes of visual control through the use of trees. *Orientation* is the use of trees to stimulate a reaction such as "I am enclosed", "I am exposed", "I am in it", "I am outside it", or "I am below it". Trees are also obvious devices to serve as a point of reference—"over there" or "here at the tree" or "under the tree". *Focus* is the transferance of attention. For example, a tree placed near an architectural element seizes our eye and holds our interest, resulting in a strong focus of attention. *Sense of direction* is control over the extent of the observer's view. It includes enframement of a vista, the partial screening of a vista, the linking of the near view with the far view, and the closed vista.

Enframement involves the use of trees to force viewing a special feature or remote landscape.

Linking the near view with the far depends on compartmentalizing the overall view, forcing the observer to see only sections of the total scene. When trees are arranged so the trunks form a series of "windows", the remote area is framed

into a series of "pictures". This directs the observer's attention to the details of the remote scene.

Partial screening of a feature or vista utilizes the crown of a tree to withhold the total view until the observer has moved past the tree. This technique works well when the feature is large enough to be partially viewed over or around the screening tree. This introduces intrigue and curiosity that is climaxed by the dramatic impact of the full view once one has passed the tree.

Finally, a blocked vista limits the observer's view to the immediate space he presently occupies. The result is added interest in the immediate environment.

Trees selected for screening or blocking of vistas should have strong form and be relatively dense. At the same time they should have interesting details for the nearby observer.

Truncation is the use of trees to mask the upper portion of buildings so that the building is not seen in its entirety. This break of the vertical mass directs attention to the space at eye level (the area below the tree's crown). The immediate space is no longer overwhelming to a person because the dwarfing influence of architecture is reduced by truncation.

The dramatic involves incidence, sequence, anticipation, infinity, and illusion. Establishing an *incidence* involves the capturing of the eye and attention in the midst of a monotonous field of vision. A continuous row of buildings quickly becomes boring because of number and dominance. If such a scene is interrupted by a tree or group of trees, the total scene has interest for the viewer. *Sequence* is a process of revealing a succession of views by having trees arranged to suggest a path of visual or physical movement. *Anticipation* is the exploitation of human inquisitiveness. Instead of giving orientation and meaning to the scene, trees are used to arouse one's curiosity as to what will be seen next after passing beyond the visual block. An attempt to use trees to expand the boundary of the immediate area provides a *sense of infinity*. Trees with strong line and form can direct the eye and attention, suggesting an expansion of size and infinity. *Illusion* involves suggestion and contradiction of perception. Past experience has taught us what we expect to perceive in depth, size, and distance; but by skillful placement or juxtaposition of trees, the visual experience can contradict the intellectual. If carefully handled, it can be intriguing and delightful.

ADDITIONAL CHARACTERISTICS AFFECTING ESTHETICS

Some additional characteristics of trees that also must be included in our digest of esthetic quality include silhouette, sculptural effect, shadows, reflections, intricacy, geometry, scale, foil, intimacy, and detail. A brief description of each follows.

1. Silhouette.—View of a tree as seen against the sky or building. It is a quality that is dynamic and expressive as well as appealing and satisfying.
2. Sculptural quality.—Refers to the three-dimensional form of the tree. It may be bold or varied, yet always interesting because of the changing visual angle that results from the movement of the observer.
3. Shadows.—Two-dimensional elements that have tremendous potential for esthetic effects. Shadows on the vertical walls of architectural or paved surfaces of the ground add detail, contrast, and animation to the man-made surfaces.
4. Reflections. — Two-dimensional patterns, like shadows, but created by water, glass, and other mirror-like surfaces. Surfaces that upon quick glance have no significance come to life with the interesting and provocative pattern of shadow and reflection.
5. Intricacy.—A quality relating to the natural yet sometimes curious branching pattern and general habit of growth of the tree. For the observer,

this quality is sometimes curious and abstract, yet impressive and meaningful.

6. Geometry.—The interaction of the tree form with architecture, sky, and space. Geometry can transform the landscape by the scale it establishes and by the significance it gains from contrast with the surrounding environment.

USE OF TREES FOR ESTHETICS AND UTILITY

Combining Both Functions

The foregoing discussion of the theory of esthetics and the cataloging of esthetic qualities of trees provide us with the necessary background information to consider now the various urban situations in which trees and their intrinsic qualities can be used effectively. We need to talk not only about esthetics but also about utilitarian function. There can be no dichotomy between the two. For too long, trees have been promoted on the basis of appealing to the imagination and emotions to the complete exclusion of reason and function. Both utilitarian and esthetic functions must be considered and exploited. Only on this basis can we convince the businessman, the developer, and the politician of the need for trees in the urban environment.

What is being suggested is *practical esthetics*. It is based upon how the physical qualities can be grouped and patterned in the urban environment to provide a satisfying and visually pleasing appearance and fulfill a utilitarian function. To do this it is necessary to establish two concepts.

The first concept is that people develop an intuition as to what is beautiful. Theoretically it is possible to explain the visual aspect of every object or scene on the basis of the physical qualities of materials. But in actual practice the relationships among line, form, color, and texture are grasped intuitively; and this intuition is sufficient for people's enjoyment.

The second concept is that esthetic value judgments are made on the character and type of the total landscape environment (architectural materials, trees, and space) rather than on the detailed arrangement of individual elements in the landscape scene.

As a first step towards establishing practical esthetics, we have to accept the premise that trees are uniquely capable of (1) creating and defining space, (2) establishing the scale of the area, and (3) developing a harmony with the surrounding urban environment. Practical esthetics involves more than merely filling open spaces with trees. Urban situations are so diverse in size and character that each calls for different techniques and criteria in selecting and using trees. There should not be one constant method or pattern. The decisions should be based on the tree's line, form, color, and texture; the interplay of spatial areas in plan and elevation; and the tree's relation to buildings, to the "offscape" and to human use of the space.

Trees for Different Urban Settings

The typical urban situations in which trees should be included can be grouped into (1) the single site, (2) the project site, (3) open space areas, and (4) the connector system. How trees, a basic material, are used for esthetics and function depends on many variables that make each site unique.

The *single site* usually involves a small unit of land on which there is one building with limited open space, such as a plaza. The goal for its development should be to define and reinforce the space, making the site pleasing and delightful to the user. Therefore, the size of the tree must be large enough to have a good scale relationship with the building. If it is a high-rise structure, the tree's crown should be massive and large enough to truncate the towering architec-

ture so that the building will be viewed as a backdrop for foliage and branches.

Because the site will be viewed mostly by pedestrians, the trees selected should contribute interest in line, branching patterns, texture, and color (for foreground views). These esthetic qualities provide delightful contrasts to the hard surfaces, harsh lines, and cold materials of the architecture.

The *project site* usually includes more than one building and has sidewalks, streets, and parking areas. Shopping centers, industrial parks, and housing projects are examples of project sites. The goal in the use of trees should be to facilitate visual identification, to create a memorable scene and to establish the feeling of a sense of place.

Often this landscape is characterized by an openness between buildings, roads, and walks. Trees can be used to provide continuity to the spaces and to articulate the form of space simply by dividing it into smaller units. As trees will be viewed mostly as background, their forms will be a critical esthetic factor. Similarly, parking lots are large and incomprehensible. They can be given architectural form through the repeated use of tree forms that are visually strong. An added functional benefit will be to give order and pattern to the movement and parking of cars in the lot.

Trees may also be used to direct the movement of people. When the direction of movement is defined, the user can have a fuller enjoyment of space and be relieved of confusion and indecision.

Finally, trees can be used to control spatial experiences, to interpret the use of the space and to orient the user. All of these considerations require an evaluation of line, form, color, and texture on the basis of how well selected trees will accomplish utilitarian requirements and at the same time heighten the user's visual and emotional experiences. Which qualities will have priority will depend on the proximity of the tree to the observer and his rate of movement through the space.

Open spaces are varied and serve different needs and functions. Open space may be a greenbelt for separating or blending different parts of the city. It may be open lands for active and passive recreation. Or it may be a large-scale plaza for a variety of mixed uses such as sitting, walking, playing, eating, concerts, and art shows.

Greenbelts can be used as a transition or buffer between various districts—as commercial, residential, industrial, recreational, and educational. Trees can be used as either barriers or elements of transition, depending on the degree of physical and visual penetration they permit. The individual tree's form, color, or texture is not important, but those of the aggregate are. The composition must be carefully conceived to convey a harmonious and visually satisfying combination of the physical qualities.

Parks are unique environments in the city because they are distinctly different types of landscapes. They are deliberately planned alternatives to the dominant man-built environment. Here trees should be used in two ways. First, they should establish a green outdoor environment, a view or a background from a distance, and the visual impact will be from the combined appearance of all the trees. Second, the same trees should be used in an architectural and space-organizing role, which requires interesting pattern and detail for the foreground and middleground scales.

Major plazas and open malls should capitalize on human activity—sitting, walking, chatting, people-watching, etc. To ensure active use of such space, it must have a good microclimate, which is a function trees easily perform. Plazas must have a sequence of subdivided interior spaces that give a sense of intimacy, contrast, leisure, and activity. Trees can serve as subdividers while adding character to the skyline, providing

shelter and conveying a sense of place. Utilizing physical qualities and compositional scales, the esthetic use of trees should clarify and express the emotional mood to the spaces and visually support the activities.

The *connector system* involves streets that extend throughout the city, connecting many diverse elements. The connector system is potentially the unifying element of an urban scene that is awkwardly fragmented into separate uses and zones. Esthetic qualities of trees provide one of the most powerful agents for unifying and joining the city.

The criteria for tree selection will be based upon the character of the street—residential, arterial, strip-commercial, and pedestrian-shopping.

The residential street provides access to homes. It is the path of cars and utilities and, to a lesser extent, pedestrians. Here trees should mask utilities without interference, separate pedestrians from automobiles, and soften and blend varying architectural styles into a harmonious whole.

The arterial street has a high volume of traffic and provides a higher speed of travel, while bisecting the whole range of urban spaces. Arterial streets may develop into strip-commercial areas characterized by an inordinate number of oversized, garish, and flashing signs in front of a tawdry collection of franchise architecture and ill-matched buildings. Trees can do little to solve the overbearing visual and traffic problems, but they can ameliorate them. A basic attraction of the arterial street for commercial activities is the high degree of visibility, and tree plantings should not reduce it. Therefore, the criteria for esthetics and function will be large trees that permit visual penetration at windshield height to areas beyond.

For arterial streets in general, selection of trees should consider speeds of the observers. The importance of form is obvious. Whether the crown should be open or dense depends on how much visual penetration is desired beyond the street corridor. Trees do not have to be regularly spaced at 30 to 40 feet to be effective. In fact utilities, curb cuts, and other physical elements usually prevent such rhythmic repetition. Nevertheless the introduction of trees wherever space is available creates visually pleasing effects along a monotonous street. Such trees should be sharp in silhouette feature, strong in texture, line, and possibly color, so as to add variety and interest.

The gridiron pattern of most urban streets allows for scanning the total scene within seconds, and the observer is soon bored. Trees of special interest in line, form, texture, and color can often be used to close off the endless vista. The result is containment of vision and intrigue for the observer.

Varying the street-tree pattern by alternating trees in a projection-and-recession pattern eliminates the effects of a straight-line green facade imposed on straight-line architectural facades. This provides an intricacy and pattern that is stimulating and enjoyable. Form and habit of growth are primary considerations.

Trees for minor streets should be used in much the same way as for arterial streets. However, on narrow streets, trees may be limited to one side, alternating sides by blocks. For narrow streets and small buildings, relatively small trees are preferred.

The pedestrian shopping street, as in the central business district, performs many functions: a thoroughfare, storage of parked cars, a servicing and delivery access to stores, and a space for pedestrian shoppers. Here the observer moves at pedestrian speed in a space classified as foreground scale. Trees of high interest in the details would be appropriate. At the same time trees should function to separate cars from pedestrians, to provide human scale in the midst of oversized buildings, to serve as focal points, as vistas and as places to sit, and to harmonize variable styles of architecture and a diverse and unorganized scene.

CONCLUSION

I have presented the theory of esthetics, an outline of physical qualities as units for manipulation to achieve esthetic results, and a catalog of esthetic qualities as they relate to trees and typical urban sites. To be meaningful, this discussion must be carried one step further, suggesting an approach for breeding and selecting of plants for different regions of the country.

Since esthetic impact results from the relationship between the physical qualities (line, form, color, texture) and the observer, the designer selects trees for their suitability in functional requirement and for their fitness to the esthetic needs of urban space. The latter implies the right form and habit of growth, the right color, and the right texture. These are genetic traits that the plant scientist can manipulate in his efforts to breed and select new trees to meet this very demanding man-made environment.

Any recommendation as to what plant breeders should be striving for in terms of form, habit, color, and texture must be developed on a regional basis, using vegetation that is common to the area as a basis of evaluation. Such an analysis should take into account the distinctive character of the predominant regional vegetation. This will then serve as a basis for determining what is needed in new introductions to provide a complete palette of plants that also meet other use criteria. It will also serve as a measure for evaluating the line, form, color, and texture of new introductions. Care must be taken to avoid the exotic and the unnatural. Instead the new trees must have a tolerance for urban environments, yet have sufficient similarities to the existing kinds of trees to assure that the distinctive character and sense of local identity are not lost. The importance of developing a tree planting that is in harmony not only with the immediate space, but with the surrounding landscape as well, cannot be overemphasized.

Harmony refers to the selection of trees that are appropriate in the degree of enrichment and in their role of strengthening and reinforcing the function and purpose of the space. Harmony's influence is not restricted, however, just to the space being developed. It also relates to how well the space being developed harmonizes with the surrounding landscape.

The rational and emotional level of aesthetics as discussed in this paper have had to be limited by necessity. This paper has dealt with the tangible physical qualities of aesthetics and the fact that they have value and emotional meaning to the observer. These two aesthetic concepts create possibilities for the plant breeder to add significance and value to new introductions.

In aspiring to assist breeders in aesthetic engineering, designers must learn how to define the design problems involved in selecting trees for urban use. In this way the solutions will respond to more than just cultural and physiological problems. This symposium is, in my opinion, an important beginning to bring into the breeding process an explicitness about its aesthetic consequences.

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SOME PSYCHOLOGICAL AND SOCIAL ASPECTS OF TREES IN THE CITY

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ABSTRACT. Recent studies in environmental perception indicate that the meaning and function of forest vegetation in the city may not be the same for urban residents as it is for rural and suburban residents. These studies suggest advantages for collaboration between behavioral scientists and forest geneticists in planning future research. Several possible psychological and social benefits of urban trees are discussed. Further behavioral studies may indicate desired attributes of trees bred especially for inner-city environments.

VISIONARY MEN like William Penn and Thomas Jefferson stressed the need for wooded tracts among the shops and residences of cities. However, until the late 19th century, most American cities contained few woodland tracts or parks. But with the conception and development of Central Park in New York, trees, grass, and water were retained in the heart of the city and were made accessible to residents of the inner city for pleasure and relaxation. By the turn of the century, similar parks had been designed for many other cities—Albany, Baltimore, Hartford, Philadelphia, and Pittsburgh among others (*Zube 1971*).

Now questions are being asked about these parks. In a recent critique of the nonuse of neighborhood parks Gold *(1972)* noted that parks designed for middle-class white patrons of the inner city in 1900 may no longer be relevant to current residents of other ethnic and racial backgrounds.

For a long time urban planners and designers have assumed that people have an innate and deep-seated need for intimate contact with nature. This need may be a learned cultural trait, characteristic of western civilization. The concept of the pastoral ideal has been a persistent theme throughout western civilization (*Marx 1964*), expressed even now by those who identify with the dominant culture. However, the contention that all people, adults and children, have an innate need for contact with nature is debatable and without strong empirical support.

Recent evidence suggests that the meaning of trees and forests for urban residents may not be the same as for

their rural counterparts. One study has found that residents of the inner city tend to evaluate scenes at the urban fringe differently than do suburban and rural residents. The scenes used in the study were predominantly natural, but included examples of a residential subdivision and a commercial-strip development. The scenic ratings of the inner-city subgroup were more likely to represent the extreme range of values in both natural and urbanized scenes. The group of adult inner-city residents was too small a sample on which to base firm conclusions, but the data do indicate that there may be strong differences in the way these citizens perceive and evaluate outdoor environments (*Zube and others 1974*).

In a pilot study to measure the quality of life in urban and rural counties in New York State, Milbrath and Sahr[1] found that urban people placed more importance on upward mobility and material consumption than did their rural counterparts. Urban people also placed less importance on natural outdoor recreation, landform and topography, unspoiled nature, and variety of wildlife than did people living in a rural county in the Adirondack Mountains. Despite these lifestyle differences in the two counties, there was considerable agreement on basically important things such as clean water, medical care, security, privacy, comfort, and freedom.

This suggests that we should be wary of imposing on urban residents our values for trees and forest vegetation that do not have meaning for them. There does not seem to be sufficient information about the values of forest vegetation for inner-city residents. Before we set out to design better trees for urban environments, we need to ask some basic questions. What are the indicators of the quality of life in urban environments? How do urban residents perceive their physical surroundings? And what importance, if any, do trees and forest vegetation have in their lifestyle?

[1] Lester W. Milbrath and Robert C. Sahr reported the results of their study in a paper, "Perceptions of Environmental Quality" delivered at the VIII World Congress of the International Sociological Association in Toronto, Canada, on 23 August 1974.

TREES FOR CHILDREN'S PLAY

One psychological benefit from trees in cities is their potential use for children's play. We know from our own experience and from direct observation that children in rural and suburban environments use trees in their play. They climb in trees, hide in trees, build in trees, and swing from trees. Would children living in inner-city neighborhoods use trees in the same way?

As a part of another study, our colleague Robert Williamson informally interviewed a number of rural, suburban, and inner-city children. Among other things, he asked them: "What does a tree mean to you?" The children's answers were surprising. The rural and suburban children tended to view trees as either a place to play (climbing, hiding, or building tree forts) or in a general way that might be termed a nonutilitarian response ("You can talk to a tree," said one child).

The responses of the inner-city children were quite different. None of these children responded to trees in a playful or esthetic sense. Almost invariably they responded that trees were a source of wood—raw material to be used in housing, floors, furniture, and so on. The response of city children to trees may have been influenced by their lack of contact with trees and forests. The number of trees in their neighborhoods may have been too few or too large to climb, or were surrounded by fences.

Assuming that inner-city children would enjoy playing in trees if they were available and accessible, we could give some thought to the attributes of trees that are conducive to play, such as smooth bark and stout low limbs close together for climbing.

TREES AS SOURCES OF INFORMATION

One value of trees in cities that is seldom considered is as a source of information. We are using "information" here in the technical sense of information theory *(Shannon and Weaver 1949)*. Here, rather than being considered as something to be obtained from a magazine or a television news show, information can be conceived as signals that come to a person from his or her environment in terms of "bits," often in a nonverbal manner.

Cities, despite all claims for their infinite variety, tend to be places of extreme regularity. Street systems are usually laid out in a grid system, buildings tend to be rectangular and symmetrical, and there is a certain sense of visual sameness. There is little information in the sense of novel stimuli, change, or complexity. For residents of such a section, this low level of information can produce monotony, boredom, or tedium. Prolonged exposure to information-deficient environments creates pathological problems *(Heron 1957)*. The problem is to increase the amount of information in these environments by providing novelty, change, motion, and complexity. Trees can help accomplish this in a variety of ways. Moreover, some kinds of trees may be more effective than others.

A variety of factors associated with the tree itself are important in producing information. One is shape. An irregular shape contains more information than a regular shape. Consider, for instance, the irregular shape of a mature, open-grown, white pine (*Pinus strobus*) relative to the regular shape of a spruce (*Picea* spp.).

A second factor associated with the tree itself is color. Colorful flowers add to the novelty of a tree. In the fullmoon maple (*Acer japonica*) the foliage color is novel, and many other deciduous trees have color in the fall. This seems to imply that deciduous trees contain more information than coniferous trees. Overall, this may be true. Yet the color of coniferous trees makes an important contribution to the bleak landscape of winter.

Motion (and especially leaf motion) is another factor that can increase the amount of information. Some trees have rigid branches and leaves, while others have more supple limbs and leaves. Consider the quaking aspen (*Populus tremuloides*) when even the slightest breeze stirs the leaves and provides much variation in light and dark.

A fourth information factor is seasonal change. Trees, especially deciduous ones, contribute to information-deficient environments by signaling the change of the seasons. From the first buds of spring, through the luxuriant summer foliage, to the cold and brilliant colors of autumn, deciduous trees signal the onset of the seasons.

Factors external to the trees themselves may also be important in providing novelty or change. On how many city streets have we seen one species of tree planted at evenly spaced intervals? It might be better to vary this spacing so that several trees occur together after an open space. Or the species could be varied as well.

Then, too, we cannot afford to consider only the single tree: the context it appears in is important too. Texture and contrast are both important variables in increasing the amount of information.

These are but a few of the information factors associated with city trees. The key point is that trees can and do serve useful roles in providing information in otherwise information-deficient environments. Such uses of trees merit future research attention.

SHADE FOR OUTDOOR ACTIVITIES

The need for shade in the heart of cities may seem obvious. In the city where the form of the outdoor environment is floor and walls and pavement

and buildings, the shading from the high summer sun is only a narrow strip along a wall. There are few ceilings or canopies that shade the pavement and allow movement and activities to occur beneath. Mature single trees and clusters of trees provide shelter from the sun for whatever human activities may occur beneath their branches—a quiet conversation, a picnic, a game of tag, or a pickup game of basketball.

Shade trees and cities are not always compatible. In fact, most trees exist in the heart of cities only by the deliberate action of man; they must be planted and cultivated. City trees hardly constitute what we might call a forest, but natural regeneration does occur in time on vacant lots, along steep unbuildable slopes, and in deserted alleys. Such natural vegetation is more like weeds: fast-growing, tolerant of heat, shade, drought, and meager soil. Such trees are often scrawny, yet some people appreciate them even so because of the scarcity.

In conclusion, we suggest a possible contribution of forest-genetics research by using a hypothetical situation. A park planner in New York City recently posed this problem. In a severely depressed section of Queens, many apartment houses had been taken over by the city for overdue taxes and torn down. Vacant lots are new scattered over many city blocks. What could urban foresters do with these vacant city-owned lots to improve the physical environment that didn't involve money? The obvious answer is—not much. Vacant land in cities may not remain vacant for long. Trees take time to grow; transplanting large trees costs plenty. And then who is to say that the trees wouldn't be vandalized, mutilated, or cut down in spiteful contempt?

Assuming that some group of persons in a neighborhood cared enough to plant trees on the vacant lot and watch over them, what trees could grow there? Planted as seed or seedlings, what species could tolerate low moisture and poor soil yet provide shade in a few years? Fast-growing boxelder (*Acer negundo*), quaking aspen, or the tree-of-heaven (*Ailanthus altissima*) could fill the bill. Perhaps particular attributes desired by urban residents could be bred into such trees. Perhaps some of the rapid growth could be sacrificed for sturdier branches that children could climb in, or perhaps the tree-of-heaven could be deodorized.

For urban residents who cannot escape the heat of the city in the summer, fast-growing trees could provide relatively instant shade in 3 to 5 years. Shade for vacant lots could provide a cool place for elders to meet, for teens to rap, and for kids to pedal their trikes or climb to a tree house while mothers can watch them from shaded benches. Outdoor shade in summer might make a vacant lot or two into social meeting places for a neighborhood of strangers, a place to go outdoors that is close to home. Planting city-owned vacant lots to trees and other vegetation, however temporary their status may be, could make neighborhoods more stimulating and could satisfy unmet needs for outdoor activities close to home.

The research question for behavioral scientists is to find out what attributes of forest vegetation in the city are perceived as desirable by urban residents. The question for geneticists is how to improve hardy weed trees that already have a foothold among the cracks in the concrete. Research in both areas would gain from mutual cooperation.

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SELECTION OF TREES FOR MODIFYING METROPOLITAN CLIMATES

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ABSTRACT. The current state of knowledge about effects of trees on microscale and mesoscale metropolitan climate is discussed. Emphasis is placed on the potential role of trees in ameliorating climate for human thermal comfort outdoors and for reducing consumption of energy for heating and air-conditioning buildings. The physics of the energy exchanges that control metropolitan climate are summarized. Suggestions are made for the selection of species and kinds of trees for modifying the climate in metropolitan areas.

WHAT ARE THE REASONS for concern over the possible roles that trees play in moderating or controlling metropolitan climates? Trees can directly affect human comfort outdoors as well as the energy required for maintaining comfortable temperatures indoors. Also by altering climate, trees may indirectly affect dispersion of pollutants and distribution of rainfall. We will concentrate on the more direct effects of trees in metropolitan areas.

Much has been written about trees and the climate of urban areas. Most of this information has been developed from subjective evaluations of the influence of trees or has been extrapolated from experiments conducted in forest conditions. This has led to some quantitative and even some qualitative misinterpretations of the effects of trees on climate. Other misinformation is due to a lack of communication between physical scientists and urban designers.

Recently, research has been completed that more accurately describes how trees ameliorate climates of urban areas. In particular, insight has been gained into the effects of trees on environmental conditions important to "human thermal comfort" and the heating and cooling of buildings. However, it is still not possible to do more than make general suggestions about selecting tree species for modifying urban climates.

One of our primary goals in this paper

is to provide background information about the physical basis for selection of trees to modify climate. The effects of trees on metropolitan climates have also been discussed by Federer *(1971)*, Heisler *(1974, 1975)*, Herrington and others *(1972)*, and Herrington *(1973)*.

THE PHYSICS OF CLIMATE AND CLIMATE MODIFICATION

Scales of Climate

Climate is usually defined in terms of averages of air temperature, relative humidity, wind speed and direction, solar radiation, cloudiness, precipitation, etc. The average can take place over various times. The usual connotation of climate is that it is the average taken over ten's of years and over an area of several hundred square miles. Partly to avoid local surface effects, National Weather Service observations of temperature and humidity are made at 2 meters above ground level in ventilated shelters. These large-scale climatic averages are known as the *macroclimate*.

We can define smaller scales of climatic characterization—the *mesoscale* and the *microscale*. The mesoscale has horizontal dimensions on the order of ten's of miles. The microscale is much smaller—usually a few hundred feet or less horizontally and ten's of feet vertically. This organization of climates forms a nested structure in which the climate of the smaller scale is a modification of the climate of the larger; that is, smaller-scale climates are deviations from the mean climate of the larger area. These modifications are primarily due to deviations of the "surface" from the mean "surface," which is a combination of soil, plant cover, blacktop, rooftops, etc.

As we go to smaller and smaller scales, we find that wind, temperature, and balances of radiation (solar and infrared) undergo increasingly larger changes due to changes in the physical structure of the surface. Trees, being surface features, will have their largest effect at smaller scales.

Energy Flow

The exchange of energy between a surface or an object (either can be considered a "system") and its environment is of central importance in understanding the controls of climate and microclimate of an area. Climatologists and meteorologists usually attack this problem by use of an energy budget model of the system under study. Energy flows into the system are considered positive, and those out as negative.

For example, during daylight hours, systems in the sun absorb radiant energy. This energy is converted to sensible heat, and the system increases in temperature. Generally, the temperature of the system rises above the temperature of its environment, and heat then flows from the system to the air by convection and to any solid in contact with the system by conduction. If the system has a wet surface, energy is consumed by evaporation. There is also an infrared radiant-energy exchange between the system and its surroundings.

In every case, heat flows down temperature gradients from high to lower. Sometimes, as at night, radiational cooling causes the temperature of a system to drop below that of its surroundings; and some, or perhaps all, of the avenues of heat exchange reverse themselves and supply heat to the system.

The relationship between temperature and flows of heat within and between systems and their surroundings may be very complex. For instance, radiation frosts are the result of a combination of strong outgoing (negative) net infrared radiation along with low wind speeds. In this case, the high infrared-radiation exchange is due to clear skies, which are thermally cold relative to cloudy skies. Under these conditions, the temperature of a bare soil surface drops rapidly because heat is removed by radiation and because the still air brings little heat by convection. The

only source of heat is that brought by conduction from deep soil layers to the surface. If the soil has low density, it will be a poor conductor of heat and will have low heat capacity, with little heat stored. Surface cooling will be faster than for a high-density soil.

Similar types of interactions occur in the energy budgets of plants, except that storage and conduction are less important than for soil, because most plant parts have far lower heat conductivity and heat capacity than soils. Human beings have energy budgets with an additional source of heat to consider: heat produced by metabolic activity. For energy budgets of buildings, temperature regulation by furnaces and air-conditioning must be considered.

ROLES OF TREES IN METROPOLITAN CLIMATE

Mesoscale Temperatures

Little work has been carried out to determine the effects of various kinds and amounts of city trees in moderating the climate of entire cities or metropolitan areas. Many comparisons between rural and urban temperatures have been made, but usually temperature differences have been ascribed only to differences between city structures and the surrounding generally vegetated areas. The amount and kind of vegetation in the non-city areas are not specified and are usually described only vaguely as part of a rural landscape.

Mesoscale temperature differences between city and country are frequently called "urban heat islands" because cities are usually warmer in both summer and winter. On summer nights, rural areas may be cooler than built-up areas by 10°F and occasionally even as much as 20°F *(Peterson 1969)*.

In one of the few studies of the distribution of urban surface materials *(Marotz and Coiner 1973)*, aerial photographs were used to charactize several cities in Kansas. The percentage of area covered by woody and other vegetation in cities of different size was determined (table 1). The authors suggest that the amount of vegetated surface within cities has been grossly underestimated. However, no temperature differences are given.

In an earlier experiment in mapping and modeling the effect of land use on urban thermal regimes *(Outcalt 1972)*, the term "urban cold doughnut" was coined. Thermophotography of farmland, a city center, new subdivisions, and old residential areas showed the existence of a daytime cold annulus (the doughnut) in the old residential neighborhoods about the city core. The cooler temperatures in the old neighborhoods were attributed to relatively wet but rough surfaces—mature transpiring trees.

Table 1.—Percentage of surface materials in some northeastern Kansas cities[1]

[From Marotz and Coiner 1973.]

Material	Kansas City (pop. 168,213)	Lawrence (pop. 45,698)	Baldwin (pop. 2,520)	Eudora (pop. 2,071)	Tonganoxie (pop. 1,717)
Natural:					
Grass	31	24	61	56	62
Woody	18	36	16	11	14
Total	53	63	85	72	79
Modified					
Asphalt	46	32	7	13	11
Concrete	1	2	1	2	—
Gravel	2	2	5	13	9
Total	51	39	15	28	21

[1] The method of sampling apparently yields approximate area percentage figures so that the totals "natural" and "modified" may equal more than 100 percent when added.

tunnel studies to model air-infiltration rates for the previously mentioned town houses in the planned unit development of Twin Rivers, N.J. A single row of trees was modelled by mounting triangular-shaped wire screens on vertical metal shafts. Visual density approximated that of a single row of white pine *(Pinus strobus)* or Norway spruce *(Picea abies)* trees. Tree models were equal in height to house height. Potential reduction of infiltration by trees was as much as 60 percent. Because infiltration was estimated to cause one-third of winter heat loss, the reduction in infiltration by a single row of tall conifers could mean a 20-percent reduction in fuel use at certain times. The average reduction for the entire season would not be as great.

Flemer *(1974)* compared fuel consumption in the same eastern house before and after an evergreen windbreak was installed. When the trees reached the height of the house, a fuel saving of 10 percent per winter over the former exposed condition was recorded.

Trees for summer shade.—We know of only one study that provides quantitative information about the effect of tree shade on temperatures within buildings. Working in California, Deering *(1956)* found that dense shade from trees might reduce maximum temperatures in houses by 20 F. He used a 20- by 8-foot house trailer to simulate a typical low-cost frame house. Construction included 2- by 3-inch studs with white clapboard siding and an asphalt-shingled roof. Data from 3 days with similar conditions of wind and ambient air temperature were used to compare temperature regimes inside the trailer for three different shade conditions.

When the trailer was beneath a group of large fig trees that provided shade all day, the temperature inside the trailer remained over 75 F only 5 hours in comparison to 11½ hours in full sun. Maximum temperature inside the trailer was 84 F in the shade, and 104 F in full sun. Shade of eucalyptus provided results similar to those for the fig shade, but direct comparison was not possible because the trailer was situated beside rather than within the eucalyptus grove, and no shade was provided in the morning.

CONCLUSIONS

Some literature about the ability of trees to modify climate exhibits a degree of sensationalism. Thus a knowledge of basic principles of energy flows that control climate in metropolitan areas is important for realistic selection of trees for metropolitan use.

Control of radiation, particularly solar radiation, is probably the most important use of trees for controlling microclimate in urban areas. However, existing knowledge does not permit us to say much more than the obvious about using and selecting trees for control of solar radiation. Designers need a number of tree species with different solar-radiation-transmission characteristics to fit varied metropolitan environments. Deciduous species are preferable in temperate regions. Around new construction, fast-growing species that provide at least moderately dense shade are desirable. The albedo (reflectivity of solar radiation) does not vary sufficiently among species to warrant selection for climate control on this basis.

We can provide examples of species for use in the temperate climates of the eastern United States. Tall trees with normally wide-spreading, medium-dense crowns and high decurrent branching such as London plane *(Platanus* x *acerifolia)* or American elm *(Ulmus americana)* are usually most useful for yard or street shade trees. Low branching not only prevents shading of buildings, but also obstructs air flow in summer. The new "Urban elm", a cross between *Ulmus* x *hollandica 'Vegeta'* and *Ulmus carpinifolia (Agricultural Research 1975)*, probably will not be as useful for moderating urban climate because of its low branch-

ing. More desirable from the standpoint of urban climate modification would be a revival of *Ulmus americana*. Thornless honeylocust *(Gleditsia triacanthos f. inermis)* has too thin a crown and is too short at maturity to provide sufficient shade for most urban sites.

Where windbreaks are desirable to reduce strong winter winds, several rows of low-branching deciduous species such as Lombardy poplar *(Populus nigra 'Italica')* or one of the columnar-shaped elms new being developed *(Agricultural Research 1975)* would be somewhat effective. However, evergreens would be generally more effective. We have no conclusive information for recommending particular evergreens as windbreaks.

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TREES AND FORESTS FOR NOISE ABATEMENT AND VISUAL SCREENING

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ABSTRACT. Noise pollution is common in metropolitan areas, comes from many sources, and is a problem in human comfort and health. Noise measurement and the physics of noise propagation and reduction are complicated. Mechanisms of noise attenuation by forests are discussed, as well as the amount of reduction produced by various planting. Plantings are more effective as visual screens than as reducers of noise. Plantings occupying relatively narrow strips of land can fully serve screening purposes, whereas plantings usually must be at least 100 feet wide to be significantly effective for noise control. Because of insufficient data, recommendations on species composition desirable for either purpose are vague.

COMPLEMENTARY USES of trees for noise abatement and visual screening are often possible in metropolitan areas. Many sounds are not objectionable if the source cannot be seen. Also, visual screens are sometimes sufficiently dense and wide so that they create a real and significant reduction in noise. Hence, it is entirely appropriate to consider sound-abatement properties along with the screening properties of trees.

Excessive noise from highway traffic, industry, construction equipment, air-conditioning units, power mowers, and other appliances typical of our civilized metropolitan environment has resulted in strong complaints from residents—particularly home owners and apartment dwellers. Excessive noise interferes with communication by speech or telephone, sleep, and enjoyment of radio, records, and television. Excessive noise levels can cause psychological disorders and permanent hearing loss.

For these reasons, attempts have been

made to limit levels of noise emission in communities by federal, state, and local legislation. In all cases, this legislation involves compromises between economics, technical practicality, and personal annoyance. As with all compromises, none of the parties involved are fully satisfied, and some of the legislation is virtually unenforceable. Therefore, additional means of noise reduction, including the use of vegetative barriers, are being studied and applied to improve the metropolitan environment.

Metropolitan scenery frequently abounds in unsightly views that people find depressing—dilapidated buildings, refineries and factories, parking lots, storage yards, and the like. Trees can do much to improve views. Even a single row of shade trees along the side of a street will block much of the unsightliness of nearby buildings; and a single row of dense-foliage trees can often block more distant scenes of storage yards, factory parking lots, and in some places the factories and refineries themselves. In addition, tree barriers may be used to emphasize extraordinary pleasant views by blocking out those that are merely commonplace.

This paper summarizes the state of the art on using trees for noise reduction and visual screening, and discusses some aspects of selecting trees for these purposes. A brief review of noise sources, measures, propagation, and community reaction to noise is included.

NOISE SOURCES, PROPAGATION, MEASUREMENT, AND HUMAN REACTION

Noise levels from such sources as automobiles, motorcycles, trucks, industrial plants, and most other community noise sources may be expressed in a number of ways. For our purposes, we will describe briefly only the four most common measures of noise. For those interested in a detailed discussion of acoustical measurements, Beranek *(1971)* is one of several good references.

Essentially all measurements of noise make use of the decibel (abbreviated dB) system. Decibel measurements are used for convenience where a large range of values must be compared. In general, decibel values are proportional to the logarithm of the ratio of a measured value divided by a reference level. In acoustics, the ratio is usually a sound pressure divided by a reference pressure of 0.0002 microbars. A line chart (fig. 1) may be used to add two decibel values. Note that if one sound source is placed beside another of equal intensity, the increase in sound pressure level will be only 3dB, regardless of the sound levels of the two equal sources.

One means of representing a noise source is to show the sound spectral content; that is, the noise amplitude distribution as a function of frequency at one time or averaged over a given time period. Typical octave band spectra for transportation and air-conditioner noises

Figure 1.—Line chart for the addition of sound-pressure levels.

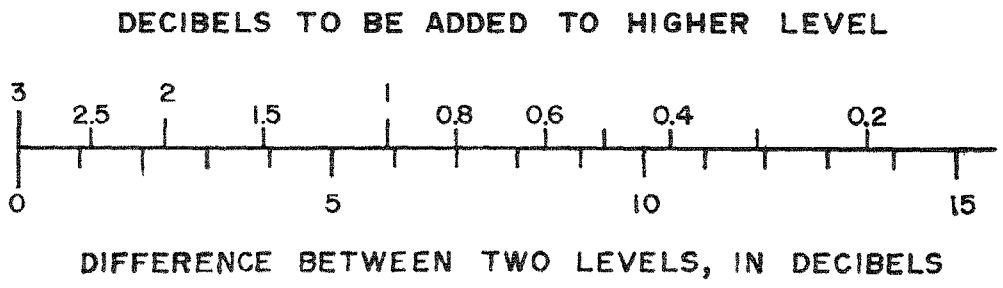
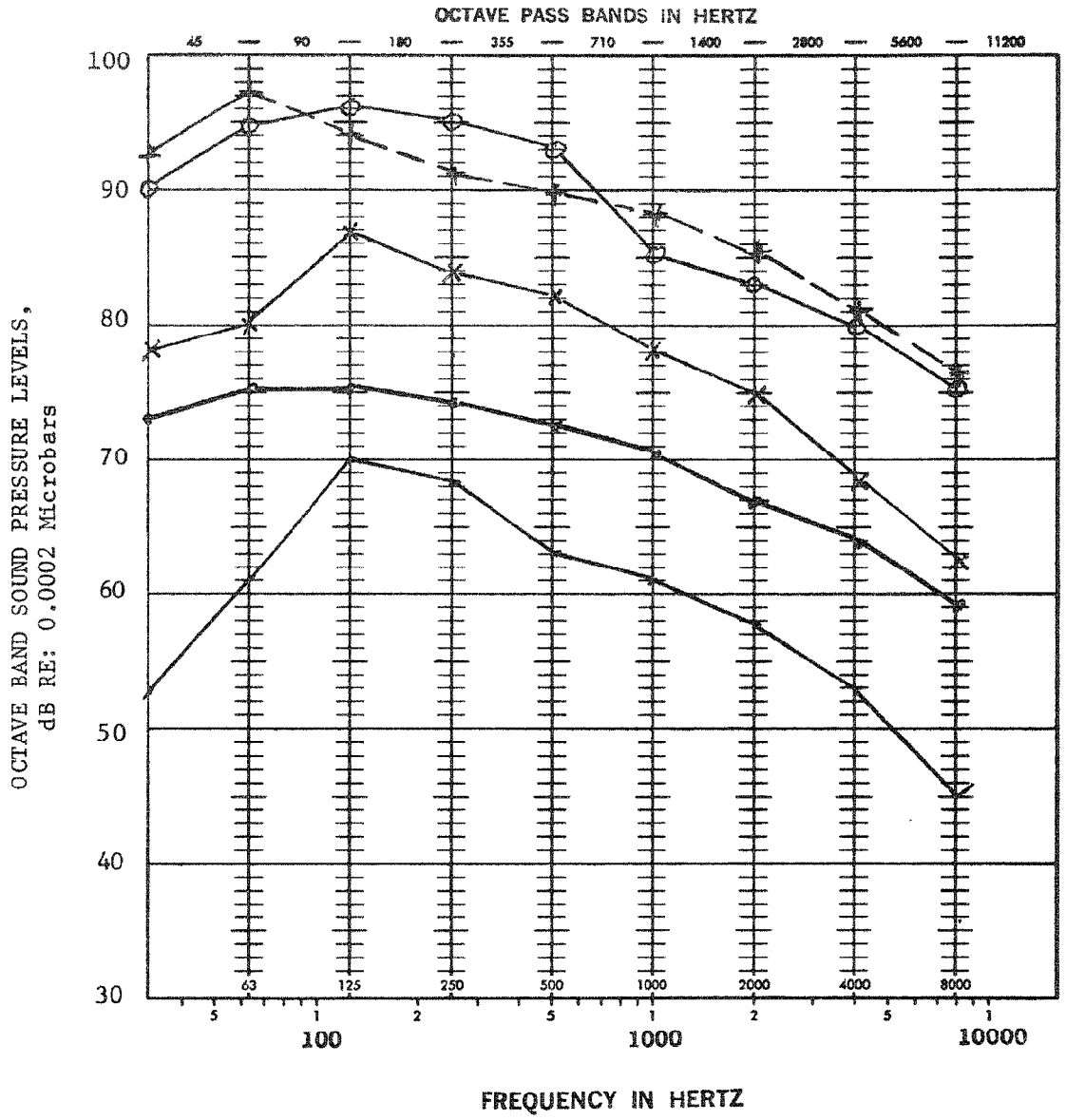


Figure 2.—Typical octave-band sound-pressure levels for noise from several transportation vehicles and an air-conditioner.



——— Air Conditioner

o——o Motorcycle at 50 feet

x——x Trucks at level cruise at 50 feet

•——• Passenger cars at 55 mph. at 50 feet

+ -- + 3000 HP Locomotive at 50 feet

are given in figure 2. The variation from these average values can be expected to be as much as 10dB. Community noises in general have a fairly broad spectrum.

The human ear does not react equally to all frequencies of sound, and the so-called "A" weighting characteristic is used to adjust sound-pressure levels to obtain a measure called dBA, which approximates the loudness of sounds as they are perceived by humans. The range of frequencies the typical young adult can hear is from about 20 to 15,000 Hz (Hertz, cycles per second). However, our hearing is most acute in the 1,000 to 4,000 Hz range. Table 1 shows how sound-pressure levels given in octave bands are adjusted for A-weighting. Typical sound-pressure levels in dBA for various sources are given in table 2.

A third means of describing noise is by Speech Interference Level (L_{SI}), which is obtained by calculating the arithmetic average of the 500-, 1,000-, and 2,000-Hz octave-band sound-pressure levels. Speech communication is one of the most important human activities. For particular indoor environments, the permissible noise in terms of L_{SI} values ranges from 35dB (42dBA) for homes to 45dB (52dBA) for private offices to 60dB (67dBA) for secretarial areas. Thus, most of the noise from transportation, construction equipment, and manufacturing plants will interfere with speech communication at the distances from the sources listed in table 2.

Another widely-accepted evaluation of community noise is the Noise Pollution Level (L_{NP}). It provides a measure of statistical variation with time of noise levels measured in dBA. In terms of community reaction, the U.S. Department of Housing and Urban Development has established the outside Noise Pollution Level criteria given in table 3.

In using these measures of community noise, remember that the hearing acuity of human beings varies substantially from one person to the next. People respond differently to noise based on background,

Table 1.—Corrections for A-weighted octave band analysis

Band center frequency	A-weighting correction
Hz	*dB*
31.5	−39.4
63	−26.2
125	−16.1
250	− 8.6
500	− 3.2
1,000	0
2,000	+ 1.2
4,000	+ 1.0
8,000	− 1.1

Table 2.—Sound-pressure levels of typical noise sources

Source	Sound-pressure level range	Distance
	dBA	*Feet*
Whisper	25-40	5
Residential area at night	35-45	
Large transformer	48-55	200
Automobile:		
< 35 mph	62-72	25
> 35 mph	70-78	25
Accelerating	82-88	
Truck with muffler:		
< 35 mph	74-78	50
> 35 mph	80-85	50
Accelerating	82-90	50
up 4% grade	85-88	50
Truck without muffler up 4% grade	93-100	50
Motorcycles:		
< 35 mph	75-83	20
Accelerating	90-97	25
Earthmoving scraper	80-92	50
Concrete mixer	75-88	50
Pile driver	95-105	50
Air compressor	75-85	50
Rock drill	81-98	50
Lawnmower	68	50
Freight train 3,000-hp diesel, 30-40 mph	85-95	100
High-speed turbo train	100	100
Can-manufacturing plant	52-65	—
Oil refinery	51-68	—

Sources: Lyon 1973, EPA 1971a and 1971b, NASA 1970.

Table 3.—Community noise criteria based on noise-pollution level

Criteria	Noise level
Clearly acceptable	< 62dB (L_{NP})
Normally acceptable	62 < 74dB (L_{NP})
Normally unacceptable	74 < 88dB (L_{NP})
Clearly unacceptable	> 88dB (L_{NP})

prior exposure, interests, and various physiological factors. In addition to the level of noise, the existence of pure tones, impulsive sounds, duration of noise, and time of day or night also affect community reaction to noise.

Some precautions need to be taken in interpreting sound measurements and attenuation. For example, a pure-tone sound travelling over a flat hard surface will result in destructive wave interference between the direct wave at a particular location and the reflected wave that, since it travels a longer distance, may be out of phase with the direct wave. Thus, measurement at one location may indicate a very high attenuation that would not be recorded at a slightly different location. This phenomenon may also occur to a somewhat lesser degree over porous ground. On the other hand, at another location the relative phase relationship between direct and ground-reflected waves may be such that augmentation takes place, resulting in a sound increase or negative noise reduction.

A second example occurs in thermal inversions on clear nights when there may be significant noise increases at particular locations as the "sound ray" actually bends down toward the earth near the receiver location. The speed of sound is proportional to the square root of the absolute temperature of the air, so an increasing air temperature with increasing height above the ground will cause this phenomenon. In midday, when radiation from the sun heats the air near the ground, the opposite phenomenon occurs, and actual "shadow zones" are generated where less sound is heard.

SHRUBS, TREES AND FORESTS FOR NOISE ABATEMENT

The use of trees, shrubs, and various ground covers for the purpose of attenuating the noise from highways and industries has been under study for the last 5 years. The intent of these studies was to establish the so-called "excess attenuation" achieved by the intervening "noise barrier". This excess attenuation is the noise reduction obtained from the attenuation means adjusted for the spherical spreading of sound in a free field and the absorption of sound by the atmosphere.

The processes that result in the attenuation by forests are quite complicated. Consider a forest having a floor of decayed material, grasses, some sand, and rock. There are some deciduous shrubs and a variety of deciduous and coniferous trees up to 60 feet tall, having trunks up to 2 feet in diameter. As the sound wave approaches the forest edge, the ground cover will absorb some of the sound in grazing incidence. The very low frequencies (20-100Hz) will either pass right through the forest or be absorbed by the ground. The high frequencies (2,000 to 8,000Hz) will be reflected and diffracted by the larger trunks and branches, resulting in multiple scattering and some absorption. Recent tests in The Pennsylvania State University Noise Control Laboratory show that even the thickest barks on large trunks are very poor acoustic absorbers. On the other hand, typical forest floors of either decaying leaves or needles are excellent acoustic absorbers over a fairly wide range of frequencies. Generally speaking, the denser the forest, the better the absorption.

Several researchers *(Embleton 1963, Eyring 1946, Reethof 1973, Wiener and Keast 1959)* have made tests in extensive moderately dense forests where visibility was between 100 and 200 feet. Their results show that the excess attenuation per 100 feet of depth, as a function of octave band frequencies, is very modest at the important low frequencies and becomes very significant at the high frequencies (fig. 3). On the other hand, the weighting correction is quite large at low frequencies. Thus, a 200-foot-deep forest typical of the northeastern United States would result in the reduction of typical locomotive noise as shown in table 4 (which also indicates the various steps in

Figure 3.—Sound attenuation by forests (Reethof 1973).

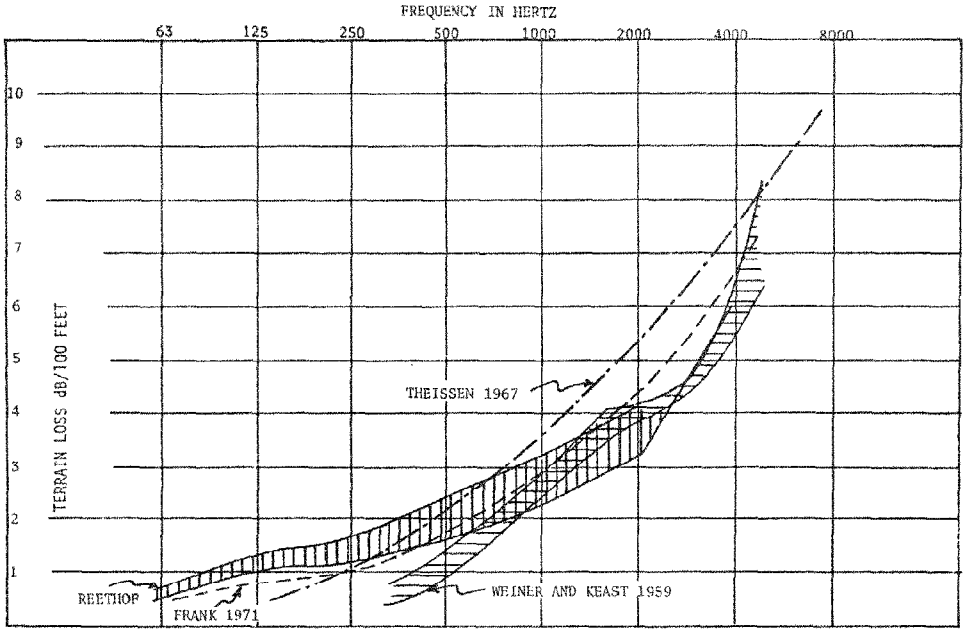


Table 4.—Locomotive noise attenuation with and without a 200-foot-deep forest

Octave band center frequency	Locomotive noise at 50 feet	Spherical spreading for 200 feet	Excess attenuation by forest	"A" correction	"A" correction of unattenuated locomotive noise at 50 feet	Locomotive noise at 250 feet without forest	Locomotive noise at 250 feet with forest
Hz	*db*	*dB*	*dB*	*db*	*db*	*dB*	*dB*
31.5	92	14	0	−39	53	39	39
63	97	14	1	−26	71	57	56
125	93	14	2	−16	77	63	61
250	91	14	3	−9	82	68	65
500	90	14	4	−3	87	73	69
1,000	88	14	6	0	88	74	68
2,000	85	14	8	+1	86	72	64
4,000	81	14	12	+1	82	68	56
8,000	76	14	20	−1	75	61	41
Total	101	—	—	—	93dBA	79dBA	73dBA

the calculation). The locomotive noise at 50 feet has an A-weighted level of 93dBA, whereas the locomotive noise reduced by spherical spreading from 50 to 250 feet and attenuated by the forest is reduced to 73dBA. Without the forest effect, the level of 50 feet is 79dBA. This example indicates that 200 feet of forest may provide an important reduction in transportation noise.

Work done by Whitcomb and Stowers *(1973)* in Florida shows that hedges also provide significant reduction in noise from lawnmowers and traffic. They tested

a broad-leafed dense hedge *(Illicium anisatum)* 5 feet thick and 8 feet high, using a source and a receiver located close to the hedge. A 5dB reduction in A-weighted level was obtanied when source and receiver were located about 13 feet apart, each being about 4 feet from the hedge and at a height of 3 feet above the ground. Whitcomb and Stowers showed that leaf size, shape and density were of prime importance in modifying the amount of noise reduction. Aylor *(1972a, 1972b)* studied various types of high-density ground covers and again showed the importance of leaf density and leaf size, and the effect of frequency on excess attenuation.

Cook and Van Haverbeke *(1971)* found that 65- to 100-foot-wide belts of trees and shrubs can be effective barriers of noise from high-speed traffic if the near edge of the belt is within 80 feet of the nearest traffic. The approach to the barrier should have soft ground and a grass cover, and not be in hard paved surfaces. To increase the effectivenes of plantings, 8 to 10 feet high, 50- to 100-foot-wide earth landforms should be constructed and should be planted with dense shrubs on the highway side *(Cook and Van Haverbeke 1974)*. A strip at least 20 feet wide beyond the shrubs should be planted with coniferous and deciduous trees that will grow tall in time. Excess attenuations of about 10dB of typical traffic noise can be expected from the tree and landform combinations.

TREES FOR VISUAL SCREENING

Architectural Basis

Many architectual uses of trees involve visual screening of some kind. Robinette *(1972)* uses the term "screening" to refer specifically to "view blockage" or the hiding of objectionable objects or scenes from view. In reality, however, many other architectual uses for trees include their use as barriers or screens. Such other uses are space definition or articulation (room-making), privacy control, and "progressive realization". Robinette defines progressive realization as "enticement and tantalization", the gradual opening to view of a special scene by showing a small glimpse, then more of the scene, and eventually the whole picture. There are numerous other ways that skilled landscape architects make use of tree barriers for guiding the movement of people through spaces, for guiding their eyes to objects or parts of buildings that are to be emphasized, and for creating particular optical impressions. References are available that describe techniques for using trees for screening and barriers *(Lynch 1971, Simonds 1961, Robinette 1972)*.

Species Selection

There seems to be a definite lack of information about when and how to use particular plant materials for screening. Some landscape planners have learned much about the use of different plant species for screening in their own local areas. However, Robinette *(1972)* indicated that available information about the effectiveness of plants as screening elements "has not been well catalogued and indexed". Although planting screens for highway beautification "gained wide acceptance in the mid 1960's, quantitative data was unavailable to show ways plants can be used to screen and what their limitations are". Even in the Great Plains, where shelterbelt planting has provided many years of experience in the establishment of tree barriers, only limited information on the use of trees for highway screening and beautification is available *(Davidson 1970)*.

In spite of some gaps in our ability to prescribe tree species for screening and barriers, some suggestions can be made. Evergreen coniferous species are usually best for year-round screening. The trees are often sheared to produce maximum density. Depending on the location, deciduous species are also valuable as visual screens. If the screen is to hide a view that is objectionable only in sum-

mer, deciduous species obviously have a place and might be preferable because of faster growth. Further, visual screens need not always be essentially opaque to be effective. Particularly if the observer is moving, a partially open screen may be just as effective as a wall of vegetation, and a hemmed-in feeling may be avoided. In some situations an eye-catcher such as a lone clump of white-barked birches or other specimen tree may distract people from views that are best unseen.

Living Screens for America, a booklet recently published by the American Association of Nurserymen, provides a list of species that have screening potential. This booklet is a good start in the effort to catalog species for screening purposes. Suggestions are based on plant hardiness, rapidity of growth, availability, disease resistance, low maintenance, and reasonable cost.

Sufficient diversity of useful plant materials to provide variation in design is one requirement for successful landscape planning. In many metropolitan residential areas, adequate diversity probably already exists. For example, in the heart of the eastern megalopolis are vast areas that serve as bedroom communities for New York, Philadelphia, Baltimore, and Washington. These exurban areas (outside the suburbs, containing plentiful open space and with primarily single-family dwellings) can easily be classed as metropolitan even though they are as much as an hour travel by fast train or bus from truly urban areas.

Central New Jersey has many exurban landscapes. Here, where stresses that must be endured by plants in large cities are generally reduced, plant materials for barriers are in good supply and are adequately diverse in characteristics. The species which Robinette *(1972)* lists as some of the most visually dense are easily grown for screens. In order of decreasing density these species include arbor-vitae *(Thuja occidentalis)*, eastern hemlock *(Tsuga canadensis)*, Douglas-fir *(Pseudotsuga menziesii)*, white spruce *(Picea glauca)*, and white pine *(Pinus strobus)*.

In many metropolitan residential communities, the selection of species for visual screening is more difficult. For example, in New England and upper New York State the variety of plants that can survive is somewhat reduced because of more severe winters. If air-pollution problems and highway salting are added to the list of stresses on plants, many coniferous species, which are so useful for visual screening, cannot be used. Selection and breeding of a greater variety of stress-resistant conifers for visual screening would be desirable.

In major urban areas, the need is still more critical. The list of useful coniferous species for visual screening is definitely limited, and we need more variety in deciduous species that can withstand urban stresses. Often the urban view most in need of screening is directly overhead. The thin lacy foliage of thornless honeylocust *(Gleditsia triacanthos f. inermis)* forms a pleasant over-head veil; but sometimes a dense canopy is called for. Some *Ginkgo biloba* clones form a solid canopy, but others are little better than honeylocust. London planes may suffice, but often even their canopies are not sufficiently dense, particularly in cities.

Coal-mine spoil banks are definitely detrimental to both the economy and the esthetic quality of some highly populated regions. Guides for selecting species to screen coal-mine spoils in northeastern Pennsylvania are available *(Frank 1964, Czapowskyj and McQuilkin 1966)*. To hide these spoils, Frank recommended planting about a million trees in multirow screens: slow-growing evergreens that retain their branches, such as spruces, in the front; faster-growing evergreens, such as pines, in the center; and still faster-growing deciduous species, such as black locust or larch, in the back. His recommended width of screen was 100 feet, a width that would also reduce the noise of highway traffic according to many authors.

For screening and beautification of highways in the Great Plains, Davidson *(1970)* listed 16 tree species and 13 shrub species, described their hardiness and site requirements, and discussed in general terms their screening abilities.

CONCLUSIONS

Dense and tall ground cover and particularly dense and extensive plantings of trees and shrubs can be used effectively to reduce transportation and industrial noise. Low frequencies, typical of low-speed truck noise, are attenuated to a far lesser degree than the higher frequencies characteristic of high-speed traffic and industrial noise sources. However, low-frequency truck noise is in a frequency range in which the human ear is quite insensitive to sound. A thick litter layer is an important element in the sound absorption process of forests.

Mature forests, whether coniferous, deciduous, or mixed, attenuate noise similarly over the audible frequency range. Natural forests should be 200 to 500 feet wide to provide significant noise reduction from traffic noise; but planted barriers of shrubs and a mixture of coniferous and deciduous trees can be made denser than most natural forests, and the width of the barrier may be less—100 to 200 feet. A few studies have indicated that dense tree or hedge barriers, only 20 feet or even less in width, are effective. However, other studies showed no significant attenuation from such narrow vegetative barriers. It is generally agreed that narrow belts of vegetation are psychologically effective by screening noise sources from view. Tree barriers on raised landforms, 15 to 30 feet higher than the source and the receiver, are more effective than either trees or landforms alone.

There are a number of applications for trees as visual barriers beside the obvious purpose of hiding an unpleasant scene from view. Although evergreen conifers are generally the most desirable for visual-barrier plantings, faster growth may make deciduous species the best choice for barriers where some visual permeability is acceptable in winter or where space is available for a wide barrier. Deciduous species may also be used in a parallel combination with evergreens to add variety to a screen.

Some studies indicate that leaf sizes and shapes are important variables in the ability of trees to attenuate noise. However, other studies have shown that leaf size and shape are unimportant. Selection of trees for noise barriers should be based on the ability of the species for survival and rapid growth of a dense tree barrier. Fast-growing, shade-tolerant species would usually be most suitable. For visual screening, there is a definite need for selection and breeding of trees to provide a greater variety of species—especially conifers—that can withstand urban stresses.

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CAPABILITY OF METROPOLITAN TREES TO REDUCE ATMOSPHERIC CONTAMINANTS

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ABSTRACT. The most damaging levels of air pollution are reached in industrial and urban areas. Atmospheric contaminants in metropolitan areas include both particulate and gaseous pollutants. Since trees have evolved in the presence of numerous materials presently considered air pollutants, and since trees are frequently abundant in urban areas, it has been speculated that trees may function as effective sinks for trace contaminants. Mechanisms for removing particulate matter may include sedimentation onto tree surfaces, impaction on tree surfaces, and precipitation transfer to tree surfaces. Mechanisms for gaseous removal by trees may include uptake via plant pores and surface adsorption. Sufficient potential for this sink function is indicated to justify consideration of this amenity function in tree selection and breeding programs for metropolitan trees.

AIR POLLUTION is the phenomenon of atypical increase in trace contaminant levels of the atmosphere, resulting from the activities of man or extraordinary natural events such as volcanic eruptions, dust storms, or fires. The ramifications of numerous air pollutants are global in nature. Acute (high-dosage) effects of air contaminants, however, are generally regional or local phenomena associated with roadways, commercial and industrial facilities, or urban areas.

The air pollutants of significance to man and vegetation are varied; they include solid, liquid, and gaseous materials:

I. PARTICULATES:
  A. Solid (organic, inorganic)
    1. Nonviable
    2. Viable
  B. Liquid
II. GASES:
  A. Primary (released directly into the atmosphere)
    1. Inorganic
      a. Oxides
        i. Nitrogen
        ii. Sulfur
        iii. Carbon
      b. Halogens

i. Fluorine
ii. Chlorine
c. Other
i. Hydrogen sulfide
ii. Ammonia
2. Organic
a. Hydrocarbons
b. Aldehydes (ketones)
c. Mercaptans
B. Secondary (synthesized in the atmosphere)
a. Ozone
b. Peroxyacetylnitrate and homologues

Air-quality considerations in metropolitan areas are especially critical because of the tremendous aggregation of people and machines. In addition, urban regions cover impressively large areas. By the year 2000 the total urban-suburban land area may exceed 300 million acres *(Pickard 1971)*, with approximately 85 percent of us residing in urban communities. The emission trends of numerous air pollutants have been increasing in the recent past *(Cavender and others 1973)*; and the total national cost of air pollution, with much of this damage concentrated in urban areas, was estimated to be in excess of 16 billion dollars in 1968 *(Barrett and Waddell 1973)*. All strategies to reduce urban air pollution must be considered. One of the strategies may involve the ability of vegetation to remove air pollutants from the atmosphere.

Numerous particulate and gaseous materials classified as air pollutants have natural origins. Carbon monoxide, hydrogen sulfide, ammonia, oxides of nitrogen, and hydrocarbons derived from natural sources greatly exceed the emission of these gases from anthropogenic sources *(Robinson and Robbins 1968, Weinstock and Niki 1972)*. The annual global contribution of hydrocarbons by forests is 175 x 10^6 metric tons of reactive hydrocarbons from tree foliage. This is six times larger than the emission level from man-made sources *(Rasmussen 1972)*.

Components of ecosystems that remove pollutants from the atmospheric compartment and store, metabolize, or transfer them are termed "sinks" *(Warren 1973)*. Since plants have evolved in the presence of numerous compounds presently considered air pollutants, and since vegetation covers 90 percent of the land in the United States, it is reasonable to hypothesize that terrestrial ecosystems act as important sinks for air contaminants. Vegetative, soil, and water compartments of natural ecosystems may all be important sinks for numerous atmospheric contaminants. If plant tolerance is great enough, the sink function may extend to low pollution loads generated by man. This suggestion has been made by numerous investigators *(Dochinger 1975, Hanson and Thorne 1970, Lamanna 1970, Stewart and Wilken 1966, Waggoner 1971)*. Forest ecosystems have been suggested to be potentially important air-pollution sinks *(Smith 1974)*.

Evidence that soils may be particularly important sinks for numerous particulate and gaseous air contaminants is accumulating. In a recent review, Bohn *(1972)* indicated that while soils do emit some compounds considered air pollutants, they readily absorb numerous particulate and gaseous pollutants. He indicated that the amount of air pollutants absorbed by animal life is negligible and that most air pollution is absorbed by vegetation and soils.

In recent years many people have examined the specific capabilities of individual plants to remove contaminants from the atmosphere. Most of them have dealt with gaseous pollutants and nonwoody plant species. Some evidence to support the hypothesis that plants remove both particulate and gaseous pollutants from the atmosphere has been provided.

PARTICULATES

Characterization

Particulates are solid or liquid trace elements in the atmosphere. Their character is extremely varied; they may be

viable or nonviable, organic or inorganic. The inorganic fraction usually contains a few dozen elements, many metallic, the most common being silicon, calcium, aluminum, and iron. The organic fraction may contain a large number of aliphatic and aromatic hydrocarbons, aldehydes, ketones, and acids. Viable particles include pollen grains, fungal spores, and bacterial cells.

Particulates may range in size from approximately 0.0005 to 500 micrometers (μm) in diameter. Because of their large mass, large particles have a high rate of sedimentation and short longevity in the atmosphere. Small particles are usually electrically charged and frequently attach to other particles. Particles larger than 10 μm frequently result from mechanical processes: for example, wind erosion, grinding, or spraying. Many pollen grains and fungus spores are larger than 10 μm. Soil particles, process dust, industrial combustion products, and marine salt particles are typically between 1 and 10μm in diameter. Particles in the 0.1- to 1-μm range frequently represent gases that have condensed to form nonvolatile products. Lee *(1972)* has suggested that particulate matter suspended in urban air in the United States is predominantly less than 1 μm in size. Aerosols close to roadways are larger than those found some distance away because of reentrainment of debris by traffic-induced turbulence.

The annual mean concentrations of suspended particulate matter in United States urban areas range from 60μg/m^3 to 200μg/m^3. The maximum 24-hr average concentration is usually approximately three times the annual mean. Urban areas generally have higher particulate loads in the winter than in the summer *(Spirtas and Levin 1971)*.

Mechanisms of Removal

Much of the understanding of the mechanics of deposition of particles on natural surfaces has been gleaned from studies with particles in the size range of 1 to 50μm and is reviewed in the papers of Chamberlain *(1967)* and Ingold *(1971)*. Basically particulates are deposited on natural surfaces by three processes: sedimentation under the influence of gravity, impaction under the influence of eddy currents, and deposition under the influence of precipitation.

Sedimentation usually results in the deposition of particles on the upper surfaces of plant parts and is most important with large particles. Sedimentation velocity varies with particle density, shape, and other factors. Impaction occurs when air flows past an obstacle and the airstream divides; but particles in the air tend to continue straight—due to their momentum—till they strike an obstacle. The efficiency of collection via impaction increases with decreasing diameter of the collecting obstacle and increasing diameter of the particle. Chamberlain *(1967)* suggested that impaction is the principal means of deposition if: (1) particle size is of the order of 10's of microns or greater, (2) obstacle size is of the order of centimeters or less; (3) approach velocity is of the order of meters per second or more; and (4) the collecting surface is wet, sticky, hairy, or otherwise retentive.

Ingold *(1971)* presented data indicating that leaf petioles are considerably more efficient particulate impactors than either the twigs (stems) or the leaf blade. Impaction is not efficient for particles of 1 to 5μm, and interception by fine hairs on vegetation is possibly the most efficient retentive mechanism. The efficiency of washout of particles by rain is high for particles approximately 20 to 30μm in size. The capturing efficiency of raindrops falls off very sharply for particles of 5μm or less. Particulate removal by stomatal uptake has been suggested *(Jordan 1975)*, but is of unclear significance. The latter process would probably involve small ($<1\mu$m diameter) particles.

Vegetation as Particulate Sinks

Because of the considerable interest in the distribution of radioactive material

following the use of nuclear weapons or nuclear accidents, several investigators have examined the ability of aboveground plant parts to intercept radioactive aerosols *(Chamberlain 1970, Oak Ridge National Laboratory 1969)*. Dahlman and others *(1969)* examined the behaviour of ^{137}Cs-tagged particles (^{137}Cs fused to 88-177μm silica sand) in a fescue meadow. Sand particles intercepted by grass blades were readily dislodged by light wind, and maximum retention time was approximately 10 days. If trapped in leaf axils, particles remained for longer periods.

Witherspoon and Taylor *(1971)* studied retention by soybean and sorghum plants, using smaller (average diameter 7.5μm, range 1 to 44μm) sand particles tagged with ^{134}Cs. Initial interception of particles was similar, with values of 40 and 38 percent of the deposition quantity retained by soybeans and sorghum respectively. Over 80 percent of the soybean interception was by the foliage. The major site of sorghum interception, however, was the axil where the leaf joins the stalk and forms a sheath. Very rapid loss of particles occurred during the first week after deposition, soybean losing 79 percent and sorghum 88 percent of the particles.

In their study of common grasses (zoysia, bluegrass, fescue, and Bermuda) treated with ^{134}Cs-sand particles (44-88μm dia), Peters and Witherspoon (1972) observed that initial interception varied between 68 and 82 percent. Weathering half-lives of particles on foliage averaged 4, 37, and 81 days, respectively, for the time periods of 0-3, 3-35 and 35-48 days after deposition. This suggested that grasses have relatively effective structures for particle retention.

Chadwick and Chamberlain *(1970)* observed that the loss of radionuclides from an old grassland in England was faster in summer than winter. Moorby and Squire (1963) documented the loss of radioactive particles from the leaves of several agricultural crops, even when the plants were protected from precipitation.

Other evidence for the ability of plants to trap atmospheric particulates comes from studies concerned with sodium and plant nutrient cycling in maritime ecosystems *(Martin 1959, Oosting and Billings 1942)*. Numerous studies have demonstrated that the effective surface for salt deposition is larger where plants are present than over bare ground. Clayton *(1972)* described the trapping of particulate salts by *Baccharis* brushlands in coastal California. Woodcock *(1953)* provided evidence that the shape of plant leaves influences the amount of salt deposited. By employing plates of various shapes, he found that long narrow plates accumulated more salt per unit area than did plate centers. Edwards and Claxton *(1964)* found over four times the deposition of salt on the windward side of a hedgerow compared to the leeward side.

Parallel studies of the retention of dust, sodium, nutrient, and radioactive particles by woody plants are also available *(Warren 1973)*. In addition, several studies have stressed the ability of trees to accumulate heavy metal particulates. In an Ohio study, Dochinger *(1972)* examined dustfall and suspended particulate matter in three areas: treeless, deciduous canopy, and conifer canopy; he concluded that trees have the capacity to reduce particulate pollutants in the atmosphere. Trees may be especially efficient filters of airborne particles because of their large size, high surface to volume ratio of foliage, and frequently hairy or rough leaf, twig, or bark surfaces.

Witherspoon and Taylor *(1969)* treated seedling white pine and red oak with 88 to 175μm diameter quartz particles tagged with ^{134}Cs. Initial particle retention by oak foliage was 35 percent, by pine only 24 percent. After 1 hour, however, the oak leaves lost 91 percent of their initial concentrations while pines lost only 10 percent. Most pine particles were trapped at the base of needle bun-

dles around branch termini while oak particles were retained in small hairy recesses along leaf veins. Particle half-lives were calculated at intervals of 0 to 1 day, 1 to 7 days, and 7 to 33 days. For pine the values were 0.25, 5, and 21 days respectively. For oak they were 0.12, 1, and 25 days. Particulate loss was primarily attributed to the action of wind and rain. Zinke *(1967)* estimated that the retention of airborne materials ranged from 17 to 57 percent in pine stands and 82 to 86 percent in hardwood forests.

Numerous investigations, reviewed by White and Turner *(1970)*, have indicated that trees catch airborne nutrient particles. These authors found that their mixed deciduous forest was capable of annually removing 125 kg/ha sodium, 6 kg/ha potassium, 4 kg/ha calcium, 16 kg/ha magnesium, and 0.1 kg/ha phosphorus from the atmosphere. Degree of leaf hairiness was inversely correlated with particle retention. Apparently the small droplets employed had insufficient inertia to penetrate the stable boundary layer created by the hairy leaves. Small branches were more efficient particle collectors than large branches in all species examined.

Wedding and others *(1975)* found, under controlled wind tunnel conditions, that particulate deposition on rough pubescent sunflower leaves was 10 times greater than on smooth, waxy yellow-poplar leaves. They concluded that particulate retention could be quantitatively determined for plants existing in an environment of known aerosol concentration. Many investigators, for example Raynor and others *(1966)*, have shown that the concentration of particles carried by an air mass through a woodland decreases rapidly from the edge. Considerable rainfall interception data *(Helvey 1971)* indicate that canopy interception loss is greatest in the spruce-fir-hemlock type, intermediate in pine, and least in broad-leaved deciduous forests.

Trees located in industrial regions can become excessively contaminated with particulate emissions. Documentation from limestone operations *(Manning 1971)* and metal smelters *(Buchauer 1973, Little and Martin 1972)* is available. Rural, suburban, and urban roadside environments are also sites of excessive particulate subtraction by woody plants *(Smith 1975)*. Particularly abundant particulates include salt *(Smith 1970)* and heavy metals *(Heichel and Hankin 1972, Smith 1971, 1972, 1973)*. Smith *(1974)* estimated that the leaves and current twigs of a 30-cm (12-inch) diameter urban sugar maple remove from the atmosphere 60, 140, 5,800, and 820 mg of cadmium, chromium, lead, and nickel respectively during the course of a single growing season.

GASES

Characterization

The most significant gaseous contaminants of urban atmospheres are listed in table 1. Because of their abundance, human and vegetative health consequences and ability to deteriorate materials, the oxides of nitrogen, sulfur and carbon, hydrocarbons, and ozone are the most important.

Mechanisms of Removal

The primary way vegetation removes gases from the atmosphere is by uptake through the stomates. Minor methods by which plants remove gaseous pollutants from the atmosphere may include uptake by plant surface microflora, uptake through bark pores, and adsorption of gases to the surface of plant parts.

The processes of transpiration and photosynthesis require that plants exchange gases with the ambient atmosphere through leaf, branch, and stem pores. Contaminant gases present in the atmosphere in the vicinity of a plant may be absorbed when the stomates or lenticels are open.

Spedding *(1969)* investigated the uptake of SO_2 by barley leaves and found a 6-fold increase in average deposition ve-

locity with open stomata compared to closed ones. In related work, Rich and associates *(1970)* reported that uptake of 0_3 by bean was regulated by the same factors that control the exchange of water vapor between leaves and the atmosphere. This conclusion is also supported by Thorne and Hanson *(1972)*. Once inside the leaf, gases probably become dissolved in water. Hill *(1971)* compared the rates of uptake of pollutants by alfalfa with the water solubility of the pollutants. Fluorides had the highest water solubility and uptake. As the rates of uptake of pollutants decreased, their water solubility was also reduced. Any factor that affects the stomata influences the uptake rate of gaseous pollutants. Some of the environmental factors that are important in the action of stomata are light, humidity, temperature, wind, and the available supply of soil water.

Atmospheric pollutants themselves are also reported to have an effect on stomatal activity. Majernik and Mansfield *(1970)* and Unsworth and others *(1972)* reported that SO_2 caused stomata to open faster in the light, to achieve a greater aperature, and to close more slowly in darkness. All of these would allow for the absorption of more SO_2.

Guderian *(1970)* reported that the concentration of the pollutant in the air affected the sorption of the pollutant. He found that sulfur was sorbed least when the concentration was the highest and that the sorption of SO_2 increased with decreasing atmospheric concentration of SO_2 and increased exposure time. Brennan and associates *(1964)* reported somewhat different results. They found that the sulfur content of leaves increased as the SO_2 concentration increased during 4-hour fumigation periods. The sulfur content of leaves injured by high concentrations of SO_2 exceeded 0.30 percent. The sulfur content of leaves exposed to lower concentrations of SO_2 for longer periods of time was equally high, but no injury was noted.

Martin and Barber *(1971)* measured loss of atmospheric SO_2 over a hawthorn hedge. Maximum foliar intake was through foliar absorption during the warm daylight hours, but during rain or dew periods, especially at night, it was primarily through surface adsorption.

Godzik *(1968)* observed that the greatest amount of sulfur was absorbed by leaves of a *Betula* species, which is resistant to SO_2, and the least by a *Picea* species, which is susceptible to SO_2. He concluded that the susceptibility of species is not governed by the amount of pollutant absorbed. Conversely, Materna and Kohout *(1963)* concluded that susceptible species absorbed more pollutants than resistant trees.

Ozone reportedly causes stomatal closure in a number of plant species. Rich and Turner *(1972)* observed this and concluded that closure also depended on plant hydration, atmospheric humidity, and plant species.

Tingey *(1968)* reported that aerial pollutant concentration affected the uptake rate. He found that the initial rate of uptake of NO_2 by alfalfa and oats was directly proportional to the concentration of NO_2 over the range of 0 to 24 pphm. However, as the length of exposure increased, the rate of uptake remained linear from 0 to 8 pphm but became nonlinear over the range of 8 to 24 pphm. The rate at which the pollutant was metabolized, translocated, or otherwise removed from the absorption site appeared to limit the rate of uptake of the pollutant.

Hill *(1971)* examined the uptake of aerial pollutants by alfalfa and found gaseous uptake in chambers approximated those measured under field conditions. Alfalfa absorbed gaseous pollutants from the atmosphere in the following order: $HF > SO_2 > Cl_2 > NO_2 > O_3 > PAN > NO > CO$. Uptake was influenced by wind velocity, height of canopy, and light intensity.

Vegetation as Gaseous Sinks

Hill *(1971)* calculated that a square mile of alfalfa could remove SO_2 at the rate of 7.25×10^6 lbs yr^{-1} and NO_2 at the rate of 2.04×10^5 lbs yr^{-1}. Based on these figures, he concluded that vegetation could be a significant sink for gaseous emissions in polluted areas. Tingey *(1968)* measured the foliar uptake rate of NO_2 by oats and alfalfa. His data indicated plant removal of NO_2 could be important in alleviating smog concentrations.

Similar studies have demonstrated that corn seedlings *(Porter and others 1972)* and soybeans *(Hutchinson and others 1972)* are effective sinks for atmospheric ammonia.

Rich and associates *(1970)* measured the rate of uptake of O_3 by bean leaves. They found that the conditions favoring transpiration also influenced uptake of O_3. Their data suggested that in theory a forest could remove about one-eighth of the O_3 content of the atmosphere in 1 hour and could reduce O_3 levels from 14 pphm at the top of the canopy to 7 pphm at its base.

Ledbetter and others *(1960)* demonstrated with labeled F^{19} that tomato leaves take up gaseous fluorine from the atmosphere. Similar findings of foliar uptake are reported by Weinstein *(1961)*, Dassler *(1969)*, and Knabe *(1970)*.

Data on the uptake of numerous gases by a standardized plant canopy of alfalfa have been provided by Bennett and Hill *(1973)*.

Thorne and Hanson *(1972)* compared the relative abilities of various plant species to remove ozone from their microenvironment under laboratory conditions. The authors concluded that herbaceous species absorb more ozone than woody species. For example, they demonstrated that *Petunia hybrida* had a velocity of deposition of 13.7 cm min^{-1} while *Quercus engelmanii* had a rate of only 1.5 cm min^{-1}. Nevertheless, increasing evidence is being accumulated that woody plants may effectively remove atmospheric trace gases.

Two criteria were recommended by Flemming *(1967)* for curtailing emission levels in forest woodlands. First, the pollution concentration must decrease with elevation. Second, the distance of the forest belt from the pollution source should not be too far. Flemming cited Wentzel's *(1962)* report as an example of a forest belt fulfilling these criteria.

In Western Germany, Bernatzky *(1968)* has investigated the importance of protective plantings against air pollution for 25 years. He believes tree plantings can substantially assist in cleaning up polluted air if (1) tolerant tree species are planted, (2) meteorological and topographical conditions are properly evaluated, and (3) proper planting designs are used. To reduce gases, he stated, dense stands are needed whose areas are at least 5 times the height of the stand at the windward side and 25 times at the leeward side.

Townsend *(1974)* worked on the sorption rates of O_3 and SO_2 of several seedlings. White oak and white birch removed larger quantities of O_3 than red maple and white ash, the least efficient of the nine species investigated. No consistent relationship existed between uptake rate and reported ozone susceptibility.

Roberts *(1974)* concluded that the foliage of certain woody plants (including some commonly planted urban trees) may significantly reduce ambient SO_2 levels in the microenvironment immediately surrounding individual leaves.

In opposition to the generally accepted belief that trees can reduce gases, Lampadius *(1963)* concluded that the ad- or absorption of SO_2 occurring in the crown levels of trees compared to atmospheric concentrations was negligible. He did suggest that woodlands were most effective as a buffer against injurious climatic elements, which may in turn increase tree susceptibility to SO_2 damage. Materna and Kohout *(1963)* compared SO_2 emis-

sion levels in coniferous woodlands. Their conclusions coincided with those of Lampadius.

FATE OF TRANSFERRED POLLUTANTS

A most critical concern in the consideration of trees as pollutant sinks relates to the fate and impact of the contaminant once transferred from the atmosphere of the tree. The impact of transfer is variable and depends on the nature of the pollutant. In exposure to very low levels of reactive materials such as O_3 and PAN, the conversion to nontoxic innocuous compounds is probably quite rapid, with no detectable or significant tree perturbation. In the case of SO_2, NO_2 and NH_3, conversion may proceed to compounds useful as nutrient sources. Nitrogen, for example, may be absorbed from the atmosphere and utilized. Porter and associates *(1972)* measured the uptake of NH_3 and its metabolism by plants. Approximately 7 to 16 percent was translocated to the plant roots. If absorption is large enough, particularly with regard to nitrogenous gases and the nitrogen budget, the long-term impact on some trees may be stimulatory. Thomas and associates *(1944)* suggested that SO_2 is absorbed into the cell in the form of sulphurous acid. This acid is oxidized by some means within the cell and converted to sulfate. In this form it may be translocated and utilized by the plant.

Recent studies with radioactive sulfur have confirmed this conclusion. Fried *(1948)* found that $^{35}SO_2$ was absorbed by vegetation and subsequently translocated to other parts of the plant. He concluded that SO_2 from the atmosphere is a source of sulfur nutrition for plants. Similar results were observed by Jensen *(1963)*.

DeCormis and associates *(1969)* measured the uptake of $^{35}SO_2$ in tomato plants. They found radioactive sulfur in both organic and inorganic forms throughout the plant. Materna and fellow workers *(1971)* measured the transfer of sulfur within trees. Movement occurred not only between individual parts of a branch, but also within the whole tree. After the transfer of absorbed pollutants to the roots, some of the pollutants may diffuse into the soil. DeCormis and associates *(1969)* and Fried *(1948)* reported radioactive sulfur in liquid media around the roots of plants exposed to $^{35}SO_2$. Romney *et al. (1969)* reported similar results with fluorine.

With regard to accumulative and recalcitrant materials such as chloride, fluoride, and heavy metals, their fate become particularly critical. Precipitation may act to wash or leach these materials from the plant to contaminate the soil below. In cities with leaf-collection programs, fate of persistent air contaminants (especially heavy metals) must be considered in regard to leaf-disposal methods. If, for example, leaves are burned are, the particulates reintroduced to the atmosphere?; if they are buried at landfill sites, could leaf contaminants pollute the soil or ground water?

SELECTION AND BREEDING CRITERIA TO MAXIMIZE TREE SINK FUNCTION

If trees are capable of reducing urban air-pollution loads below some meaningful biological or economical threshold, what are some of the selection and breeding criteria appropriately employed in new planting programs?

1. Trees selected or bred to provide this amenity function must be tolerant of the acute adverse influences of air pollution. Clearly, if the tree is severely damaged or killed by one or an interaction of air contaminants, its utility as a sink will be short-lived. In addition to air-pollution tolerance, suitable tree varieties should be capable of withstanding other urban stresses such as poor soil aeration and drought, nutrient deficiencies, and microclimatic extremes. A suitable variety should be

capable of more than mere persistence in the urban environment. It should be able to grow vigorously. Vigorous growth will require maximum stomatal aperture and insure maximum uptake of gaseous pollutants.

2. Coniferous species retaining their foliage year-round may appropriately be favored over decidous species. The atmospheric burden of both particulates and gases is generally higher in winter than in summer for most urban areas. It is important, therefore, to have maximum plant surface available for absorption and adsorption during the winter months. Since evergreen foliage persists longer than deciduous foliage, the opportunity for pollutant removal is correspondingly longer. The morphology of coniferous foliage (for example, pine, spruce, fir) results in a high surface-to-volume ratio, which may be instrumental in more efficient removal rates.
3. Since petioles are especially efficient particle receptors, species with long petioles (for example, ash, aspen, maple) may be favored.
4. Surface hairiness on plant parts (leaves, twigs, petioles, buds) may be especially effective for retention of particles. Those species possessing these hairs (for example, oak, birch, sumac) should be considered.
5. Species with small branches and twigs should be selected or bred over species with large branches or twigs as the former are more efficient particle collectors.
6. Since gases are removed from the atmosphere primarily by the stomates, species should be selected or bred with maximum stomatal capacity for absorption. This ability may be related to absolute stomate number per unit of leaf surface, size of stomatal aperature, and length of time the stomates are open.
7. Species should be selected or bred that have maximum resistance to stomatal closure occasioned by environmental variables such as moisture availability, temperature, wind, light intensity, and air pollution.
8. In selection and breeding, one should consider the relative ability of tree species to utilize pollutant gases as partial sources for required nutrients.

SUMMARY

We have considerable evidence indicating that trees in urban environments have considerable potential to remove both particulate and gaseous pollutants from the atmosphere. In the case of particulates, much of this evidence comes from experiments employing particles larger than most that are present in urban atmospheres. Further, much of this evidence was accumulated in nonurban environments with objectives unrelated to air pollution. In the case of gaseous pollutants, much of the evidence comes from controlled environmental studies with nonwoody species. We do not have adequate information to document the ability of trees to remove meaningful quantities of pollutants from actual urban atmospheres. Trees have yet to be shown capable of reducing a particular air contaminant below a significant threshold of effect for any urban area. Models must be developed so that the ability of specific plantings to remove contaminants can be estimated for specific urban environments.

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SELECTION OF TREES FOR TOLERANCE OF AIR POLLUTANTS

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ABSTRACT. Sources of pollutants and pollutant injuries to plants are briefly described. The basis for ranking tree species in susceptible, intermediately susceptible, and tolerant to sulfur dioxide and to ozone are given. While these lists must be used with caution, they do indicate appreciable differences among woody plants in susceptibility. Nurserymen and arborists can use such lists in producing and selecting trees for specific environments. Plant breeders should capitalize on the differences in susceptibility in creating or selecting hybrids and cultivars that are sufficiently tolerant to different sets of environments.

SOURCES OF AIR POLLUTION can be classified into five major categories (table 1). The pollutants arising from these sources may be categorized arbitrarily as general (all air pollutants) and those that injure plants (phytotoxic pollutants). Transportation is a significant source for both categories. It, industry, and the generation of electricity represent the major sources of phytotoxic air pollutants.

Sulfur dioxide and ozone are probably responsible for more air-pollution injury to woody plants than all other air pollutants combined. Fluorides may cause extensive tree damage around large point sources such as smelters or fertilizer plants, but are probably not as significant as sulfur dioxide and ozone. Ethylene, ammonia, chlorine, hydrogen chloride, dusts, and heavy metals are also capable of injuring woody plants to some extent.

However, the influence of these minor pollutants is often limited to a localized

Table 1. Sources of general air pollutants and phytotoxic air pollutants

Source	All major pollutants	Phytotoxic pollutants
	Percent	*Percent*
Transportation	60	28
Industry	18	30
Generation of electricity	14	26
Space heating	5	9
Refuse disposal	3	7

area surrounding a spill, leak, or industry. In contrast, tree damage from sulfur dioxide or ozone can be much more extensive. Since these two pollutants are generally recognized as the most important gaseous air pollutants in the United States, this report will deal primarily with selecting trees resistant to sulfur dioxide and ozone.

SOURCES OF SULFUR DIOXIDE AND OZONE

The burning of coal accounts for nearly 60 percent of the sulfur dioxide released annually in the United States. Upon burning, the sulfur in the coal is converted to sulfur dioxide; thus, the higher the sulfur content of the coal, the more sulfur dioxide released. The production, refining, and utilization of petroleum and natural gas adds another 20 percent to the sulfur dioxide emission. Ore smelting and refining (principally iron, lead, zinc, copper, and nickel) produce 7 percent of the sulfur dioxide emissions. The remaining sulfur dioxide in the atmosphere originates mainly from industries that manufacture or use sulfuric acid and sulfur. Natural sulfur dioxide arises from various sources, including volcanoes.

Ozone is a natural component of our air, existing in the upper atmosphere, where it filters out dangerous ultraviolet radiation. Turbulence and vertical downdrafts may occasionally bring down small quantities of ozone to ground level. Small amounts of ozone are also formed by electrical discharges such as lightning. These sources are of minor importance, however, when compared to the amounts of ozone formed in our urban environments. Hydrocarbons and oxides of nitrogen are emitted into the atmosphere from automotive exhaust. Once in the atmosphere, these compounds undergo photochemical reactions in the presence of sunlight, producing ozone along with a variety of other compounds. Ozone formed in this manner may travel long distances and cause plant injury.

INJURY TO PLANTS

Air-pollution injury to plants is often classified as chronic or acute. Chronic symptoms usually imply tissue injury but not death, while acute injury signifies tissue death. Chronic symptoms often result from exposure of a plant to low levels of pollution for a long time, or occur when a plant is fairly resistant to a pollutant. Acute injury occurs after a short-term high level of pollution, or to very sensitive plants.

Typical sulfur dioxide injury on broadleaved trees appears as areas of injured tissue between the veins. The interveinal injured tissue appears yellow in chronic cases, or ivory to tan in acute cases as the tissues die. The cells and tissues adjacent to the veins usually remain green, resulting in the characteristic pattern.

Acute sulfur dioxide injury on conifers usually appears as a reddish-brown discoloration of the needle tip. The discoloration may progress towards the needle base in severe cases. Chronic injury may also involve some tipburn, but mainly is observed as a general yellowing of needles followed by premature defoliation of older needles. The defoliation may give the crown a sparse, tufted appearance. A young seedling may become severely dwarfed by repeated assaults over a period of time.

Ozone symptoms on broadleaved trees appear as small flecks or stipples of light-colored or reddish-purple tissue on the *upper* leaf surface. Individual spots of this type are usually less than $\frac{1}{8}$ inch in diameter. Injury is not produced on the lower leaf surface.

Acute ozone injury to conifers often results in death of the needle tip, or in severe cases, death of the entire needle. In less severe cases, chlorotic mottling is observed when small patches of yellow or brown injured tissue alternate with green healthy patches of tissue. As with most pollutants, ozone may induce premature defoliation of older needles, giving the tree a tufted appearance.

SUSCEPTIBILITY TABLES

If an arborist wishes to plant trees that are resistant to the common air pollutants, he usually seeks listings of the susceptibility of various species to different air pollutants. Although such lists are useful to a degree, they also possess inherent limitations, which must be understood. Some of the limitations and problems with such lists follow.

Criteria for Ranking Species

The relative rank of a plant species or variety in its susceptibility or tolerance to a given air pollutant is often influenced by the criterion used for ranking. Criteria range from cellular or physiological effects to changes in species composition or succession in a plant community. The same species may be ranked quite differently depending upon the criterion utilized.

Criteria used to assess susceptibility are sometimes based upon the ultimate use of the plants. Timber species or fruit trees may be rated by direct loss of yield; ornamentals or Christmas trees by foliar discoloration. Trees used for wildlife management, recreation, or watershed stabilization may require more complex rating schemes, because they can tolerate different amounts of injury and still fulfill their primary functions. Regenerative capacity, regardless of degree of foliar injury, is very important and must also be considered.

Foliar injury is often one of the early manifestations that leads to the other effects. It is an obvious symptom, fairly easy to estimate or measure. Thus the majority of the species contained in such lists are ranked by percentage of foliar injury induced by a given air pollutant. However, when several small lists of susceptibilities are combined into a large table, the species within the table will be ranked according to different criteria; and some comparisons within the table may not be valid.

Basis of Original Data

Another aspect that must be considered when using susceptibility tables is the manner in which the original data were collected. Data may have originated from: field observations of injury on native vegetation; symptoms on vegetation purposely transplanted into an area suffering from air pollution; artificial exposure of various species in chambers in the laboratory or in the field; and artificial exposure of plants in the field without the use of chambers.

Each method has its advantages and limitations. Field observations and rankings may be complicated by the presence of other air pollutants, especially in industrial regions. Symptom intensity may vary with genotype and locality. In addition, field observations near a long-established source of air pollution may reflect only the relative susceptibility of a residual tolerant plant population, since highly susceptible individuals or species would have died long ago. It is also sometimes useful to know the highly susceptible species. Transplanting species into an area overcome this latter problem, but results are still influenced by local factors.

Artificial exposure of trees in chambers is usually restricted to studying the influence of single pollutants on small seedlings. Results from such studies do not necessarily correlate with field observations of mature stands exposed to the multiple pollutants present in many areas. Environmental conditions within the exposure chamber may also bias the results, since it is difficult to duplicate ordinary field conditions. Fumigation techniques may vary among researchers, further complicating the resulting susceptibility ratings. Also, it is imperative that each plant species or variety be identified as clearly as possible, because definite interspecific as well as intraspecific differences in susceptibility may occur within the same genus.

Geographic Location

Many susceptibility lists are derived from plants growing in various countries of the world. This is an important consideration, when using susceptibility tables, because pollutant regimes, plant genotypic and phenotypic characteristics, seed source, environmental parameters, etc. differ radically from country to country. These differences may in turn drastically affect relative susceptibility. Plants listed as resistant to city air pollution in industrialized cities of Europe may be subjected to entirely different pollutants than those in Washington, D.C. In the former case, trees might be subjected simultaneously to sulfur dioxide, chlorides, fluorides, heavy metals, etc. In Washington, Los Angeles, or Philadelphia, resistance to ozone may be the primary prerequisite for a tree to tolerate air pollution. An arborist seeking pollution-resistant trees must first acquire a listing of the phytotoxic air pollutants prevalent in his area.

VALUE TO ARBORISTS

In spite of the above considerations, a listing of the relative susceptibility of various plant species to specific air pollutants can be useful to arborists. Field observations have supported results obtained from artificial fumigations, and vice versa, especially at the extremes of susceptibility or tolerance. Species found to be extremely tolerant in artificial exposures seldom develop injury from that specific air pollutant under ambient conditions. Likewise, artificial exposures usually produce injury on species known to be very susceptible to ambient levels of a specific air pollutant. However, the broad category of intermediate susceptibility is of less value, since sensitivity of these species to a given pollutant may vary with genotype or different environmental conditions.

In summary, compilations or lists of relative susceptibility of plant species to air pollution must be used with caution and understanding. Rankings at the extremes of susceptibility or tolerance are most useful, while those in an intermediate category are less useful. Also, these lists cannot begin to estimate the tolerance of a species to the multitude of other stresses to which it may be subjected. This is best done by planting and observation.

Tables 2 and 3 of this report were based on a thorough literature review. Original references were searched for susceptibility lists and tables. The senior author's personal comments and observations were also used to categorize species. A list of the references that were searched may be obtained from EPA, Corvallis, Oregon.

OPPORTUNITIES IN TREE BREEDING

Large genetic differences in resistance to air pollutants have been found among species, races within species, and individuals within populations. Therefore, it is possible for plant breeders to select and breed cultivars that will have greater resistance to phytotoxic gases. Just how much effort should go into such breeding work is not at all clear at this time, however.

Control of emissions may reduce or stabilize the levels of certain air pollutants in the most severely affected areas, but in the foreseeable future we will continue to have an appreciable spread in the amount of pollution. Air quality standards are being set at levels that safeguard the health of humans, but not always the most sensitive plants. Resistant cultivars would be especially useful in species that are frequently injured, or in which there are detrimental effects on growth or general health.

Evidence of variation in resistance has been found in at least 15 tree species through controlled experiments in fumigation chambers and also through comparisons in nature after pollution episodes. The latter are more useful for purposes of selection, as the actual con-

Table 2.—The relative susceptibility of trees to sulfur dioxide

Sensitive	Intermediate	Tolerant
Acer negundo var. *interius*	*Abies balsamea*	*Abies amabilis*
Amelanchier alnifolia	*Abies grandis*	*Abies concolor*
Betula alleghaniensis	*Acer glabrum*	*Acer platanoides*
Betula papyrifera	*Acer negundo*	*Acer saccharinum*
Betula pendula	*Acer rubrum*	*Acer saccharum*
Betula populifolia	*Alnus tenuifolia*	
		Crataegus douglasii
Fraxinus pennsylvanica	*Betula occidentalis*	*Ginkgo biloba*
Larix occidentalis	*Picea engelmannii*	*Juniperus occidentalis*
Pinus banksiana	*Picea glauca*	*Juniperus osteosperma*
Pinus resinosa	*Pinus contorta*	*Juniperus scopulorum*
Pinus strobus	*Pinus monticola*	
Populus grandidentata	*Pinus nigra*	*Picea pungens*
	Pinus ponderosa	*Pinus edulis*
Populus nigra 'Italica'		*Pinus flexilis*
Populus tremuloides	*Populus angustifolia*	*Platanus* X *acerifolia*
Rhus typhina	*Populus balsamifera*	*Populus* X *canadensis*
Salix nigra	*Populus deltoides*	
Sorbus sitchensis	*Populus trichocarpa*	*Quercus gambelii*
Ulmus parvifolia	*Prunus armeniaca*	*Quercus palustris*
	Prunus virginiana	*Quercus rubra*
	Pseudotsuga menziesii	*Rhus glabra*
		Thuja occidentalis
	Quercus alba	*Thuja plicata*
	Sorbus aucuparia	*Tilia cordata*
	Syringa vulgaris	
	Tilia americana	
	Tsuga heterophylla	
	Ulmus americana	

Table 3.—Relative susceptibility of trees to ozone

Sensitive	Intermediate	Resistant
Ailanthus altissima	*Acer negundo*	*Abies balsamea*
Amelanchier alnifolia	*Cercis canadensis*	*Abies concolor*
		Acer grandidentatun
Fraxinus americana	*Larix leptolepis*	*Acer platanoides*
Fraxinus pennsylvanica	*Libocedrus decurrens*	*Acer rubrum*
		Acer saccharum
Gleditsia triacanthos	*Liquidambar styraciflua*	
Juglans regia	*Pinus attenuata*	*Betula pendula*
		Cornus florida
Larix decidua	*Pinus contorta*	*Fagus sylvatica*
Liriodendron tulipifera	*Pinus echinata*	*Ilex opaca*
		Juglans nigra
Pinus banksiana	*Pinus elliottii*	*Juniperus occidentalis*
Pinus coulteri	*Pinus lambertiana*	
Pinus jeffreyi	*Pinus rigida*	*Nyssa sylvatica*
Pinus nigra	*Pinus strobus*	*Persea americana*
Pinus ponderosa	*Pinus sylvestris*	*Picea abies*
Pinus radiata	*Pinus torreyana*	*Picea glauca*
Pinus taeda		*Picea pungens*
Pinus virginiana	*Quercus coccinea*	
	Quercus palustris	*Pinus resinosa*
Platanus occidentalis	*Quercus velutina*	*Pinus sabiniana*
Populus maximowiczii X		*Pseudotsuga menziesii*
trichocarpa	*Syringa vulgaris*	*Pyrus communis*
Populus tremuloides		*Quercus imbricaria*
	Ulmus parvifolia	*Quercus macrocarpa*
Quercus alba		*Quercus robur*
Quercus gambelii		*Quercus rubra*
Sorbus aucuparia		*Robinia pseudoacacia*
Syringa X *chinensis*		*Sequoia sempervirens*
		Sequoiadendron giganteum
		Thuja occidentalis
		Tilia americana
		Tilia cordata
		Tsuga canadensis

ditions that plants encounter are represented. These include mixtures of pollutants, stresses caused by other disease incitants, and other variables that may not be tested adequately in fumigation chambers. The relative susceptibilities of trees to polluted air of cities and industrial regions have been studied extensively in Germany, but only fragmentary information is available for North America.

Most research aimed at developing resistant cultivars has been concerned with selection methodology. Several ways of testing resistance have been used successfully, and in a few cases the results of rapid tests have been verified through subsequent pollution exposures under field conditions. The most reliable way of utilizing resistant plants is to propagate them vegetatively. Clonal materials are propagated extensively in landscape-tree nurseries, so it should be relatively simple to exploit resistant individuals once they have been identified.

Two kinds of research on air-pollution resistance seem to be justifiable in view of our present state of knowledge. (1) The relative resistance of cultivars that are in use now should be determined, so that better planting recommendations can be formulated for severely polluted localities. (2) In the more sensitive species, genetic studies of pollution resistance should be started or extended, so that resistant cultivars can be developed through selection and breeding.

In the meantime, arborists can interpret tabulated information in this report and others in the light of their own observations. The most severe kinds of damage can be avoided in this way, but many frustrations may be encountered until more precise information and more resistant cultivars become available.

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SELECTION OF TREES FOR ENDURANCE OF HIGH TEMPERATURES AND ARTIFICIAL LIGHTS IN URBAN AREAS

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ABSTRACT. In urban areas, high temperatures and artificial lights may adversely affect the growth and survival of trees already under various forms of stress. Trees close to radiative surfaces such as pavements, walls and heat vents are especially susceptible to heat damage. However, harmful effects, if any, by prolonged illumination upon urban-grown trees are yet to be experimentally determined. Specific selection or breeding programs to identify species or cultivars with resistance to thermal and light pollution are not economically warranted. However, some research on heat resistance could be combined with drought studies, and light influences could be included in studies of low-temperature effects on trees.

URBAN CHALLENGES

LONG RANGE PLANNING and programming to provide hardy, attractive trees for urbanized ecosystems are speculative at best. But current studies offer mechanisms to better comprehend the complexities of planning that link the social, physical, and biological systems within cities *(Powell 1972)*.

Urban foresters and tree breeders are plagued by the same dilemma that torments any forecaster: namely, how does one predict future events? Forecasters often rely upon previous events to assess a predictable future *(Kahn and Bruce-Biggs 1972)*. Managers and researchers concerned with the culture of urban vegatation also aspire to the role of optimistic visionaries, but are faced with the responsibility of producing and maintaining publicly acceptable trees and shrubs for an unpredictable future.

In addition to foreseeing the cultural vagaries and social imponderables of the immediate future, the tree breeder faces a challenge foreign to his training. His ancillary task is to judge what form the political, economic, and ecological environments will have when his selected species and cultivars develop to maturity along the streets and in the open spaces of an ever-urbanizing globe. *Wunderbäume* that incorporate traits assuring survival and growth in a hostile metropolitan environment are the breeder's goals in selection, breeding, development, testing, production, distribution and hoped-

for public acceptance. But he may fall victim (as he has done in the past) to political or economic changes by the time his prize tree is ready for large-scale distribution. Let's hope he will estimate correctly!

In contributing to the welfare of urban people, arborists and tree breeders have a special obligation to provide durable metropolitan trees. However, within the urban environment, excessive heat and prolonged periods of outdoor artificial light might play a capricious role in the growth and survival of trees recommended by the breeder.

These two urban climatic phenomena are of special current significance, because there has been a gradual and continuing increase in external tree temperatures both above and below soil or pavement level, and a steady increment of street lighting in urbanized areas as compared to rural counterparts. But, paradoxically, we may face the possibility of a reversal of the foregoing trends if, in the immediate future, a limit is placed on urban consumption of energy. Thermal and light pollution could be dramatically reduced through use restrictions or rationing. Thus the illuminated heat domes that now cover our major and minor cities may dim and cool.

To anticipate the effects of heat and light that may possibly confound the breeder's and arborist's endeavours, I shall examine in this paper pertinent cultural and climatic components of the urban ecosystem that may influence tree introduction, describe how trees react to high temperatures and artificial light, and suggest a strategy to incorporate stress-resistance characteristics in a tree-improvement program.

EXCESSIVE HEAT

In literature describing the heat-light islands that surround major metropolitan centres of the world, there is an abundance of material on temperature differences between urban and rural areas, but little information on changes due to outdoor artificial lights. In his review of literature describing the climates of cities, Peterson *(1969)* also noted that temperature is the best documented component of meteorological differences between urban and rural areas.

There are currently two major sources of increased temperatures affecting tree growth in cities. Urban conditions of mid and high latitudes produce a consistently higher temperature by 2 to 5°C than that of rural areas. However, radiation and fluctuation of ultrahigh temperatures in areas adjacent to the foliage and bark of city trees are important as a microclimatic stress than the background increase in temperature. A third and future source is cosmopolitan thermal-power outputs. This source of heating the city environment may increase by five times the present level by the year 2,000, but is not predicted to influence global climate *(Wilson et al. 1970)*. However, as suggested by the participants of the Study of Critical Environmental Problems *(SCEP)*, heat domes or islands may generate regional climatic effects as they enlarge.

General Temperature Changes

Temperature data showing the general effects of cities are abundant *(Sekiguti 1970)* and have been reviewed by Bach *(1972)*, Bryson and Ross *(1972)*, Peterson *(1969)*, and Terjung *(1974)*.

Cityscapes contribute to thermal accretion in several ways *(Lowry 1967)*: (1) additive surface area of buildings with large horizontal and vertical faces provides suitable conditions for substantial exchanges of energy; (2) facing materials are rocklike, with high conductivities, heat capacities, and albedos; (3) cities generate supplemental heat because of human metabolism, traffic, industrial activities, domestic heating, and air-conditioning condensers; and (4) impervious surfaces of the city structure lead to a rapid drain of rain and snow, fundamentally altering moisture and heat budgets.

Neighborhood Effects on Temperatures

Ludwig *(1970)* found that, in the center of large cities where buildings are dense and tall, local outdoor summer climates were several degrees cooler near ground level than in surrounding neighborhoods of dense but low-storied (1- to 5-floor) structures. As Ludwig suggested, that difference is due at least in part to the black flat-topped roofs that predominate in row-house areas and produce high absorption of radiation during hot summer days. Suburban fringes that included dispersed green space were several degrees cooler than the city center.

His observations are important in our consideration of heat stress on trees. We can expect that greater temperature stress will occur along city streets in areas of row houses and small shops than in the central core of tall buildings. However, the former areas constitute about 80 percent of the urban space in many cities.

Differences between neighborhoods and within neighborhood vary with the general weather conditions. As Oke and Hannel *(1970)* wrote of their study of Hamilton, Ontario, differences at street side are especially pronounced under clear, calm conditions. Various surfaces can then exert their effect on microclimate, and not have it modified by advection.

In his analysis of the thermal microclimate contiguous to a five-story urban brick building, Landsberg *(1970)* measured, with an infrared thermometer, the temperature of several surfaces that would be close enough to urban trees to influence their metabolism. On a bright, summer day at 4:00 p.m. he found the temperatures of a west-exposed wall and a parking-lot pavement to be over 45°C, the surface of a grass lawn to be 33°C, and the air over the grass and an enclosed paved courtyard to be 31°C. Repeated observations and further data from Columbia, Maryland, were similar. Infrared radiation reaching trees from adjacent emitters might heat the surfaces, especially of bark, to temperatures similar to the source. If tree tissues are already under moisture strees, such temperatures might have damaging, possibly sometimes lethal, effects.

ARTIFICIAL LIGHT

Within a large metropolitan center, artificial light is emitted from a variety of sources. Though background thermal escalation is invisible to the eye, the loom of light that marks the location of an urban complex is readily visible from afar in the countryside. Street lamps, commercial advertising displays, and flood-lit shopping centers contribute to the nocturnal urban glow. To these we can add light from office buildings, car and other vehicular headlights, light filtering through house windows, decorative residential and landscape lighting, security lamps, and 24-hour flood-lit recreation facilities that are increasing at a phenomenal rate.

At present there are some 12.5 million street and highway lights in service in the contiguous United States of America. Mercury vapour lamps dominate the total with 75 percent, followed by incandescent lamps at 20 percent; and high-pressure sodium vapour, metal halide, fluorescent, and miscellaneous lights make up the other 5 percent. During the past 10 years there has been a marked decline in incandescent lamps, which have been replaced mainly by mercury vapor. A trend toward high-pressure sodium vapor (HPS) began with the invention of Lucalox in 1966. A number of major cities in the United States began installing large numbers of HPS about 5 years ago. Today about 3 percent of our large city street lights are HPS *(Buck 1975)*. Recently the Chicago Department of Streets and Sanitation installed some 40,000 HPS lamps.

Collectively and individually, various city lights may strike trees and shrubs with intensities of from a fraction to 20 or 30 footcandles (1 fc=10.8 lux, m-c), the average being 1 to 3 footcandles *(Andresen 1974)*. In addition to quantity,

the quality of radiant energy (wavelength) also varies by source of filament or ionized gas.

During normal periods of daylight, urban trees are exposed to direct and reflected radiant energy including wavelengths between 380 and 760 nanometers (nm) millimicrons—the visible spectrum. Electrically actuated lamps also incorporate wavelengths between 380 and 760 nm, but emit different relative energy per lumen of output at specific wavelengths. For example, noontime natural sunlight emits rather uniform relative energy of 55 percent between 470 and 680 nm, but 500-watt incandescent lamps emit light that has little relative energy in the deep blue range (400 nm) and gradually builds to the peak of a smooth curve in the near infrared (770 nm) at about one-half the energy value of sunlight.

In clear mercury lamps, major resonance radiation occurs at 405, 436, 546, and 578 nm, giving the radiation a bluish-white color. HPS lamps resonate primarily at 589 nm, which provides yellowish-orange coloration. These various concentrations of emissions produce differing plant responses or photoperiodic reactions.

Before discussing the physiological effects of urban heat and artificial light on trees and shrubs, I should emphasize that these two factors of the urban climate are not independent of one another nor of other components. Complex interactions of these and other factors make difficult an assessment of the roles of increased heat and light on tree growth and survival in urban areas.

PHYTORESPONSE

For our discussion of the capacity of trees and shrubs to resist detrimental effects from heat and light of metropolitan centers, the terms thermotolerance and thermoavoidance, as explained by Levitt *(1972)*, are helpful. Thermotolerance, a synonym for heat resistance or thermoresistance, is the ability of trees, shrubs, and other woody plants to survive heat stress on internal tissues. Thermoavoidance or heat avoidance, on the other hand, suggests the ability to adjust to or resist lethal or injurious external infrared radiation.

Thermotolerance

Tolerance to heat by woody plants has been reported by Lange *(1965, 1967)*, but most of these and his earlier studies dealt with the killing of leafy twigs or small woody plants by heat. Lorenz *(1939)* immersed five species of forest trees in hot-water baths to determine the heat of protein coagulation of cortical tissues. Transplants (2-1) of *Pinus strobus*, *P. resinosa*, *Picea glauca*, *Catalpa speciosa*, and *Ulmus americana* were treated.

Based on a number of studies (including Lorenz') reviewed by Levitt *(1972)*, the conclusion is that protoplasmic disturbance becomes irreversible between 49 and 51 °C in most woody plants. However, cellular death varies with duration of exposure to high temperatures and with the degree of maturity of the subjected tissues. Little if any work has been done on entire mature trees or their component leaf, bark, or root systems. Hence, thermotolerances of urban planted trees of various size classes are yet to be determined.

Thermoavoidance

Heat avoidance can occur through: (1) insulation, (2) respiration, (3) absorption of radiant energy, and (4) transpiration cooling. The last two have the most importance *(Levitt 1972)*.

Thick and highly corky bark of tree stems and trunks normally serves as insulation under frigid conditions, but may actually deter conductive heat transfer from or into internal tissues. However, through translocation streaming, high internal temperatures can be dissipated upward and outward by transfer to cortical and parenchymous cells of thin bark shaded by the canopy.

The role of respiration is still theoreti-

cal, but a lowered respiration rate might conceivably induce avoidance.

Decreased absorption of radiant energy results in part from certain reflective characteristics of leaf and bark surface. Glabrous leaves and white-colored bark seem most effective in reflecting radiation of 775 to 1100 nm. Transmissibility also plays a role in decreased absorption: that is, thin, pale-green leaves transmit more radiant energy than thick, dark-green leaves. And absorption of infrared radiation by epidermal leaf cells high in water content could protect the protoplasmic mesophyll.

Transpirational cooling, although formerly exaggerated, can lower internal leaf temperatures 2 to 5°C, or perhaps more, below surface conditions. This decrease may be just enough to reduce tissue temperatures below the lethal range.

Photoperiodism

Photoperiodic responses of plants have long been a favorite laboratory demonstration and subject of studies, and have been economically vital to commercial floriculture and horticulture; but the responses of woody plants are yet to be fully explored. This is especially true of mature trees growing under total urban stress, including artificial light.

In his comprehensive review of photoperiodism in woody plants, Wareing *(1956)* surveyed the earlier literature. During the 20 intervening years since then, about 15 papers and further reviews have been published on this subject *(Andresen 1974; Cathey and Campbell 1973, 1975; Downs 1958; Downs and Borthwick 1956; Nitsch 1957)*. However, no controlled or replicated tests have been conducted with large trees growing in an outdoor urban environment subject to various sources and intensities of artificial illumination.

Wareing *(1956)* also tabulated some 60 species of 31 woody genera that were photoperiodically sensitive in producing extended growth. But most of his plants were juvenile forms tested under growth-conducive greenhouse or nursery conditions with a broad variety of lighting regimes. Manipulation of photoperiod and favorable temperatures can produce continuous seedling growth in such species as *Liriodendron tulipifera* and *Robinia pseudoacacia;* but *Pinus sylvestris, Acer pseudoplatanus,* and *Phellodendron amurense* assume varying froms of winter dormancy *(Wareing 1956)*.

Downs *(1958)*, working with fluorescent and incandescent sources of light, found that 30 fc of 8 additional hours of incandescent light significantly increased stem elongation of *Catalpa bignonioides, Hibiscus syriacus,* and *Pinus taeda* over that produced under 8-hour days or supplemental fluorescent illumination. He surmised that increased amounts of far-red wave lengths from incandescent lamps produced the pronounced elongation effects. Downs also reasoned that—in general—short photoperiods induce dormancy, long days (natural or artificial) prolong periods of vegetative growth, and long days can break the dormancy induced by short photoperiods. Nevertheless, as Wareing *(1956)* and many others have reported, responses to extended photoperiods vary not only within genera but also by ecotype within species.

Wareing summarized his survey of studies on photoperiodic growth and dormacy of juvenile woody plants with the statement: "Thus, conclusions regarding mature trees cannot be arrived at by extrapolation from the photoperiodic behaviour of the seedlings".

For large trees grown in open but nonurban conditions, Wareing suggested that species within the genera *Larix, Populus, Salix,* and *Betula* terminate their annual growth in primary response to onset of short days that are coupled with cooling temperatures, but these species would be responsive to extended illumination until tissues are chilled to dormancy. Other species such as *Alnus glutinosa, Acer pseudoplatanus,* and *Platanus orientalis* (grown at high latitudes) cease growth in June or July and do not respond to

subsequent extension of photoperiods. He also noted that in many woody species the seasonal period of height growth is much shorter in mature trees than in the seedling stage.

Of special interest to the tree breeder is the phenomenon of ecotypic variation of trees in response to photoperiodic regimes. Particular attention should be given to species that possess extensive latitudinal range, such as the North American *Acer saccharum*, *A. rubrum*, *Carpinus caroliniana*, *Ostrya virginiana*, *Betula nigra*, and *Fagus grandifolia*. Of these, *A. rubrum* appears to be especially responsive to photoperiods *(Cathey et al. 1975)*. Wareing *(1956)* reported that when European ecotypes of *Salix*, *Betula*, *Populus*, *Ribes*, and *Vaccinium* were introduced from southern latitudes to regions of high latitude, they suffered from autumn frosts because of extended growth under laboratory conditions.

In summarizing photoperiodic responses, I reiterate Wareing's conclusion that observations of seedling response cannot be projected to large trees. Bickford and Dunn *(1972)* stated that much is yet to be learned about the effects of photoperiod, wavelength, and level of supplemental light on the responses of woody plants. In response to a question about the effect of street lamps on plant growth, Vince *(1970)* observed that, in woody plants, autumnal low temperatures usually override the effect of extended-day length. However, Cathey and Campbell *(1975)* advise detailed studies in the urban environment to determine species and cultivar responses to artificial illumination.

Before I discuss selection and breeding needs in response to heat and light changes, six summary statements are in order.

1. Virtually all experimental and observational studies of woody-plant responses to heat increases and photoperiod extensions (artificial light) have been with seedlings or young transplants grown under greenhouse, nursery, or phytotron conditions.
2. Conclusions about effects on large trees were derived from observations on small segments of tissue without consideration of interactions with other factors.
3. In general and under urban conditions there probably is a strong linkage in trees between: (a) drought resistance and heat resistance, and (b) resistance to post-dormancy response to artificial light and low-temperature hardiness.
4. No large-scale studies have been performed in situ or in simulation of a downtown commercial or residential environment.
5. Applied physiological-genetic tests conducted within the urbanized matrix may be needed now to provide the tree breeder with a "heat-light" selection rationale—*if*, indeed, one is needed.
6. A re-examination of extended photoperiods may show that exposure to various forms of artificial light benefits urban trees.

SELECTION NEEDS

The Urban Tree

In his paper on the application of ecological genetics principles to forest tree breeding, Tigerstedt *(1974)* remarked that in the modern context of provenance research "Yield maximization has fallen to second place, ecological stability has taken over". A similar observation could be made here, because in contrast to earlier horticultural selection for beauty, form, and habit, trees are beginning to be selected for survival in urban environments.

Pauley *(1958)* recognized that photoperiodic responses exhibited by trees are under genetic control and thus subject to natural or artificial selection. However, his primary concern was with increasing the net yields of wood or fiber (Tigerstedt's subordinated objective). Tigerstedt also observed that forest geneticists and tree breeders must adopt a com-

pletely new vocabulary that incorporates ecosystem considerations.

As the forest tree breeder moves into the urban arena and attempts to select and breed trees to resist individual or collective stresses, he has the obligation to assure and maintain optimum genetic resilience within his selection or hybrid. This is especially true because agricultural and urbanization practices of both industrialized and developing nations are methodically reducing the gene pools of broadleaved trees. Current clonal-monocultural practices still evident in the arboriculture of most North American cities portend disasters similar to that due to the Dutch elm disease. Future problems resulting from overly uniform planting materials are predictable from observing the contemporary decline of large, widespread urban populations of even-aged and overmature exotic trees such as *Acer platanoides, Aesculus hippocastanum,* and *Platanus acerifolia.*

Santamour *(1969, 1971, 1973)* has established a number of sound selection and breeding criteria for metropolitan environments. Santamour *(1972)* summarized his thoughts in an article in the *1972 Yearbook of Agriculture* as he discussed the development of shade trees for urban areas. His major proposition was that the best trees for any urban area are those, either native or exotic, that have proved capabilities to prosper under prevailing hostile ecosystems. He also warned that municipal foresters and other vegetation managers prefer physical uniformity of trees to facilitate planting and maintenance. This selection practice would, as mentioned, have long-range detrimental effects.

Here then is an educational challenge to convince urban foresters that, even though clonal uniformity may have maintenance advantages, it might result in inordinate costs as diseases or insects strike or when large blocks of trees approach physiological maturity. Planting a variety of species in numerous responsive ecotypes, and spread through a sequence of age classes, holds the answer to low maintenance expenditures. Tigerstedt *(1974)* advocates the breeding of heterotic, multiclonal varieties to guard against uniclonal impotence. He writes that advantages of this concept include less average phenotypic variation than single-clone cultivations; greater ecological adaptability especially regarding host-parasite systems; and if combined optimally, a performance superior to that of pure cultures.

Results of the above suggestions should be judged by Pauley's *(1958)* rule that "Final decisions on adaptability of the proposed introduction to the new habitat must be based on the observed interaction that results between the introduced genotype and all the factors of its new environment".

Selection Strategy

Is selection specifically for resistance or endurance to high temperatures and artificial lights in urban areas worth the effort? Considering more pressing problems in urban-tree improvement to meet air and soil pollution, soil compaction, related soil alteration, and insect and disease afflictions, I think selection for resistance to high temperature and artificial light has low priority. This conclusion appears reasonable in spite of the current controversy over the effects of HPS on city trees.

I submit the foregoing because we can stretch our resources by combining drought and heat studies, including moisture stress, in one package. Because detrimental effects of artificial light on large, urban-grown trees are yet to be physiologically demonstrated, and because there is an apparent relationship between frost damage and photoperiodic response, low-temperature and light studies should be combined. Further, the minimum cost of conducting a 5-year test of 3 light sources and 10 cultivars replicated 10 times on 3 similar urban sites, would be over $100,000, and the test would require 100 acres of land. In addition, long-range, land-

consuming biological studies in cities face towering difficulties.

In essence, we are searching for trees resistant or tolerant to all the hazards and stresses of urbanized ecosystems—trees that also possess genetic resilience and social acceptability. We must also be prepared to develop specific selections tailored to meet singular requirements. For example, the city forester sets a high priority on minimum-maintenance and pest-free trees, while the home owner might not mind the maintenance but would be interested in a tree of multi-seasonal attraction. Selections desirable within cities should also vary to provide trees adapted to local sites and microclimates.

In conclusion there are several common traits that should be incorporated in all urban trees: resistance to low and high temperatures, drought, pollution, and biologic pests. In addition to these survival traits, we will have to provide varying esthetic and amenity values. Thus our selection challenge not only includes the development of trees for growth and survival in a hostile urban environment, but in addition an assignment to produce trees that satisfy the highly variable needs of our urban residents.

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DROUGHT AND TRANSPLANTABILITY OF TREES

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ABSTRACT. Studies on development of water deficits in trees and their effects on stomatal closure, wilting, photosynthesis, shoot growth, cambial growth, reproductive growth, and injury are reviewed. Drought resistance is discussed in terms of drought-avoiding adaptations (stomatal characteristics, production of leaf waxes, root growth characteristics, and leaf shedding), and desiccation tolerance. Attention is given to important cultural practices controlling water balance of transplants (including time of transplanting, pruning of shoots, site preparation, handling of planting stock, use of antitranspirants, and after-planting care of trees). Some opportunities available to the plant breeder for producing drought-resistant trees are emphasized.

DEVELOPMENT OF WATER DEFICITS

TREES ARE UNIQUELY WELL constructed to lose large amounts of water. They expose an extensive leaf area that is perforated by numerous stomatal pores through which water is readily lost by transpiration. Under appropriate environmental conditions (high soil moisture availability, high air temperature, and low relative humidity), a large tree may lose a barrel of water or more in a day. In fact, willows and cottonwoods along stream banks may absorb and transpire as much as 40 inches of water in one growing season *(Spurr 1964)*. Only a very small amount of the water absorbed by trees, probably less than 5 percent, is used in growth, and the rest of it merely goes through the tree and evaporates into the atmosphere. It has been estimated, for example, that plants may use 250 to 1,000 pounds of water to produce 1 pound of dry matter in growth of leaves, stems, roots, and reproductive tissues.

Because of their high rates of water loss, all trees, well-established as well as recently transplanted ones, undergo periodic internal water deficits of varying degree. Such water deficits are well known during developing droughts, but they also tend to develop regularly during the day even in trees growing in well-watered soils. This is so because internal water deficits in trees are controlled by relative rates of water loss by transpiration and replacement of water by absorption through the roots. During the day more water is lost by transpiration than is re-

placed by absorption. Hence, trees tend to dry out during the day, especially on hot, sunny days. During the night, however, both transpiration and absorption rates are low, but the rate of absorption is higher than the rate of transpiration, resulting in a gradual refilling of the tree with water. The rate of absorption of water by roots during the day lags behind transpiration because of resistance to water movement in various parts of its translocation path from the soil, through the tree, and outward into the air. Some resistance to water movement exists in the soil, in the roots, and in the leaves.

It is clear that dehydration of trees will result from high transpiration rates or slow absorption of water from dry, poorly aerated or cold soils or, more commonly, from both high transpiration and relatively low absorption rates. Transpiration and absorption of water are partly controlled by different sets of factors. Transpiration is largely controlled by atmospheric factors that influence evaporation (light, temperature, humidity, wind) as well as by such plant factors as leaf area, structure of leaves, stomatal size and frequency, and control of stomatal aperture. Absorption of water is controlled by transpiration rate and also by the size and distribution of the root system and various soil factors (soil water availability, temperature, concentration of the soil solution, aeration, etc.). Temporary water deficits and leaf-wilting often occur in the afternoon because of excess transpiration over absorption. This is not serious if the soil is well watered because the leaves rehydrate and recover turgidity at night when absorption exceeds transpiration. However, as soil dries over a period of days, temporary water deficits in trees tend to persist longer each successive day because leaves are less likely to recover turgidity at night *(Kramer and Kozlowski 1960; Kozlowski 1964, 1968a, 1968b, 1969, 1970)*.

EFFECTS OF WATER DEFICITS ON TREES

Water deficits in trees affect virtually all important physiological processes, including stomatal closure, photosynthesis, metabolism, mineral relations, and growth.

Stomatal Closure

The closure of stomatal pores is a very early response to drought. As the guard cells lose water and turgidity decreases, the stomatal pores close. The dehydration of trees is controlled somewhat by earlier closure of stomata during each day of a developing drought and by temporary closure of stomata during the day. However, closing stomata during a drought may not prevent killing of those trees that lose considerable water directly through the leaf epidermis after stomatal closure occurs.

After a drought, leaves may recover turgidity, and stomata may open. Nevertheless, severe droughts often damage many stomata, which may open slowly or not at all when a tree is finally rewatered. The stomata of shade leaves are more sensitive to water loss than those of sun leaves. Also, the stomata of young leaves tend to close faster than those of old leaves during drought *(Kozlowski 1972b)*.

Photosynthesis

In many species photosynthesis begins to decrease when leaves are only slightly dehydrated. Such photosynthetic inhibition is caused first by stomatal closure causing decrease in CO_2 uptake and only much later by direct inhibitory effects on the photosynthetic mechanism *(Brix 1962, Troughton and Slatyer 1969, Slatyer 1973)*. Hence, we may expect simultaneous reduction in stomatal aperture and in photosynthesis as droughts intensify, as well as midday dips in photosynthesis during periods of temporary stomatal closure.

Wilting

As leaves dehydrate and lose water they eventually wilt. Wilting varies in degree and may be classified as: (1) incipient, (2) temporary, or (3) permanent. Incipient wilting does not cause drooping of leaves. Temporary wilting involves drooping of leaves during the day and recovery from wilting during the night. During a sustained drought, plants temporarily wilted may become permanently wilted. Such plants do not recover from wilting at night. Recovery from permanent wilting requires rewetting of the soil. Trees that stay in a state of permanent wilting for an extended period often die.

Shoot Growth

Shoot formation of many trees is a 2-year process involving bud formation the first year and expansion into a shoot the following year. In many species (maples, ashes, and some pines) winter buds are telescoped shoots, which contain all the leaves that will be expanded in shoot growth during the next growing season. In such species annual shoot growth usually is completed relatively early in the frost-free season. Trees that have such fully preformed shoots in the winter bud often complete height growth in about a month or slightly longer. For example, the growth of red pine *(Pinus resinosa)* shoots in Wisconsin generally is completed by the end of June. Hence, this species completes most shoot growth before mid- and late-summer droughts occur. Its height growth often is better related to rainfall of the previous season than to current rainfall because, as mentioned, the shoots are morphologically determined in the bud laid down in the previous year. Current height growth represents only bud expansion and does not involve growth of new organs.

In contrast to species having fully preformed shoots in the winter bud and a short period of shoot expansion, other species have shoots that continue to elongate for a long time during the summer. In this second group are recurrently flushing pines of the southern United States and species that continue to form new leaves during the summer, in addition to expanding those that were in the winter bud. Recurrently flushing species produce several bursts of shoot growth each year, first from opening of the winter buds and later in the summer from new buds formed during the current year. Such species may continue shoot growth for several months in the Southern States. Their shoot growth is very responsive to mid-summer drought. But even in Northern States some trees, such as poplars, do not always have a fully preformed shoot in the winter bud. Such trees continue to produce new leaves during the summer, and their shoots continue to expand into late summer. Their shoot growth can be checked by midsummer droughts. This is in contrast to many northern species (ash, maple, red pine, etc.) whose total annual shoot growth is completed early—that is, before midsummer droughts occur *(Kozlowski 1971a)*.

Cambial Growth

Growth in diameter of trees is particularly sensitive to water supply. During dry years trees produce narrow annual rings of wood. During a summer drought, cambial growth either slows or stops altogether, depending on severity of the drought; and it accelerates or begins again following rain or irrigation. Changes in cambial growth in response to dry and wet periods may cause formation of false or multiple rings of wood in stems. These often have been mistaken for annual rings.

Drought decreases the rate of diameter growth in trees not only in one year but also in the subsequent year or years. A summer drought affects the number of leaf initials that form in new buds for the shoots of the following year, and the consequent reduction in foliage reduces the amount of growth requirements (carbohydrates, hormones) that are translocated

downward and influence cambial growth *(Kozlowski 1971b)*.

Reproductive Growth

Flowering and fruiting of trees are influenced by water supply at any stage during flower-bud formation, flowering, pollination, fertilization, embryo growth, or fruit and seed development. However, it is difficult to make broad generalizations about effects of drought on reproductive growth, partly because timing of the cycle of reproductive growth varies widely.

Formation of flower buds often is suppressed by drought, but the effect may not be obvious until the following year at flowering time. Sometimes, however, a mild water deficit at a critical time will increase initiation of flower buds by decreasing growth of vegetative tissues. Both the size and quality of fruits are improved by an adequate water supply before and during the period of fruit enlargement.

Injury

Various tissues and organs of trees often are injured or killed by drought without necessarily killing the tree. Leaf responses to drought include curling, scorching, marginal browning, early autumn coloration, and premature leaf fall. Leaf drying often causes considerable winter injury to evergreens. During winter or early spring days, the air may warm and cause considerable transpiration at a time when water cannot be absorbed by roots from cold or frozen soil. This may cause the leaves to dry out and turn brown. If drought continues, the injury to the plant may occur in dieback of twigs and branches. Following prolonged and severe droughts, stems may become so desiccated that they crack. Drought cracks may or may not heal and, if they do not, they provide openings for invasion by decay fungi and insects.

Drought injury can be avoided or decreased in two ways: (1) by selecting and breeding trees for specific characters which induce drought resistance, and (2) by intelligent handling of available planting stock prior to, during, and after transplanting.

DROUGHT RESISTANCE

Central to tree improvement and selection criteria for drought resistance is a consideration of inter- and intraspecific variation in characters that enables some trees to grow better than others under conditions of aridity. At the outset it should be emphasized that although both drought *avoidance* and *desiccation tolerance* (capacity of protoplasm to withstand severe desiccation) are involved in overall drought resistance, drought *avoidance* is much more important in enabling trees to survive under conditions of aridity *(Kozlowski and Davies 1975)*.

Drought Avoidance

Many drought-avoiding adaptations occur in certain trees and may be found in leaves, stems, or roots. Drought avoidance by a tree often involves more than one adaptation. Furthermore, adaptations for drought avoidance often vary for different species of trees growing side by side. Among the important adaptations for drought avoidance are shedding of leaves; production of small or only few leaves; small, few, and sunken stomata; rapid closure of stomata during drought; thick leaf waxes; and strong development of palisade mesophyll. Although the volume of intercellular spaces often is less in xeromorphic than in mesomorphic leaves, the ratio between the internal exposed surface of the leaf and its external surface area usually is higher in xeromorphic leaves *(Fahn 1964)*. Stem adaptations for drought avoidance include capacity for twig and stem photosynthesis, presence of living wood fibers *(Fahn 1964)*, and development of a wide cortex that protects vascular tissues from desiccation. The most important drought-avoiding adaptations of roots are capacity

for extensive root growth (high root-shoot ratios), high root regenerating potential immediately after transplanting, and production of adventitious roots near the soil surface. Some of the most important drought-avoiding adaptations will be discussed briefly.

Stomatal diffusion resistance. — The amount of resistance to water loss from leaves varies among species and genetic materials because of variations in stomatal size, stomatal frequency, and capacity for rapid stomatal closure during developing droughts. In many species stomatal size and frequency are negatively correlated. For example, whereas *Acer saccharum* and *A. saccharinum* had many small stomata, *Ginkgo biloba*, *Betula papyrifera*, and *Gleditsia triacanthos* had relatively few large stomata. Stomatal size and frequency among different species of the same genus may also vary greatly, as in species of *Quercus*, *Fraxinus*, and *Crataegus (Davies et al., 1973)*. Differences in stomatal size and distribution among *Populus* clones have also been demonstrated *(Siwecki and Kozlowski 1973)*.

Variations among species and genetic materials in capacity for early stomatal closure are commonly much more important in drought avoidance than are differences in stomatal size or frequency. Examples of woody plants that avoid drought largely by rapid stomatal closure include plants of the Mediterranean maqui *(Oppenheimer 1953)*, *Ilex cornuta (Kaul and Kramer 1965)*, and *Eucalyptus sideroxylon (Quraishi and Kramer 1970)*.

We found that transpiration rates differed greatly among *Populus* clones and were better related to variations in stomatal aperture than to stomatal size and frequency or to such aspects of leaf anatomy as leaf thickness, epidermal thickness, amount of palisade parenchyma, amount of spongy parenchyma, percentage of combined thickness of spongy mesophyll plus epidermal layers, or percentage of palisade parenchyma *(Siwecki and Kozlowski 1973)*.

Wide variations occur among species in stomatal responses to atmospheric factors (for example, high temperature, high light intensity, low humidity, and wind) which induce water deficits in trees *(Davies and Kozlowski 1974a, Davies et al. 1974b)*. For example, experiments were conducted on species that occur along an ecological gradient from xeric to mesic. These included *Quercus macrocarpa*, *Q. velutina*, *Q. alba*, *Q. rubra*, and *Acer saccharum (Wuenscher and Kozlowski 1971a)*. All species showed an increase in transpiration with increased leaf temperature. The rate of increase of transpiration resistance with rise in leaf temperature was greatest for *Q. velutina*, intermediate for *Q. macrocarpa* and *Q. rubra*, and least for *Q. alba* and *Acer saccharum*. Water use efficiency (the ratio of transpiration to photosynthesis) increased with leaf temperature up to 35°C and decreased at higher temperatures. Water use efficiency was greatest in *Quercus velutina*, intermediate in *Q. macrocarpa*, *Q. rubra*, and *Q. alba*, and least in *Acer saccharum*. At 40°C, water use efficiency of *Q. velutina* declined only slightly, but in the other four species it decreased greatly. These experiments showed that stomatal resistance decreased along the gradient from xerophytic to mesophytic species. In particular it emphasized that *Q. velutina* had the highest water-use efficiency and was the most drought-resistant species studied. It fixed CO_2 rapidly while losing little water and therefore was successful on hot and dry sites *(Wuenscher and Kozlowski 1971b)*.

We have evidence from work with herbaceous plants that there is a genetic component in control of stomatal aperture. For example, rapid wilting and desiccation injury in abnormal diploid potato plants and wilty mutants of tomato were associated with lack of capacity for stomatal closure *(Waggoner and Simmonds 1966, Tal 1966)*. Failure of wilty mutants of tomato to close stomata was associated with a deficiency of abscisic acid *(Tal and Imber 1970, 1972)*.

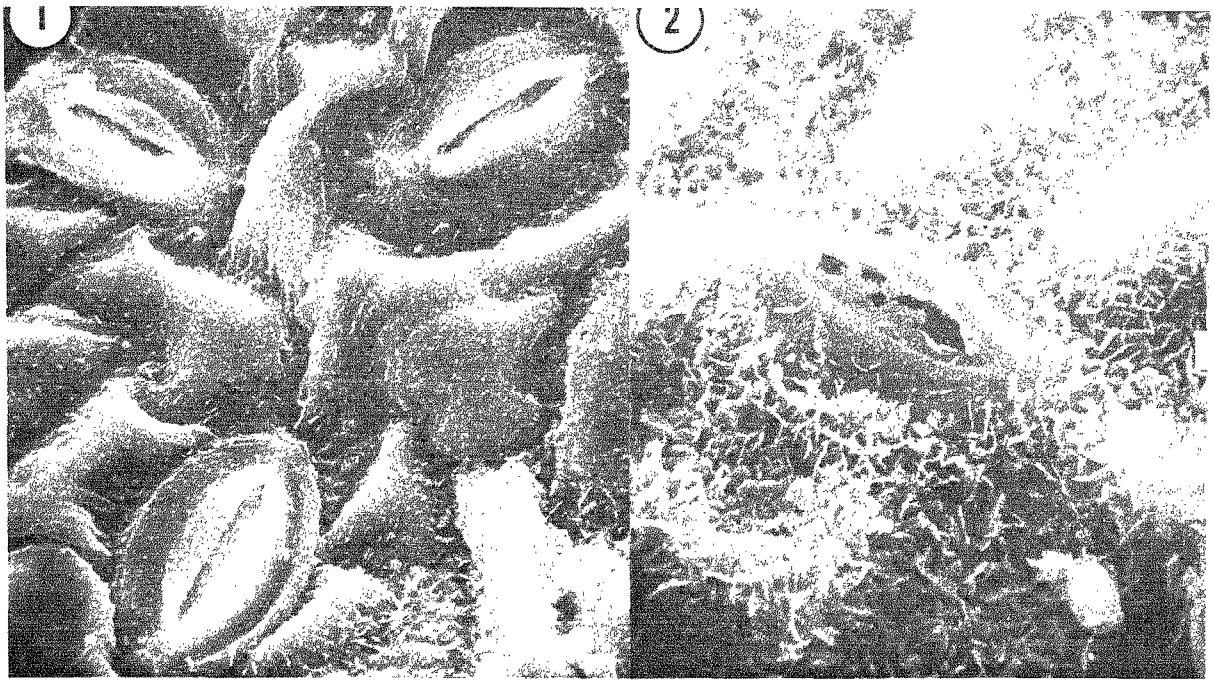


Figure 1.—Scanning electron micrographs showing leaf waxes around stomatal pores. Left: Betula papyrifera (x 1000). Right: Cercis canadensis (x 2000). Photos by W. J. Davies.

Leaf waxes.—After stomata close, cuticular control of water is an important factor in drought avoidance. For example, transpiration rates of drought-evading plants with closed stomata often vary from 2 to 20 percent of the rates when stomata are open. On the other hand, mesophytes with closed stomata generally lose from 20 to 50 percent as much water as they do with open stomata, emphasizing the importance of leaf waxes in water retention.

Our studies have shown wide variations among species in deposition of leaf waxes (fig. 1). *Fraxinus americana* leaves had cuticular lips overlapping large open stomatal pores, and they had thin leaf waxes. *Acer saccharum* leaves not only had a thick deposition of wax, but many stomatal pores were occluded with wax *(Kozlowski et al. 1974; Davies and Kozlowski 1974a).*

Gymnosperms also vary greatly in amount of leaf waxes *(Hanover and Reicosky 1971, Lehala et al. 1972).* For example, cutin layers were thin in *Thuja orientalis,* somewhat thicker in *Cupressus sempervirens,* and very thick in *Cupressus glabra (Oppenheimer 1970).* Needles of *Pinus sylvestris* had more wax than those of *P. radiata (Leyton and Juniper 1963, Leyton and Armitage 1968).* Oppenheimer and Shomer-Ilan *(1963)* demonstrated much better control of cuticular transpiration in *Pinus halepensis* than in *Pinus pinea.*

Pine needles have a stomatal antechamber that increases the length of the diffusion path for water and carbon dioxide. These antechambers often are occluded with wax *(Davies et al. 1974a),* thus increasing the tortuosity of the pathway and decreasing the cross-sectional area available for diffusion. The antechamber waxes often are more important than leaf-surface waxes in control of transpirational water loss. For example, it has been estimated that wax in stomatal antechambers of *Picea sitchensis* reduced transpiration by about two-thirds when the stomata were open *(Jeffree et al. 1971).*

In addition to environmental control of deposition of leaf waxes, genetic control also occurs with "normal" or glaucous forms being dominant and "glossy" or glabrous forms recessive. The differences in leaf appearance are due to variations in amount and structure of epicuticular wax *(Hall et al. 1965)*. In some species at least, adaptive changes in leaf waxes occur in response to selection by some ecological variable *(Harland 1947, Barber 1955)*. In Tasmania, for example, clinal analysis of glaucousness in several *Eucalyptus* species indicated high selective coefficients for genes controlling this characteristic. Nonglaucous (green) phenotypes were found in sheltered habitats, whereas glaucous phenotypes were increasingly common in more exposed environments *(Barber and Jackson 1957)*.

Root growth.—Because water in soil not penetrated by roots is largely unavailable to plants, trees with deeply penetrating and branching root systems absorb water most efficiently and prevent or postpone drought injury *(Kozlowski 1972a)*. There are many examples of the importance of a high root-shoot ratio (for example, relatively high water-absorbing capacity and relatively low transpiration capacity) to survival of trees under drought conditions. For example, on dry sites *Eucalyptus socialis* outcompeted *E. incrassata* partly because of the higher root-shoot ratios and slower growth of aerial parts, thus preventing desiccation *(Parsons 1969)*. Deep rooting also is an important factor in drought avoidance of several species of Western Australian sclerophylls *(Grieve and Hellmuth 1970)*. Woods *(1959)* attributed the high degree of success of *Pinus caribaea* trees on dry sites to initiation of root growth soon after transplanting.

In studying genetic variations in root-shoot ratios, it is vital to recognize that these change with plant age and weight according to the law of allometric growth. Ledig and Perry *(1965)* emphasized that the genetic variations they found in root-shoot ratios of *Pinus taeda* progenies were due primarily to comparing seedlings of different weight.

A useful research approach may involve grafting scion stem pieces on clonal rootstocks. We know that rootstocks influence meristematic activity and tissue development as well as the morphogenetic potential of apical and lateral meristems in many genera of forest trees *(Tubbs 1967, 1973)*. In forestry the emphasis on use of rootstocks has been on wood production or early seed production for breeding. We need to extend such work toward achieving drought avoidance through altered root-shoot balance. It seems highly relevant that dwarfing rootstocks or scions induce short laterals and spur shoots in some species, and in others they maintain an effective leaf area in the compound tree over a shorter season than do vigorous rootstocks or scions *(Tubbs 1967, 1973)*.

Root regenerating potential.—Wakeley *(1954)* demonstrated that critical internal physiological conditions of nursery stock that influenced root-regenerating potential after outplanting often were much more important to survival of trees than were morphological grades of transplants. He found, for example, that cultural practices in nurseries, especially differences in fertilizer regimes, greatly influenced survival. Matched plantings of trees from certain nurseries survived better than others regardless of season, site, and even species. In addition, he found marked variation in survival of outplanted seedlings that had been grown from the same seedlot but in different locations of the same nursery. High percentage of survival was correlated with high root-regenerating potential.

Planting of trees that show marked seasonal periodicity in root-regenerating potential should be limited to the time of year when high capacity for root growth occurs. On sites with high availability of soil moisture, adjustment of planting schedules is less important *(Kozlowski 1971b)*.

Particular attention is called to the

useful physiological grading system of Stone and Jenkinson *(1971)* for pine nursery stock in California, based on expected root growth after planting. They demonstrated that root-growth capacity could be predicted once nursery cultural practices were standardized and the nursery climate was characterized. The system involved: (1) monthly tests of root-growth capacity of seedlings lifted before and during the lifting and shipping season, and (2) a cumulative record of the number of hours that air temperatures in the nursery were below 10°C.

Root-regenerating potential varies with nursery cultural practices, nursery climate, and cold storage. Fumigation, watering, fertilizing, and root-pruning practices differ from nursery to nursery, and they vary from year to year in the same nursery. For these reasons plants from different nurseries may differ widely in root-regenerating potential. Hence cultural practices should be standardized before root-growth capacity can be predicted.

Climate also controls seasonal periodicity in root-growth capacity. Thus, if the nursery climate varies greatly from year to year, the date on which root-growth capacity reaches its peak will also vary. A shift in peak of root-growth capacity is controlled largely by the number of hours that seedings in the nursery are exposed to low air temperatures. For example, in a California nursery, a minimum exposure of 1,500 hours of air temperature equal to or less than 10°C was required before the peak was reached.

When normal nursery practice involves 2 to 4 months of seedling cold storage after lifting, the effect of cold storage on root-growth capacity can be evaluated in the same way as for newly lifted seedlings. The effect of cold storage depends on when the seedlings are lifted in the nursery. In California, root-growth capacity was reduced by cold storage if seedlings were lifted in the early autumn, increased by cold storage if the seedlings were lifted during early winter when the build-up in root-growth capacity was under way, and reduced if the seedlings were lifted during or after root-growth capacity peaks.

Root pruning.—Trees in the nursery can be conditioned to withstand transplanting by root-pruning them every few years. This will confine the absorbing roots to a small area, thus causing minimal injury during lifting. Since root-pruning also stimulates growth of many small absorbing roots, it leads to efficient water absorption by transplants. By comparison, large trees in the field, which have long roots, do not transplant readily because most of their absorbing roots are lost during lifting.

Shedding of leaves.—Leaf-shedding during drought is one of the most important drought-avoiding adaptations of trees in arid regions. For example in the "Caatinga" and "Cerrado" of Brazil the leaves of many species are shed at the height of the rainless season *(Ferri 1953, 1961, Eiten 1972)*. In southern California *Encelia farinosa* is without leaves during the dry season. A rain induces emergence of a new crop of leaves. These expand, and their final structure depends on how much water is available for cell expansion. As soil moisture supplies are depleted, the leaves developing higher on the branch have a denser structure than lower leaves. Finally, as water stresses increase, the leaves of lower density (those lower on the branch) develop higher water deficits than upper leaves, and the former are shed first *(Cunningham and Strain 1969)*. *Larrea tridentata* and *Fouquieria splendens* also drop their leaves during drought. *Fouquieria* rapidly grows new leaves after a rain, sometimes producing four or five crops in a year.

Reduction of transpiring surface by leaf-shedding is considered to be the most important adaptation for survival of desert plants in the Near East *(Orshansky 1954)*. There a number of plants reduce the weight of their shoots through abscission by amounts varying from a third to more than three-fourths. The

patterns of shedding vary among plants; seasonal dimorphism is attained by shedding and growth of various types of branches and leaves at different seasons. Leaves may be replaced by brachyblasts, reduced to stipules, or shed. Large winter leaves of some species are often replaced by small summer leaves *(Orshan 1972)*.

Desiccation Tolerance

Although drought avoidance has been emphasized here, some woody plants of desert regions do have the capacity to tolerate extreme desiccation without injury to protoplasm. For example, *Acacia aneura* of Australia shows marked resistance to desiccation. It persists in regions that may have no precipitation for three consecutive months *(Slatyer 1961)*. Another example is *Larrea divaricata* of warm North American deserts. This relatively shallow-rooted plant also has high protoplasmic tolerance to desiccation and maintains net photosynthesis throughout extended periods of drought *(Odening et al. 1974)*. Mechanisms of protoplasmic drought tolerance are not completely understood and more research is needed on this important problem.

TRANSPLANTING PRACTICES

In transplanting trees it is important to work toward decreasing transpiration, increasing water absorption, or preferably both. These objectives can be approached by attention to careful selection of trees, time of transplanting, site preparation, use of antitranspirants, and careful supervision of handling of planting stock before, during, and after transplanting *(Kozlowski and Davies 1975)*.

Time of Transplanting

Trees are best transplanted when water loss by transpiration is likely to be low. Deciduous trees are best moved in the autumn after the leaves fall and before the soil is frozen, or in early spring after the soil has thawed and before buds open. It is best to plant in the spring in areas where the soil freezes deeply, where winds are strong, or where soil water supplies are low. Some trees with roots that are easily injured (for example, species of *Cornus, Magnolia, Liriodendron,* and *Cladrastis)* are best planted in the spring. Other trees recommended for spring planting are *Carya, Fagus, Liquidambar,* and *Juglans nigra (Pirone 1972)*. It cannot be emphasized too strongly that the danger of losing growth or of killing trees by desiccation increases greatly as transplanting is postponed from spring into summer. The increasing danger results from (1) expansion of leaves, increasing transpirational water loss, and (2) increasing transpiration because of more favorable environmental conditions for evaporation of water (for example, increase in temperature, causing steepening of vapor-pressure gradient between the leaves and air).

In warm regions, conifers can be transplanted any time, but they should be watered regularly. Broadleaved evergreens, such as *Magnolia* and *Ilex*, are best planted in the spring. However, they can be planted in the fall provided that ample time is available for resumption of root growth before the soil freezes.

In cold regions conifers can be planted early in the fall or in the spring after the soil has thawed. Container-grown and balled and burlapped conifers can be planted anytime the soil can be worked. These plants should be mulched and irrigated after they are reset in the ground

Pruning of Shoots

The low absorbing capacity of roots can be dealt with by reducing transpirational capacity by pruning 15 to 40 percent of the bud-bearing branches. The extent of pruning should depend on the condition of the tree and the care it will receive after it is moved. Large trees require more pruning than small ones, and bare-rooted trees require more pruning than trees in containers or balled and burlapped trees. In fact, many containerized or balled and burlapped trees, espe-

cially evergreens, often do not require any pruning. Only secondary branches should be removed so as not to alter the shape of the tree.

Site Preparation

Trees planted in heavy or poorly drained soil do not grow well. Hence, heavy soil should be replaced with topsoil, and other steps should be taken to assure good drainage.

Soil aeration is adversely influenced by flooding, compaction, trampling, sidewalks and pavements, and increasing grade around a tree and by heavy soils. Aeration is often a problem in clay soils because most of the pores are too small for water to drain properly. Such soils hold little air, and movement of air between the soil and atmosphere is slow. By comparison, aeration problems seldom occur in sandy soils because such soils contain considerable air, drain rapidly, and allow for movement of gases. The air capacity of heavy soils can be increased by adding organic matter, cinders, or sand.

Effects of poor soil aeration, whatever the cause, include a decrease in permeability of roots to water, causing decrease in absorption of water. Root respiration becomes anaerobic, at least in part. Since absorption of minerals requires energy released in respiration, mineral uptake is reduced by lack of oxygen in poorly aerated soils. These changes in physiological processes eventually lead to chlorosis and shedding of leaves, decreased shoot and cambial growth, death of twigs and branches, and death of trees.

Handling of Planting Stock

All the work that goes into producing plantable trees can be rapidly undone by improper handling of nursery stock. Culling of nursery stock with low potential for survival is desirable. Beyond this, close supervision is needed during transplanting to be sure that nursery plants do not dry out to critical levels. Use of polyethylene packaging is helpful in conserving moisture of planting stock.

The chances of losing trees are much greater if they are moved with bare roots then with a ball of soil. Container-grown trees generally transplant better than balled and burlapped ones. Exposure of bare-rooted trees to drying for even a short time may have serious effects on growth and survival, but this varies with species and with the physiological condition of the plants at the time they are exposed. In one experiment, exposure of nursery stock for as little as 4 minutes reduced survival *(Hermann 1962)*. In another experiment, Hermann *(1964)* exposed 2 + 0 *Pseudotsuga menziesii* seedlings at 90°F and 30 percent relative humidity for periods up to 120 minutes. Survival by November of the year of outplanting was decreased with each added length of exposure. Exposures of 30 minutes influenced small seedlings more adversely than large seedlings, but size of plants was unimportant; and survival of both sizes was very low following exposure of 30 minutes or more.

Critical limits of exposure varied considerably with the physiological condition of the nursery stock. Seedlings lifted in the autumn could not survive more than a few minutes of exposure while those lifted in the winter survived exposure up to 30 minutes. These differences probably were related to root-regenerating potential. Prolonged storage also increased susceptibility to exposure. The importance of keeping exposure to a minimum was amply demonstrated. Even if long exposures did not reduce survival, they caused slow growth of seedlings.

Dipping of roots in compounds such as Agricol or Alginure also seems to have a favorable effect on absorption and water balance of transplants. Our data showed that dipping of *Pinus resinosa* roots in Alginure before transplanting increased survival and decreased the shock of transplanting. Dipping of roots in Agricol also has been useful in keeping bare-rooted plants fresh during storage and transport.

W. Tranquillini in Austria (personal communication) found that in plants treated with Alginure or Agricol the new roots dried out less, regenerated faster, and gained faster contact with soil after transplanting. Best results were achieved with Agricol.

Antitranspirants

Antitranspirants (antidesiccants) are of two kinds: (1) film type, which forms a film over the leaf surface and physically blocks transpiration; and (2) metabolic type, which induces stomatal closure and thereby reduces transpirational water loss.

Antitranspirants have sometimes been used to good advantage *(Davenport et al. 1971)*. However, they also have injured or killed trees. Hence considerable skill and caution are needed in use of these compounds.

Although many antitranspirants effectively reduce water loss, they may be toxic. Toxicity is influenced by many factors, including the compound used, dosage, species to which applied, environmental conditions for some time after application, and method of application. We have found that some film-type antitranspirants reduced photosynthesis; altered metabolism; and caused chlorosis, leaf lesions, leaf fall, and reduced growth. Eventually some treated trees were killed *(Lee and Kozlowski 1974, Davies and Kozlowski 1974b, Olofinboba et al. 1974)*. Under certain conditions metabolic antitranspirants also may be very toxic *(Kozlowski and Clausen 1970)*.

Toxicity sometimes occurred early and, at other times, late. Toxicity was much greater at higher than at low temperatures. Toxicity also varied with method of application. It was much lower when antitranspirants were applied as sprays than when applied as leaf dips. For these reasons it is emphasized that, if used, antitranspirants should be applied to a few trees in a pilot experiment before they are applied to a whole population of trees. And on individual trees antitranspirants should be applied conservatively at low dosages to only some of the leaves so if these are injured other leaves will be available to carry on the photosynthetic function.

After-Planting Care

The bark of newly transplanted trees generally will benefit from wrapping with crepe paper or burlap to prevent drying and sunscald. Trees with a stem diameter greater than 1 inch should be braced to prevent swaying, which sometimes impedes absorption of water through breaking of the soil-root contact.

Trees should be thoroughly irrigated after planting and regularly thereafter for at least the first few critical years or longer to insure that soil water deficit will not be an added barrier to maintaining a favorable internal water balance. Irrigation to a depth of 15 inches is advisable at approximately weekly intervals in well drained soils, or less often in tight soils.

Light waterings, which wet only the surface soil, are often wasted as the water evaporates rapidly from the soil surface and is not absorbed by deep-rooted trees. Watering should not be continued into late autumn in northern areas of the country that are subject to early freezes, since this may prolong growth and not give the tree enough time to harden.

Mulching of transplanted trees is beneficial in conserving soil moisture and stabilizing temperature. Trees planted in the autumn should be mulched when planted. Those planted in the spring should be mulched after the soil warms. Suitable mulches include peat moss, leaf mold, pine needles, ground cobs, and straw *(May 1972)*.

THE CHALLENGE TO TREE BREEDERS

Much can be done in the short term with cultural practices to control water loss of transplants. Such improved practices should always dominate the think-

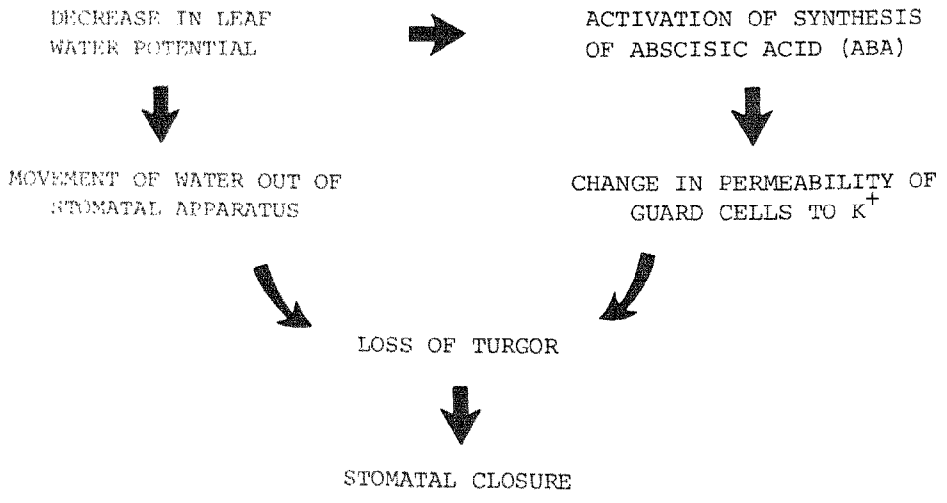
ing of arborists. In the long term, and especially in arid regions, the tree breeder can contribute toward improving planting stock with respect to one or more drought-avoiding characters (high leaf diffusion resistance, abundant leaf waxes, early shedding of leaves during drought, small leaves, high root-shoot ratios, etc.). Overall drought resistance of trees generally represents an integrated response to various degrees of specific drought-avoiding adaptations. The relative contributions of drought-avoiding characters may be expected to vary both between and within species. Hence the breeder must assess the need for improving some characters more than others in his particular plant materials. It should also be remembered that some characters that contribute to drought avoidance, such as early stomatal closure and leaf shedding, will reduce photosynthesis as well as water loss. Therefore some growth must necessarily be sacrificed in favor of tree survival and decreased drought injury.

Drought avoidance might be increased by selection or breeding for small stomata, few stomata, and stomata that close early during drought. Because control of the stomatal apparatus is both sensitive and complicated, involving hydraulic components and hormonal ones (especially production of abscisic acid) (fig. 2), the tree breeder should work closely with plant physiologists. Control of water loss may also be achieved by working for early leaf-shedding during developing droughts. Such induction also involves important biochemical controls, through hormone and enzyme systems, of acceleration of the stimulus—signal—and response phases of abscission *(Osborne 1973.*

As shown with herbaceous plants, there is also possibility of improving water-use efficiency. According to Gardner *(1963)*, it is more important to breed for water-use efficiency within a species than among species. If genotypic variation for water-use efficiency is appreciable, advances might be made by a simple breeding method such as mass selection. However, if genotypic variation is small, progeny tests may be necessary.

Some species, such as *Acer saccharum*, have leaves with relatively high diffusion resistance (small stomata and abundant leaf wax) and low rate of transpiration

Figure 2.—Control of stomatal aperture by both hydraulic and hormonal systems (from Kriedemann and Loveys 1974).



per leaf *(Kozlowski et al. 1974)*. Yet they often are injured by drought when they develop very extensive leaf areas. In such species the possibility of decreasing crown size by use of dwarfing rootstocks might prove fruitful. These considerations point up some exciting opportunities available to the tree breeder for producing drought-resistant trees.

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SOIL COMPACTION AND ITS EFFECTS UPON URBAN VEGETATION

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ABSTRACT. The urban environment imposes severe stress upon vegetation. The problems are many and interactions common, making simple solutions difficult. This paper on urban soils discusses the basic soil physics involved, reviews existing literature, and describes several research efforts in Washington. Particular emphasis is placed on soil compaction and ways to minimize its deleterious effects upon vegetation.

NATURAL SOILS

SOILS AS THEY OCCUR NATURALLY provide the basis for a better understanding of urban soils. Of particular interest to our work are the physics and the major components of a soil.

Soils are very complex, naturally formed entities that vary widely with the natural landscape. The principal mineral fractions considered are three: sand, silt and clay. The sand fraction 2.0mm-0.05mm) is virtually chemically inert but does provide vital structural capabilities for the soil mantle and assists in reducing compaction. Silt (0.05mm-0.002mm) provides structural support as well as some minor contributions to fertility. The clay fraction (0.002mm and smaller) provides most of the nutrient or fertility capabilities and also supplies much of the matrix of soil structure and tilth.

These three fractions combined form roughly 45 percent of a hypothetical or "ideal" soil. The remaining 55 percent is composed of 5 percent organic matter (decaying and decayed plant parts, organisms, etc.), 25 percent for air space (N_2 forming 79.2 of the soil atmosphere, O_2 20.6 percent and CO_2 0.2 percent), and 25 percent for water or moisture capabilities. Organic matter assists the clay fraction in maintaining the soil structure and provides nutrient exchange and food for microorganisms. The organic matter and clay content can each affect soil fertility (nutrient status) and pH. Pore space, ideally composed of equal amounts of air and water space, fluctuates widely depending upon rainfall, humidity, temperature, compaction or use.

The preceding simplistic discussion of soil physics forms the background of our discussion of urban soils and compaction. I shall not discuss pH and fertility because these characteristics vary widely and, by and large, can be modified or altered on a site-by-site basis in the city.

In the National Park Service we are concerned with the carrying capacity for

an area or simply the number of visits an area can support without deterioration of the resource we are trying to conserve. Soils are the medium in which turf, ornamental shrubs, small trees, and large trees receive support, moisture, oxygen, and nutrients. The soil also helps protect the root systems from the adverse effects of overuse. The purpose of vegetation in the city is different from that of forestry and agriculture—we are primarily interested in vegetation for esthetic purposes, not food and fiber production.

SOIL COMPACTION

In the areas of intense use, the soil parameter that seems to be the best single barometer of soil conditions is bulk density. Bulk density has been used as the index of compaction *(Pearson 1966)*. Bulk density is an expression of the mass per unit volume and can be an indicator of a wide variety of soil properties. Much has been accomplished to alleviate compaction in agricultural soils *(Barnes and others 1971)*, and one must begin with a review of this literature to better understand the basic principles involved.

Pore space, ideally 50 percent as mentioned previously, is the portion of the soil matrix that is directly and adversely affected by heavy use *(Cordell and James 1971)*. Pore-size distribution (the distribution of macro- and micropores) does not remain constant, but is altered by compaction, cultivation, aggregation, fertilization, etc. *(Waddington 1968)*.

Moisture retention or the available-moisture range is not a measure of total pore space, but does vary with soil texture. Generally sands and loamy sand have an available water range of 7.5 to 40 percent, moderate-textured soils of 10 to 18 percent, and clay loam to clayey soils of 11 to 14 percent *(Peterson and others 1968)*. Available-moisture range involves mostly micropores, plus a few of the smaller macropores. When all pores are filled with water, the soil is saturated. For simplification, pores losing their water at low tension can be considered macropores—which have been defined *(Franken 1969, Hartage and Bailly 1970)* as pores greater than 50 μ.

Hartage *(1968)* indicated that good permeabilities for water and air occurred with a variety and continuity of pore space. Pores initially affected by compaction were the very large macropores, 150-50 μ. Geisler *(1968)* indicated that, with a reduction of macropores, there is an increase in number of pores less than 10 μ —pores that provide very low permeabilities for water and air.

Dimitriu *(1974)* suggested that, as bulk density increases, more of the movement of moisture occurs through the capillary or micropore space. Sololovskaya *(1967)* suggested that the wilting point of most soils is not affected by compaction. With compaction, the solid phase of the soil increases per unit volume, and therefore, the percentage of bound water (water unavailable for plant use) is increased. The change is most notable in loamy or medium-textured soils *(Childyal and Satyanarayana 1965)*.

Baver *(1972)* has indicated the need to maintain good soil structure and/or aggregation, and high infiltration rates. If this is accomplished, a desirable portion of pore space will result. Further, the aggregates within the soil profile can be used to indicate porosity. Aggregates which are angular in nature indicate fine internal porosity, while these which are rounded indicate moderate to coarse porosity.

Total pore space can be calculated when the bulk density (BD) and particle densities (PD) are known: $(100 - BD/PD) \times 100 =$ total percent pore space.

Van der Valk *(1971)* has suggested that when the percent total pore space is less than 44 percent, the growth of flower bulbs can be impaired. When a reduction in the percentage of total pore space occurs, there is a rapid decline in the hydraulic conductivity of the soil *(Singh and Gupta 1971)*. Singh and Gupta suggested that the optimum bulk

density for agricultural crops is 1.33 g/cc. As the bulk density increases, the maximum aeration decreases and becomes the most limiting factor to root elongation *(Baver 1972, Hopkins and Patrick 1969)*. Root elongation and root penetration into soils of high bulk densities is restricted to the naturally occurring cracks rather than within the soil matrix *(Worker 1973)*. As bulk density of the soil increases, a very significant reduction occurs in the weight of roots, stems and leaves of agricultural crops *(Berben 1972, Barley 1963 and others)*. In contrast, Johnston and Wood *(1971)* noticed no significant reduction in sugar cane yield because of soil compaction. However, sugar cane is an exception. Vigor of most plants suffers under soil compaction.

Richards *(1974)*, working with peach trees, Slowik *(1970)* with apple trees, and Hatchell *(1970)* with loblolly pine, noted a negative correlation between growth or plant vigor and increasing bulk densities. Richards *(1974)* went on to indicate that, when the compaction was severe enough to reduce air space to less than 15 percent, root growth was restricted; and less than 2 percent air space resulted in essentially no root growth. Bakker and Hidding *(1970)* indicated that 20 percent air space was needed for adequate gaseous exchange between the soil and the atmosphere. Burke and others *(1972)* noted an increase in disease incidence of agricultural crops due to compaction.

Some work has been done in an attempt to reduce the adverse effect of high bulk densities through application of gypsum *(Shabassy 1973, Scotter and Loveday 1966)*. Gypsum increases aggregation and porosity while reducing the bulk density of the surface soil. Some other treatments for reducing bulk density will be discussed later.

SOIL PORE SPACE

Both soil atmosphere and water movement are directly affected by, and related to, soil compaction. In general terms there is a balance between the soil atmosphere and soil water. After a saturating rain, the soil pores are filled with water, leaving little pore space for soil gases. As water is lost to evaporation and percolation, the volume of soil gas increases. During very dry periods the gaseous phase predominates, and little water is available for plant use. Sekiguch *(1973)* noted that, for street trees, moisture depletion can occur rapidly and can vary widely from location to location.

According to Hady *(1974)*, Dasberg and Bakker *(1970)* and Youngberg *(1970)*, oxygen in the soil profile is the key to regulating plant growth. Youngberg indicated that, when the oxygen content of soil drops below 10 percent by volume, growth of Scotch pine and Norway spruce seedlings was drastically reduced. Lees *(1972)* concurred, reporting that when the oxygen concentration dropped below 10 percent, *Pinus contorta* growth was severely limited. He observed that oxygen was required for root extension in these plants. Similarly, containerized plantings commonly used in urban areas require adequate soil aeration.

Within the soil profile the principal movement of oxygen and carbon dioxide is through diffusion *(Wood and Greenwood 1971)*. Kays *(1974)* noted that an inverse relationship exists between concentrations of oxygen and carbon dioxide in the soil. In the surface soil, oxygen will generally predominant over carbon dioxide. With increased depth in the soil profile, the relationship is altered so that carbon dioxide begins to predominate over oxygen.

The gaseous phase of the soil occurs in three principal forms: (1) a free state that is found within the pores, (2) a dissolved state in which the gases are dissolved in water, and (3) an absorbed state—on the mineral and organic fractions *(Stolzy 1974)*. Stolzy concludes

that, if internal drainage is good, the oxygen content of the soil will rarely drop below 15 percent, while the carbon dioxide content is rarely above 5 or 6 percent.

Yelenosky *(1963, 1964)* found that, under poor aeration the oxygen concentration drops to as low as 1 percent, while the carbon dioxide content rises to 19 percent or higher. Soil aeration can be reduced by a layer of clay over existing soil, by compaction (as from heavy use), or by a paving operation. Under those treatments the soil atmosphere changes from aerobic to anaerobic, and the change can, seemingly, occur within a growing season. Once an area becomes compacted, re-creation of an aerobic soil condition is difficult. The relationships between soil compaction (or bulk density) and oxygen content upon root penetration are dramatic (fig. 1). Compaction and carbon dioxide have an equally dramatic effect upon root penetration (fig. 2).

Figure 1.—Effect of oxygen concentration and bulk density on depth of root penetration by cotton seedlings into compacted soil (after Tackett and Pearson 1964a, but reproduced from Plant Environment and Efficient Water Use with permission of the American Society of Agronomy).

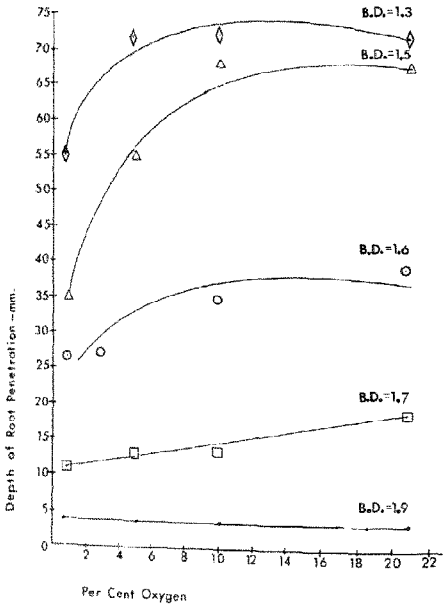
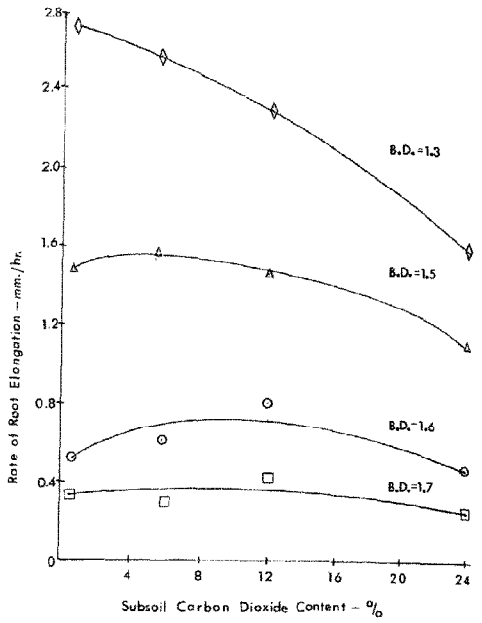


Figure 2.—Effect of carbon-dioxide level on rate of root penetration by cotton seedlings in compacted subsoil (after Tackett and Pearson 1964b, but reproduced from Plant Environment and Efficient Water Use with permission of the American Society of Agronomy).



There are means available to help recreate an aerobic soil atmosphere—although prevention of poor aeration by proper and adequate soil preparation has been most often emphasized *(Martin 1971, Hiler and others 1971, Grabert and Steinbrenner 1972)*. When a soil does become compacted, one of the most successful means to improve aeration is subsoiling *(Grabert and Steinbrenner 1972)*. This method is often very costly and, in the urban environment, difficult to perform except on large open areas. When soils are poorly drained, the installation of tile drains may improve aeration. In areas that are difficult to drain, the use of plant species well adapted to moist conditions is advisable.

Pavements cause the soil atmosphere

to change from aerobic to anaerobic, thereby reducing the vigor of plants *(Yelenosky 1964, Franken 1969, Hartage and Bailly 1970, Hartage 1968)*. On the basis of observations in Washington, D.C., I believe that the soil beneath pavements is usually quite moist and the soil atmosphere is predominately anaerobic. Pirone *(1972)* stated that pavements prevent gaseous exchange with the atmosphere, and that a general anaerobic condition occurs beneath pavements. Normal gaseous exchange between the soil and the atmosphere is necessary for tree roots and microbes to respire. This exchange can be interrupted by pavements and compaction, thus retarding root growth essential to tree vigor.

I found limited information on the topic of species tolerance to soil compaction. Yelenosky *(1964)* reported that, of seven species of seedlings, American elm was the most tolerant to poor soil aeration, while the tuliptree (yellow-poplar) seedlings were the least tolerant. Littleleaf linden, 'Moraine' honeylocust, white oak, sugar maple, and flowering dogwood were intermediate between American elm and tuliptree. Pirone *(1972)*—as reported by Kozlowski and Davies *(1975)*—listed species affected by poor soil aeration, as follows: (1) most severely injured: sugar maple, beech, dogwood, oak, tuliptree, pines, and spruce; (2) less severely injured: birch, hickory, and hemlock; and (3) least injured: elm, poplar, willow, plane, pin oak, and locust. The two authors do not wholly agree in rating the susceptibility of various species.

Soil compaction and anaerobic conditions caused by paving, heavy use or flooding do cause an unfavorable rooting environment for most trees. Differences apparently exist in the tolerance of tree species and of individuals within species to compacted conditions within the urban environment. Plants most suited to such conditions have apparently undergone some selection simply through survival of stems of adapted species. However, much research still needs to be done as a basis for selecting suitable species or cultivars.

Of possible research approaches, one would be to create variable soil conditions and to grow a variety of trees there. Another approach would be to study the effects of flooding—either through observations of flooded areas or through creation of controlled conditions. Several authors, as Bell *(1974)*, have used the former method, and a few as Hosner *(1960)* used the latter. Resulting lists of tolerance to flooding do vary:

Bell

Intolerant:
- black oak
- black cherry
- sassafras

Slightly tolerant:
- redbud
- black walnut
- shingle oak
- shagbark hickory
- hackberry
- American elm
- green ash

Tolerant:
- silver maple
- sycamore
- black willow
- bur oak
- honeylocust
- boxelder
- swamp white oak
- pin oak
- eastern cottonwood

Hosner

Least to most tolerant:
- cherrybark oak
- hackberry
- sweetgum
- shumard oak
- red maple
- sycamore
- pin oak
- American elm
- green ash
- eastern cottonwood
- black willow
- boxelder
- silver maple

Differences in such lists may be due to several factors, such as season of the year, age and vigor of component trees, and duration of flooding. For example, McAlpine *(1961)* reported that in a controlled study, tuliptree seedlings were not adversely affected by flooding for 14 days during the dormant season, but mortality occurred after 4 days of flooding in May or 3 days in June. In contrast, green ash and sweetgum seedlings were not affected by up to 14 days of flooding during any month, and the flooding seemed beneficial rather than detrimental to their growth.

Plants vary widely in their ability to withstand extremes of soil aeration and soil moisture. Chaplin *(1974)* indicated that cherry and peach trees succumb quickly to excess soil moisture. Plants do possess built-in mechanisms (stomata) that control flow of moisture through their leaves *(Kozlowski 1972a, 1972b)*. However, these mechanisms are not capable of handling excess amounts of soil moisture.

In some urban areas natural gas can cause plant stress. This topic will not be discussed here, and the reader is referred to the literature *(Groth 1971, Davis 1972, Walton 1972/73)*.

Water is vital either directly or indirectly in nearly every process occurring in plants, and its proper management is difficult to assess. Yelenosky's *(1964)* summation of soil and plant relationships was succinctly stated: "there are no simple answers to meet all situations concerning tree growth and soil aeration." This seems to be the case within the urban ecosystem.

SOIL COMPACTION IN WASHINGTON, D.C.

Tijmens *(1973)* indicated that planting should be an integral part of urban planning, and I believe that this is the direction we are all working toward.

Plants in urban areas exist under a myriad of environmental stresses and those in Washington are no exception. When you consider the effects of soil compaction, insects, disease, drainage, water pollution, deicing salt, and vandalism, which individually can reduce or prohibit tree growth, it is not surprising that their synergistic effects are quite severe *(Seibert 1973 and others)*.

Determining Present Conditions

The soils program at the Ecological Services Laboratory of National Capital Parks has focused on soil heterogeneity, compaction and related physical properties, and to a lesser extent on the chemical properties. One significant endeavor has been a comprehensive survey of Washington's soils in cooperation with the Soil Conservation Service. This survey, the first comprehensive survey of urban soils, is nearly 90 percent completed (the field mapping is completed). It will be an exceptionally valuable aid in planning and planting for Washington's plant scientists and urban planners.

Prior to the soil survey we did some soil-characterization work on the Mall. The first urban-soil profile I observed was dramatic. A distinct characteristic was realized with every swing of the pick, that of severe density or compaction. Analyses have been completed for that profile and for three others on the Mall table 1). Data on bulk density and pore space in these samples verified the inadequate pore space for moisture and air exchange. Ideally the bulk density should range between 1.3 and 1.6 g/cc, while the pore space should range between 40 and 45 percent. For the Mall soils, the bulk-density range was 1.7 to 2.2 g/cc, while pore space was 13 to 36 percent.

I conducted a small experiment to determine if in fact "urban soils are as dense as concrete." Four commonly used construction materials were tested: cinder block, brick, asphalt, and concrete. The data (table 2) reveal that our urban soils are indeed as "dense as concrete"! (The range in bulk density of brick is attributed to differing manufacturing tech-

Table 1.—Density and pore space in the horizons of four soil pits of the Mall

Location and horizons		Number of samples	Bulk density		Particle density	Calculated pore space[1]
			Range	Average		
7th & Washington Dr.			*g/cc*	*g/cc*	*g/cc*	*Percent*
Pit I:	A1	5	2.01-2.14	2.12	2.56	17.2
	C1	5	1.77-1.97	1.81	2.65	31.7
	IIC2	5	1.88-2.20	2.02	2.54	20.5
	IIIC3	5	1.90-2.02	1.95	2.54	23.2
	IVC4	5	1.98-2.13	2.08	2.59	19.7
Pit II:	Ap	6	2.02-2.22	2.18	2.51	13.1
	A2	6	1.69-1.97	1.90	2.58	36.4
	C11	6	1.67-1.88	1.81	2.53	28.4
	C12	6	1.67-1.71	1.70	2.48	31.4
Pit III:	Ap	5	1.96-2.13	2.08	2.40	13.3
	C1	5	1.76-2.06	1.81	2.47	26.7
	IIC2	5	1.82-2.00	1.90	2.50	24.0
	IIIC3	5	1.96-2.01	2.00	2.56	21.9
Washington Monument Grounds						
	C12	3	1.80-1.82	1.81	2.47	26.7
	C13	3	1.71-1.76	1.74	2.58	32.6
	IIC3	3	1.79-1.94	1.87	2.41	22.4

[1] Pore space was calculated by the following formula: $(1 - \frac{\text{bulk density}}{\text{particle density}})\ 100 = \%$ pore space.

Table 2.—Bulk density and pore space of four construction materials

Material	Number of samples	Bulk density		Particle density	Calculated pore space
		Average	Range		
		g/cc	*g/cc*	*g/cc*	*Percent*
Cinder block	3	1.67-1.71	1.70	2.64	35.6
Brick	3	1.43-2.01	1.75	2.72	35.7
Asphalt	3	2.17-2.22	2.19	2.35	6.8
Concrete	3	2.23-2.27	2.26	2.47	8.5

niques—as different clays and firing methods.)

A high bulk density and low amount of pore space seem to exist in most of the soils examined and probably form the most restrictive characteristic of urban soils for plant growth. Other characteristics I have observed as common in urban soils are extreme heterogeneity from area to area, variability in percentages of organic matter with profile depth, unoriented coarse fragments (rock and stones), highly variable fertility and pH, a wide variation in textural distribution (percent of sand, silt and clay) with depth of profile, and a tendency for the compacted soils to repel moisture or exhibit a hydrophobic nature.

Improving Present Conditions

Part of the soils work is directed toward finding economical ways to alleviate deleterious effects of soil compaction upon plants. Major areas needing renovation are heavily used: playgrounds, picnic sites, concession areas, athletic centers, etc. Soils of these areas undergo severe compaction that in all likelihood reduces the longevity of vegetation, particularly trees. A soil-amending process should assist in reducing compaction over the long term, 5 to 10 years or longer.

However, soil renovation is difficult once trees are established—because of the predominance of roots in the surface A_1 and A_2 soil horizons *(Howe 1974, Coile 1937, Hopkins and Donahue 1939, Scully 1942, and others)*.

At Hains Point, plots have been laid out under conditions of very heavy use in a picnic-playground area. The number of daily visits to the area is estimated at 800, and visitors are permitted unrestricted use of the area. The Park Service staff maintains the grounds as a part of their regular duties.

Soil amendments used in this study were four: (1) sintered fly-ash (a by-product of the hydroelectric power industry, fly-ash is heat-treated or sintered to produce a porous, inert, and rigid light-weight aggregate with about 70 percent pore space); (2) expanded slate (a commercially available material produced by a heat-expansion process so the slate, too, is porous (about 50 percent pore space), inert, and rigid); (3) coarse construction sand (not a light-weight aggregate, but an age-old and commercially available material); and (4) an organic material, digested sewage sludge.

After 4 years—even with continued visitor use—there are significant differences between treatments (table 3). The soil mix having 33 percent by volume of expanded slate has the lowest bulk density and the most pore space. The four treatments with sintered fly-ash fell between those with 33 percent and 20 percent of expanded slate. Coarse construction sand was not so effective an addition as either of the two aggregates, while the use of sewage sludge with the other materials had little or no effect. Effective soil amendments offer a partial solution for alleviating some of the deleterious effects of compaction. The best treatment gave an increase of 7 percent for pore space in the rooting zone, an increase that improves the air and water relationships for the growth of trees.

Infiltration and percolation data are not yet completed, but initial indications are that the modified plots handle more water per unit time than the controls. This is particularly important in reducing runoff and erosion during rain storms and in getting moisture into the soil so it is available for plant use. We have noticed that the plots exhibit a hydrophobic or

Table 3.—Bulk density and pore space of soils by treatments after 4 years with continued visitor use[1]

Plot treatment	Bulk density		Pore space	
	Average	Significance	Percentage[2]	Significance
	g/cc		*Percent*	
33% expanded slate	1.33	h	49.8	a
33% expanded slate with sludge	1.34	h	49.4	ab
33% sintered fly-ash	1.41	g	46.8	bc
33% sintered fly-ash with sludge	1.43	fg	46.2	cd
20% sintered fly-ash	1.44	ef	45.9	cde
20% sintered fly-ash with sludge	1.44	ef	45.9	cde
20% expanded slate with sludge	1.45	ef	45.4	cde
20% expanded slate	1.46	de	45.0	cde
33% coarse sand	1.48	cd	44.3	cdef
Rotary-tilled control	1.50	bc	43.6	defg
33% coarse sand with sludge	1.51	b	43.3	defg
Undisturbed control	1.52	b	42.9	efg
20% coarse sand with sludge	1.55	a	41.5	fg
20% coarse sand	1.56	a	41.2	g

[1] Data based on samples from three replications. Statistical analyses followed Duncan's multiple range test, and values with same letter in a column are not significantly different (at 5% level).

[2] In calculating pore space, 2.65 g/cc was used as the assumed particle density.

water-repellent tendency. This characteristic can apparently develop when soils become compacted. We hope further work will substantiate these indications and suggest possible amelioration measures.

Within the environment of the city and its parks, the general procedure has been to remove leaves and other naturally produced organic matter. This practice removes nutrients and organic matter from city soils *(Meyer 1973 and personal observations)*. However, organic materials as urban-soil amendments should be included in maintenance operations. Use of these materials is economically feasible, partly because of the number of brush and log chippers currently available and partly because of the high cost of purchasing adequate amounts of topsoil, fertilizer, and peat moss. The materials can be composted with sewage sludge (as the USDA has demonstrated at Beltsville) and provide a very desirable organic material for modifying urban soils. Such organic wastes do not, of course, totally replace topsoil and fertilizer in amending urban soils.

However, the value of these organic wastes is demonstrated by their use in Constitution Gardens, a 42-acre site between the Lincoln Memorial and Washington Monument *(Patterson 1975)*. Nineteen-hundred trees, numerous shrubs, and other vegetation are being used to create an informal park where Bicentennial visitors can relax. Typical urban soil existed at this site, so National Capital Parks had to choose between purchasing adequate topsoil to support the trees and other vegetation and building a soil—using the existing soil, 3 inches of USDA compost (digested sewage sludge and wood chips), 4 inches of leaf mold collected within the Washington area, and a small amount of topsoil. The existing soil, compost, and leaf mold were thoroughly mixed to form a soil mantle of 14 inches, over which a 3- to 4-inch layer of topsoil was placed. The results of soil data (table 4) indicate that

Table 4. Results of analyzing the soil mixture of Constitution Gardens[1]

Date	pH	Organic matter	Soluble salts[2]	Magnesium[3]	Phosphate[3]	Potash[3]	Manganese	Zinc
		Percent	*ppm*	*lbs/acre*	*lbs/acre*	*lbs/acre*	*lbs/acre*	*lbs/acre*
11 Nov. 1974	6.7	4.6	2,100	300+ VH	750+ VH	450+ VH	105	200+
22 Jan. 1975	6.2	4.6	660	300+ VH	640+ VH	297 VH	50	183
1 April 1975	6.6	4.6	340	300+ VH	750+ VH	351 VH	60	177

[1] Analyses made by the Soil Testing Laboratory of the University of Maryland.
[2] ppm = parts per million.
[3] VH = very high.

the fertility is mostly adequate to date. Nitrogen will have to be added because of the very low amount in the organic amendment. (Nitrogen analyses show 4 to 18 pounds of available N per acre.) We plan to continue such uses of organic materials in amending urban soils.

Still another soil-improvement project was in connection with a planting of elms that line the Reflecting Pool. The site received heavy use during Resurrection City and continues to receive heavy use annually during the National Folklife Festival. Soil beneath these trees was compacted, and the shading and compaction prevented adequate establishment of turf. Wood chips were applied broadcast during the summer of 1973 prior to the Folk Festival, and a year later observations were made. At the interface of wood chips and soil there was a dramatic proliferation of rootlets. Observations indicated that, as the wood chips decayed, the soil surface was beginning to reflect their influence. Additional wood chips can be applied as the old ones decay. Ultimately, this organic matter will improve water and aeration relationships through reducing compaction effects.

CONCLUSIONS

Soil compaction imposes severe stress upon urban vegetation. Treatments tested by the Ecological Services Laboratory of the National Capital Parks have produced a significant reduction in soil compaction as measured by bulk density. Lightweight aggregates rotary-tilled into plots reduced soil compaction, even though the area was continually used as a playground-picnic area. Composts of leaves, wood chips, and sewage sludge help to reduce compaction of urban soils and also increase their fertility and content of organic matter. Wood chips, when used on heavily compacted soils in shaded areas, reduce damage to soil and to tree roots from continued heavy use. Such applications of organic materials aid the development of a "natural" soil profile.

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SALTS AND WOODY-PLANT INTERACTIONS IN THE URBAN ENVIRONMENT

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ABSTRACT. The extensive use of de-icing salts in urban environments has resulted in significant plant pollution. Plants growing along highways, on lawns, and along sidewalks exhibit stem dieback, and many are killed. The salts are deposited as spray on buds, stems, and leaves or are accumulated in the root zone. Subsequent injury results from osmotic and specific ion effects. Several woody plants exhibit resistance to abnormal salt levels, and systematic breeding and selection for salt-tolerant plants are recommended.

TREES AND SHRUBS are often used indiscriminately for landscaping metropolitan areas where their adaptation to the habitat is questionable. Consideration is seldom given to the pollutants, soil conditions, and maintenance factors that determine the ultimate survival of the plant. Esthetic considerations — form, texture, foliage, flower, fruit, and fall color —often override the common-sense factor of whether the plant will survive. Man has created environments where a limited number of woody plants can be grown successfully. Unfortunately this complement of plants is primarily restricted to the weedy, less ornamental plant taxa.

We, as plant scientists, have not systematically selected plants for adaptation to specific habitats. Much of the selection accomplished to date has been by serendipity, and I strongly believe there is a pressing need for systematic and organized breeding and selection of pollution-tolerant trees and shrubs that have significant esthetic characteristics. Gold *(1975)* noted that plant species must be selected for tolerance to urban conditions; and the conditions he included were drought, poor aeration, compaction, mineral deficiencies, contamination by salts, heavy metals and pesticides, air pollution, and mechanical impacts by man. Epstein *(1972)* wrote that, like other stressful features of the mineral environment, salinity often results in the evolution of races, or ecotypes adapted to it. The possibility of breeding salt tolerance into plants exists, but the strategy has not been tried in any sustained energetic manner *(Demeritt 1970)*.

THE NATURE AND SCOPE OF SALINITY:PLANT INTERACTIONS

The extensive use of de-icing salts in northern states has created a synthetic

saline environment unlike that encountered in the saline soils of the world. The increased interest in highway and municipal beautification, coupled with the increased use of de-icing salts, *(Westing 1969)* has produced an incongruous, but not unreconcilable, situation. Westing estimated that approximately 12 million tons of salt are applied to northeastern highways per year. Chicago freeways, in severe winters, have received as much as 80 tons per lane mile (45 metric tons per lane per km). On six-lane freeways the total reaches 480 tons per mile. The soluble salt content *(Hughes and others 1975)* of soils along the Chicago freeways varies considerably, and concentrations of 20,000 ppm (2 percent) were found on sparsely vegetated areas and up to 50,000 ppm (5 percent) in denuded soil from the medians. However, these high-salt soils represent only a small percentage of the total area, and the average soil would fall in the range of 500 to 2,000 ppm, which presents no problem to plant growth *(Richards 1954)*.

The metropolitan areas receive the greatest quantities of salts: in Illinois approximately 300,000 tons (272,000 metric tons) were applied to state-maintained roads during the winter of 1969-70, and Chicago expressways received 18 percent of this. Hutchinson *(1970)* indicated that average annual application of 15 to 25 tons per mile (8 to 14 metric tons per km) was common in several states, but also that rates within states varied widely.

De-icing salts present a significant cultural problem—one to which there are few logical alternatives. Plant injury occurs along freeways, along sidewalks, on lawns of suburban streets, and in other areas where salts are liberally used on the nearby roadways. The two principal de-icing salts are sodium chloride (NaCl), the primary source, and calcium chloride ($CaCl_2$).

Plants are injured by salts that are deposited by drift on dormant stems and buds of deciduous trees and on stems, buds, and leaves of evergreens, or by excess amounts of salts that leach into the root zone. Along Chicago freeways, plant injury was evident as far as 150 to 200 feet from the pavement's edge. Several authorities *(Hall and others 1972, Hofstra and Hall 1971, Lumis and others 1971, Lumis and others 1973)* agreed that the greatest percentage of injury to roadside plants resulted from aerial deposition, and not from soil-soluble salts, although injury has been attributed to salt accumulation in soils *(Davidson 1970, Hanes and others 1970, Holmes and Baker 1966)*. In suburban areas that are heavily de-iced and plowed, excess salts often accumulate in nearby lawns. Holmes *(1964)* reported that the superintendent of a New York City apartment house used copious amounts of NaCl for the sidewalks and could not understand why the trees were of reduced vigor and stunted appearance until someone broke a stem and was able to detect a heavy salt taste.

The resultant plant injury from soil salts may be caused by differences in osmotic potentials between the plant and the soil solution, by a specific ion effect usually related to the Na or Cl ions, or by a combination of the two *(Epstein 1972)*. Injury through osmotic effects results when the osmotic potential of the soil solution is significantly lower than that of the plant cells. Water does not move into the plant and could even move osmotically from the cells into the soil solution.

Another interesting explanation for osmotic injury *(Bingham and others 1968, Oertli 1968)* is that salt is absorbed by roots and moves into the outer spaces (vessels, cell wall areas) of leaf mesophyll cells. The osmotic potential of the extracellular solution may be low enough to cause an intracellular water deficit. This in turn could lead to the death of cells, especially those around the margins of leaves.

Plants injured through the osmotic mechanism are often stunted *(Dirr 1975)*; they may exhibit yellowing and eventual

abscission of lower leaves; development of leaf injury is usually acropetal. However, some plant taxa show no significant discoloration of leaves, but may have growth differences revealed by their fresh or dry weights compared to those of control plants. Separating osmotic from toxic effects of specific ions is almost impossible in the field because one may override or mask the effect of the other *(Dirr 1974)*. Although some plant injury is attributable to the osmotic effects of soil salts, the consensus of opinion is that plant cells are able to accumulate and maintain high intracellular concentrations of solutes—thereby keeping internal water potentials sufficiently lower than that of the external medium to effect an osmotic adjustment and prevent physiological drought *(Epstein 1972)*.

The mechanism of plant injury due to specific ions (Na or Cl) has not been established. Various salts or ions may disrupt the structure of enzymes or other macromolecules *(Rauser and Hanson 1966, Warren and Cheatum 1966)*, may damage cellular organelles *(Blumenthal-Goldschmidt and Poljakoff-Mayber 1968)*, may affect photosynthesis and respiration *(Boyer 1968, Nieman 1962)*, and may inhibit protein synthesis *(Kahane and Poljakoff-Mayber 1968)*. Disruption of any or all of these plant structures or processes could lead to death of cells, tissues, organs, and eventually the plant.

SYMPTOMS OF AERIAL-SALT INJURY

Plant injury by salt is manifested in many different ways, but the consistency, intensity, and magnitude of injury can be accounted for only through the mode of aerial deposition. The following symptoms, as described by Lumis and others *(1971)*, accurately chronicle the visual evidence associated with salt injury. Evergreens often show:

1. Needle browning is moderate to extreme, beginning at the tip.
2. Needle browning and twig dieback occur on the side facing the road, but none or very little on the back side.
3. No needle browning or dieback occur on branches near the ground under continuous snow cover.
4. Needle browning and twig dieback are less severe farther from the road.
5. Browning usually is first evident in late February or early March and becomes more extensive through spring and summer.

Deciduous plants show:

1. Leaf buds on the terminal part of branches facing the road are very slow to open or do not open.
2. New growth arising from the basal section of branches facing the road results in a tufted or witches'-broom appearance.
3. Flower buds on the side facing the road do not open, but those on the back side develop variably.

General injury patterns include:

1. Injury is more severe on the side facing the road; plants are one-sided due to branch dieback.
2. Damage is more pronounced on the down-wind side of the highway.
3. Plants farther from the road are injured less.
4. Branches that were covered by snow are not injured.
5. Injury to evergreens becomes apparent in late winter; injury to deciduous plants is not evident until spring.
6. Branches above the spray-drift zone are not injured or are injured less.
7. Damage increases with the volume and speed of traffic and the amount of salt applied to highways.
8. Plants damaged over several years lack vigor and soon begin to die.
9. Less winter-hardy plants are injured more severely.
10. Salt spray penetrates only a short distance into dense plants.
11. Plants in sheltered locations lack injury symptoms.

THE TOXIC PRINCIPALS

The Na and Cl ions are the two agents that must be considered in judging salt injury to woody plants. Sodium can replace essential cations (Ca, Mg, K) on the soil colloids and at the same time can deflocculate the soil. The reduction in flocculation (loss of granulation) affects drainage, soil-oxygen tensions, and, indirectly, microbial activities.

Most investigators *(Baker 1965, Dirr 1974 and 1975, Hofstra and Hall 1971, Holmes 1961, Holmes and Baker 1966, Shortle and Rich 1970, and Walton 1969)* attributed woody plant injury to the Cl ion, although Na has been implicated as a causal agent *(Bernstein and others 1972, Rich 1972)*. Chloride is a negatively charged ion and, unlike Na, is readily leached and therefore is briefly available in the root zone, especially in areas of high rainfall. C. R. Belcher *(personal communication 1975)* reported that 6 months after the application of 16,000 pounds per acre of rock salt, neither Na or Cl ions could be found in the top 12 inches of soil. Westing *(1969)* also reported that Cl is readily leached and is seldom available in significant concentrations in the soil for any length of time.

When Na and Cl ions are aerially deposited on plants, they usually penetrate the stems, buds, and leaves. Lumis and others *(1973)* noted that, although the basis for plant resistance to salt spray is not known, increased amounts of wax (bloom) on spruce needles added to their protection, because the bluer the spruce, the more resistant it was to salt spray. Deciduous trees and shrubs having resinous buds or buds partially embedded in the stem are resistant, while plants with naked buds (lacking scales) are susceptible to salt spray. Dirr *(1974)* speculated that the salt tolerance of thornless common honeylocust, *Gleditsia triacanthos inermis*, under highway conditions, was attributable to the inability of Na and Cl to penetrate the waxy branches and protected buds of dormant trees. However, honeylocust seedlings grown under controlled conditions where NaCl and KCl were soil-applied showed severe injury. Total soil-soluble salts were not responsible for injury, and tissue Na had no adverse effect on growth, although Na levels of shoots were greater than 2 percent of dry weight. Shoot content of Cl was a reliable index of the degree of salt injury, because the greater the tissue amount of Cl, the more rapid was the onset and the more severe the injury.

Dirr *(1975)* showed that *Hedera helix*, English ivy, was severely injured by soil and foliar applications of Cl-salts (NaCl, KCl, $CaCl_2$). The injury developed more rapidly, and initially was more severe, from foliar applications. However, the dry-weight reductions were similar among all Cl-treated plants at the end of the experimental period. Plants treated with foliar-applied Na_2SO_4 were vigorous, healthy, dark green, and similar to the controls, although Na levels of shoots were approximately 1 percent of dry weight. Levels of this magnitude produced visual injury in other woody ornamental species *(Bernstein and others 1972)*. The shoot-Cl levels that caused visual injury in honeylocust and English ivy were greater than 2 percent of dry weight regardless of the type of Cl salts or application methods.

My work to date has led me to believe that the degree of salt tolerance among woody plants depends on their ability to preclude Cl, and possibly Na, from entering cells and tissues. Work comparing *Pinus thunbergii* (Japanese black pine), a reported salt-tolerant species, to *Pinus strobus* (white pine), a salt-susceptible species, showed that both species were severely injured by daily foliar applications of Cl salts. Tissue analyses showed that needles of severely injured white pines had Cl contents greater than 3 percent, while injured needles of Japanese black pine contained approximately 2 percent. When Cl reaches a threshold level in plant tissue *(Dirr 1974)*, there are no cellular adjustments that offset toxic effects. Tissue levels of injured

plants are often extremely variable because of (1) "species specificity" (genetic differences among plants), (2) plant part sampled (leaves usually possess greater concentrations of ions than stems, and stems greater levels than roots), (3) time of sample collection [*Hall and others 1972* showed that foliar concentrations of Na and Cl declined from abnormally high levels, up to 1 percent in May to normal levels, 0.02 to 0.1 percent, by August in white pine], and (4) analytical techniques. LaCroix and others *(1970)* showed that different analytical techniques indicated different Cl levels in the same tissue.

The data in tables 1 and 2 show the great variation in shoot Na and Cl levels among various plant species. The visual injury and degree of salt tolerance observed on the plants listed in table 2 correlated very closely with shoot contents of Cl: *Hedera helix* was more salt tolerant than *Viburnum*>*Pyracantha*>*Coleus*>*Cercis*. Table 3 presents a compilation of leaf or shoot levels of Cl that produced plant injury. Shortle and Rich *(1970)* reported that foliar contents of Cl at the injury threshold were correlated with the degree of visual injury.

Salt tolerance of woody plants has too often been based on whether the plants had branch dieback or some other visual disorder. I have shown *(1975)* that the evaluation of a specific plant's adaptability to saline environments must be based on several parameters. Plant survival in saline soils does not automatically imply survival where salt is aerially applied and vice versa. *Thuja occidentalis* (eastern arborvitae) will withstand soil salts but not foliar-applied salts, while the opposite is true for honeylocust *(Dirr 1974)*. The appearance of the plant is not always indicative of the severity of salt-induced damage *(Lumis et al. 1973)*, and dry weights of shoots or other growth parameters should be used to augment visual evaluations. *Ailanthus altissima* (tree-of-heaven) seedlings were tested for tolerance to soil-applied Cl salts, and on the whole exhibited minimal resistance.

Table 1.—Sodium content of shoots of selected plant taxa as affected by salts and concentrations

[In percentage of oven-dry weight]

Taxon	Control	Na_2SO_4		NaCl	
		0.05N	0.15N	0.05N	0.15N
Coleus blumei	0.21	3.70	4.53	3.62	4.93
Pyracantha coccinea 'Lalandi'	.04	.47	.61	.58	1.92
Cercis canadensis	.03	.36	.86	1.18	7.06
Hedera helix	.16	.35	.40	.77	.75
Viburnum x burkwoodii	.03	.23	.52	.46	.98

Table 2.—Chloride content of shoots of selected plant taxa as affected by salts and concentrations

[In percentage of oven-dry weight]

Taxon	Control	Na_2SO_4		NaCl	
		0.05N	0.15N	0.05N	0.15N
Coleus blumei	1.14	1.37	1.44	6.19	9.41
Pyracantha coccinea 'Lalandi'	.31	.31	.24	1.71	3.67
Cercis canadensis	.64	.96	1.26	3.61	11.64
Hedera helix	.38	.34	.41	1.39	1.94
Viburnum x burkwoodii	.27	.36	.58	.94	2.19

Table 3.—Chloride levels corresponding with plant injury as reported by various investigators

Tree species	Chloride level in percentage of dry weight		Investigator
	Damaged trees	Uninjured	
Acer platanoides	0.4 or greater	—	*Walton 1969*
Acer rubrum	1.01	0.3	*Shortle & Rich 1970*
Acer saccharum	1.0 (leaf necrosis)	.61	*Baker 1965*
	3.64 (stems dying)	—	*Holmes 1961*
	1.0 (leaf necrosis)	.05-0.06	*Holmes & Baker 1966*
	.84	.24	*Shortle & Rich 1970*
Aesculus hippocastanum	1.0 or greater (leaf necrosis)	—	*Ruge 1968*
Ailanthus altissima	2.0 to 3.0	—	*Dirr, unpublished*
Alnus rugosa	.91	.54	*Shortle & Rich 1970*
Carpinus caroliniana	.94	.34	*Shortle & Rich 1970*
Carya illinoensis	1.0 (leaf necrosis)	—	*Harper 1946*
	.6 or greater (trees were damaged)	—	*Harper 1946*
Carya ovata	1.27	.38	*Shortle & Rich 1970*
Gleditsia triacanthos inermis	2.56 (leaf necrosis, death of plant)	—	*Dirr 1974*
Pinus mugo	1.12 (leaf necrosis)	—	*Hofstra & Hall 1971*
Pinus nigra	.78 (leaf necrosis)	—	*Hofstra & Hall 1971*
Pinus resinosa	1.08	.00	*Shortle & Rich 1970*
Pinus strobus	2.0 to 3.0		*Dirr, unpublished*
	1.36 to 1.76 (leaves 70 to 90% necrotic)		*Hall et al. 1972*
	.58	.24	*Shortle & Rich 1970*
Pinus sylvestris	.76	—	*Hofstra & Hall 1971*
Pinus thunbergii	1.5 to 2.5 (severe leaf necrosis)	—	*Dirr, unpublished*
Thuja occidentalis	.83 (leaf necrosis)	—	*Hofstra & Hall 1971*
Tilia species	1.0 or greater (leaf necrosis) Levels up to 6.0 were found.	—	*Ruge 1968*
Tilia americana	.90	.27	*Shortle & Rich 1970*
Tsuga canadensis	.68	.50	*Shortle & Rich 1970*
Ulmus americana	1.13	.36	*Shortle & Rich 1970*

The seedlings did vary: 6 of 100 were uninjured while the others were defoliated during the 21-day experimental period. However, this species is sometimes listed as salt-tolerant (table 4). Near highways most of the salts reach *Ailanthus* stems aerially and apparently do not enter the dormant tissues of this species.

Evaluations of salt-induced plant injury should be based on salts, concentrations, application methods (aerial versus soil-applied), osmotic effects, shoot or leaf contents of Cl, and perhaps, shoot levels of Na. Elimination of any of these factors from consideration could result in misinterpretation of the salt resistance or susceptibility of a particular plant. The plants listed in table 4 have been reported to be salt-tolerant by various authorities; however, they have not been thoroughly tested and therefore cannot be recommended unequivocally.

There are several obvious inconsistencies in the list of salt-tolerant plants. These inconsistencies occur because evaluations are based on a single parameter and insufficient data.

MINIMIZING SALT DAMAGE TO WOODY PLANTS

Salt damage to woody plants can be minimized or largely eliminated by:

1. Avoiding de-icing salts completely (often not feasible), reducing quantities applied, or using alternative deicing salts *(Krappenbauer et al. 1974, Westing (1969)* or alternative methods of snow and ice removal.

Table 4.—Relative salt tolerance of trees

[By authors: (1) Carpenter 1970, (2) Dirr 1974 and 1975, (3) Lumis and others 1973, (4) Pellett, (5) Shortle and Rich 1970, and (6) Wyman 1965 and 1969.]

Species	Salt-tolerance rating			Species	Salt-tolerance rating		
	Good	Moderate	Poor		Good	Moderate	Poor
Abies balsamea	—	1	4	*Picea pungens*			
Acer negundo	—	1,4	3	*glauca*	6	1	—
Acer platanoides	2,3,6	4	—	*Pinus banksiana*	3	—	—
Acer pseudoplatanus	6	—	1	*Pinus mugo*	3	—	—
Acer rubrum	—	3	1,4,5	*Pinus nigra*	3,6	—	—
Acer saccharinum	—	3	4	*Pinus ponderosa*	—	1	—
Accer saccharum	3	—	1,4,5	*Pinus resinosa*	—	—	3,4,5
Aesculus				*Pinus rigida*	6	—	—
hippocastanum	3,6	—	—	*Pinus strobus*	—	—	3,4,5
Ailanthus altissima	3,6	—	—	*Pinus sylvestris*	6	4	3
Alnus glutinosa	—	—	1	*Pinus thunbergii*	6	—	—
Alnus incana	—	—	4	*Populus alba*	1,2,4,6	—	—
Alnus rugosa	—	3	1,5	*Populus alba*			
Amelanchier				'Pyramidalis'	2	—	—
canadensis	6	—	—	*Populus angustifolia*	1	—	—
Amelanchier laevis	—	—	3	*Populus deltoides*	3	1	—
Betula				*Populus*			
allegheniensis	5	—	—	*grandidentata*	5	3	—
Betula lenta	5	—	—	*Populus nigra*			
Betula papyrifera	5	3,4	—	'Italica'	—	3	1,4
Betula pendula	—	4	—	*Populus tremuloides*	5	1,3	—
Betula populifolia	5	3	—	*Populus* species	—	3	—
Betula species	—	1	—	*Prunus armeniaca*	1	—	—
Carpinus betulus	—	—	1	*Prunus serotina*	5,6	—	—
Carpinus caroliniana	—	—	4,5	*Prunus virginiana*	3	—	—
Carya ovata	3	—	5	*Pseudotsuga*			
Carya species	—	—	4	*menziesii*	—	1	4
Catalpa speciosa	—	3	—	*Pyrus* species	—	3	—
Celtis occidentalis	2	—	—	*Quercus alba*	1,2,4,5,6	—	—
Corylus species	—	—	1	*Quercus macrocarpa*	4	—	3
Crataegus crusgalli	6	—	—	*Quercus marilandica*	6	—	—
Crataegus species	—	—	3	*Quercus robur*	1	—	—
Elaeagnus				*Quercus rubra*	1,3,4,5	—	—
angustifolia	2,3,4,6	—	—	*Rhamnus cathartica*	2,3,6	—	—
Fagus grandifolia	—	1	3,4	*Rhamnus frangula*	2	3	—
Fagus sylvatica	—	—	1,4	*Rhus typhina*	2,3,6	—	—
Fraxinus americana	5	3,4	—	*Robinia*			
Fraxinus				*pseudoacacia*	2,3,4,5,6	—	—
pennsylvanica	—	1,4	—	*Robinia*			
Gleditsia triacanthos				*pseudoacacia*			
inermis	1,2,3,4	—	—	'Umbraculifera'	2	—	—
Hippophae				*Salix alba*	—	1	—
rhamnoides	6	—	—	*Salix alba* 'Tristis'	4	—	—
Juglans nigra	3	—	1,4	*Salix matsudana*			
Juglans regia	3	—	1,4	'Tortuosa'	2	—	—
Juniperus virginiana	5,6	1,4	—	*Salix nigra*	—	3	—
Ilex opaca	6	—	—	*Salix* species	4	—	—
Larix laricina	3	—	—	*Sorbus* species	—	3	—
Larix species	—	—	1,4	*Syringa amurensis*			
Magnolia				japonica	3	—	—
grandiflora	6	—	—	*Tamarix pentandra*	1,4,6	—	—
Malus baccata	—	1,4	—	*Taxus cuspidata*	—	4	—
Malus species and				*Thuja occidentalis*	—	1	—
cultivars	—	2,3	—	*Tilia americana*	—	3	4,5
Morus alba	1,4,6	—	3	*Tilia cordata*	—	—	1,4
Nyssa sylvatica	6	—	—	*Tsuga canadensis*	—	—	3,4,5
Picea abies	—	3,4	—	*Ulmus americana*	—	3,4	5
Picea asperata	6	—	—	*Ulmus glabra*	1	—	—
Picea glauca	—	1	3	*Ulmus pumila*	4	3	—
Picea pungens	3	—	—	*Viburnum* species	—	—	1

2. If soil is inundated with salty water, or plants receive aerial drift, a thorough leaching of the soil or washing of the plant parts will aid in reducing injury—if done soon enough. Obviously such ameliorative treatments are impossible in large-scale situations (highways, malls, planters) but could be used to advantage by some homeowners. Another recommendation is the addition of gypsum to soils that are high in Na. The calcium displaces the Na and improves soil structure and aeration.
3. Snow fences, including living fences of shrubs, and certain changes in highway engineering could significantly reduce the problem of salt drift and salty runoff and provide other advantages as well *(Westing 1969)*. Mounding of planting areas would prevent accumulations of excess salt in the root zone. Flemer *(1975)* advised that planting pits in sidewalks and blacktop areas should have a lip so the salty water does not run into the pits.
4. Plants that are injured and exhibit dieback should be pruned, fertilized, and watered. Weakened or stressed plants are often attacked by insects and diseases to which healthy trees are resistant.
5. Use plants sufficiently tolerant to the expected amounts and types of salt (soil salt or salt spray). As already mentioned, plants resistant to soil salts and those resistant to salt spray are not necessarily the same species. No plants are wholly immune to salt injury, although certain plant taxa endure more salt than others. A working list of woody plants, including those of good tolerance and moderate tolerance to the two types of salt, would significantly aid the landscape planner. Trees and shrubs with the highest degree of tolerance should be used in the most exposed areas, and those with moderate tolerance (and often increased ornamental characters) should be used in low-salt areas. The intolerant taxa would be restricted to areas where salts are not a problem.

The success or failure of our municipal landscaping programs depends on the use of trees and shrubs tolerant to salt and other pollutants. The mechanisms of plant resistance or susceptibility to salt are related to anatomical, morphological, and physiological considerations *(Bernstein and Hayward 1958, Epstein 1972, Hayward and Bernstein 1958, Sutcliffe 1962)*. A thorough understanding of the factors that govern plant tolerance to salt will permit systematic and organized breeding and selection. Any other approach to a research program will result in wasted time, effort, and money.

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DISEASE STRESSES OF URBAN TREES

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ABSTRACT. The significant causes for disease stresses and decline of trees growing in an urban environment are reviewed. Both the effectiveness of various disease control procedures and the importance of proper tree selection in reducing future tree maintenance are discussed.

THE THREE NATURAL HAZARDS of field-crop production are weather, insects, and diseases. The same hazards are involved in growing and maintaining trees in urban environments. Although the same natural hazards occur in all plant cultivation, urban "tree farming" is complicated by the direct or indirect effects of man's concentrated habitation—his machinery, concrete, and soil disturbance. The fact that urban trees survive in seemingly impossible situations indicates their tenacity and ability to adapt to the many stresses that influence their growth and vigor.

Growing shade and ornamental trees in an urban situation involves planting conditions unfavorable for good growth. Even the native tree species may be regarded as exotic when planted along streets and around homes, because of the many unnatural environmental stresses placed on them. The effects of clay fill, soil compaction, rapid runoff of water, and the reflected heat from buildings and concrete are compounded by insect and disease problems.

This discussion is primarily concerned with significant noninfectious and infectious diseases that cause stress and decline of ornamental and shade trees grown in urban areas. Tree diseases, and all other stress factors, such as insects, mechanical injury, and unfavorable environmental factors, cause physiological stresses of various degrees. The arbitrary fragmentation of stress factors into pathological, entomological, and other types, is unfortunate, as the division gives the impression that these factors operate independently. The total effect of all stresses determines the vigor and ultimate survival of all plants. The evaluation of all potential stress factors must be considered in the selection of tree species for future planting.

EVALUATION OF DISEASE DAMAGE

The International Society of Arboriculture *(1975)* recently published a guide for the professional evaluation of landscape trees, specimen shrubs, and ever-

greens. Most transplantable trees have a replacement value that can be easily established for a particular species and locality. However, because of esthetic qualities, medium- and large-size trees do not have readily ascertainable replacement values and are worth many times the value of similar timber trees growing in the forest. The value of such trees when used in noise abatement, atmospheric purification, screening, and control of solar radiation and wind is difficult to quantify. It is impossible to assess accurately the loss to a community from a devastating disease such as Dutch elm disease. Published figures on losses due to Dutch elm disease have been educated guesses rather than appraisals based on accurate data.

NONINFECTIOUS DISEASES

Environmental Stresses

The importance of several environmental stress factors to predispose plants to disease susceptibility was reviewed by Schoeneweiss *(1975)*. Of all the stresses related to climate, prolonged dry periods and soil-water deficiencies have the greatest effect on the amount of growth a tree produces each year. The cambium growth either slows down or completely stops, depending upon the amount of available soil moisture. Drought will not only affect growth during the current growing season, but can affect growth in later years. A summer drought affects the number of leaf initials formed in new buds, which produce shoot growth in the following year. A reduction in both the number and size of leaves directly affects the amount of carbohydrates and hormones produced the following year *(Kozlowski and Davies 1975)*.

Although there have been periods when only portions of the United States have been affected by drought, there have been years or series of years when drought has been general over the entire continent. Serious droughts occurred in 1749, 1762, 1860, 1925, the 1930s, and 1957 *(Parker 1965)*. General droughts throughout the country are perhaps not as important as sporadic and scattered localized droughts that occur annually.

Frequently, tree declines are associated with excessive soil moisture, due to excessive rainfall, and with prolonged drought periods. Decline and permanent damage to the root system usually results. Some of the major diebacks and declines resulting from too much or too little moisture are birch, sweetgum, maple, and ash dieback; and oak and sycamore decline. A brief description of these follows. For additional information on tree decline, the reader is referred to a paper by Sinclair *(1966)*.

Birch Dieback in Canada

The yellow and paper birch species are affected primarily by diebacks. The symptoms are thinning of the crown and chlorotic and curled leaves. Low precipitation, early March thaw, and high soil temperature have been considered as possible causes for decline *(Braathe 1957, Hawboldt 1947, Redmond 1957)*. Berbee *(1957)* and Clark and Barter *(1958)* believe the disease may be caused by a virus.

Sweetgum Blight in the South

Sweetgum blight appears as a thinning of the crown due to the reduction in the number of active buds and as dwarfed and chlorotic leaves. Prolonged drought periods seem to coincide with periods when disease development is most severe *(Toole and Broadfoot 1959)*.

Maple Blight in the East and North

Maple blight was described by Welch *(1963)* and Hibbin *(1962)* in New York and by Houston *(1962)* in Wisconsin. The first symptoms are the death of terminal buds and dieback of branches. The disease appeared to be associated with insect defoliation in 1956 and 1957 in conjunction with dry summer periods. General recovery occurred in following years.

Ash Dieback in the East

Ash dieback appears as a dieback of twigs, followed by dwarfed and chlorotic foliage and extensive dieback of larger branches. Cankers commonly develop on weakened branches. It is concluded that dieback is induced by periods of low rainfall, with fungi acting as secondary invaders and accelerating the death of affected trees through severe stem and branch cankering *(Ross 1966)*.

Oak Decline in the East and North

Oak decline was first reported to affect scarlet, red, and black oaks in Pennsylvania and West Virginia. The symptoms appear as a general decline and dieback with stunted and chlorotic foliage. Generally, it is believed that this disease is the result of a severe and prolonged drought, associated in most cases with insect defoliation, canker-producing fungi, and bark beetles *(Goddard 1955, Fergus and Ibberson 1956, Gillespie 1956, True and Tryon 1956, Tryon and True 1958)*.

In 1972, there were reports of oak decline occurring in northern Illinois, primarily in the Chicago area. Those species most affected were white, swamp white, bur, red, and black oaks. Along the lake shore north of Chicago, oak decline is believed to be caused by several years of partial to complete spring defoliation by the fall cankerworm. Oak decline was also attributed to excessive rainfall. In widely scattered areas around Chicago and northern Illinois, excessive spring rains for three consecutive years are believed to have damaged the roots of red and white oaks. The weakened trees were then heavily attacked by various species of bark borers (author's unreported observations).

Sycamore Decline

Sycamore decline was first observed in 1961 in the East St. Louis area. The symptoms are a general scorching of leaves followed by extensive dieback over a period of 2 to 4 years. The disease is believed to be caused by the combined effects of several stress factors. Drought, sycamore anthracnose, and air pollution are most likely involved. Canker-producing organisms extensively attack trees under stress and kill the affected trees *(Ricketts 1975)*.

OTHER COMMON STRESS FACTORS

Low-Temperature Injury

Plant tissues may be injured when temperatures drop near or below freezing (32°F). Freezing conditions following a gradual drop in temperature are seldom harmful to most trees after they have started to go dormant in the fall. However, a rapid drop in temperature following a period of mild weather can cause extensive damage. Trees exposed to winds or direct sunlight are more likely to be injured than those in sheltered locations. Low-temperature injury usually occurs on species planted outside their natural range, especially those moved from a mild climate to a severe climate.

A sudden drop in temperature following a warm autumn may cause the death of plant tissues that are not mature enough to withstand freezing conditions. The injured tissue is often confined to succulent shoot growth that is still internally active beyond the point of normal growth cessation. Terminal dieback will become evident the following spring.

Low-temperature injury during the winter dormant season affects the roots, trunk bark, twigs, and vegetative and flower buds. This injury occurs following abnormal warm periods during the winter months. Poor drainage, the genetic character of the root system, lack of snow cover, and soil type are other factors that contribute to root injury during the dormant period.

Frost cracks on trees are caused by the expansion and shrinkage of bark and wood, which cause internal mechanical stress and result in the cracking or splitting of the wood and slipping of bark at the cambium layer. Tree species

commonly affected by frost cracks are London plane, oak, elm, maple, horsechestnut, linden, tuliptree (yellow-poplar), and willow. Frost cracks on London plane trees often reopen when the air temperature falls to 8°F and remain open until temperatures warm in late winter. Usually these cracks never close completely, making entrance easy for insects and wood-rotting fungi and eventually causing deterioration of the heartwood.

Frost-heaving many times affects newly planted trees. Ice formation in the friable soil around and under new trees often displaces or heaves the tree and causes root damage. Displaced trees lean, and the displaced root systems do not settle to their original levels.

Soil Nutrient Deficiencies and Soil Pollution

Of the 16 nutrient elements commonly required for normal tree growth, 9 are required in substantial amounts and 7 are required in relatively small amounts. Abnormal metabolism may result if one or more of the essential elements are lacking, or if they are in abnormally high concentrations in the soil.

Tree nutrition is often emphasized as very important in nursery production, but less emphasis is given after transplanting. Proper nutrition is essential for normal growth and development throughout the entire life of any tree. Tree nurseries are usually located where soils are optimum for rapid tree growth. If nutrient problems occur in the nursery, they are rather easily corrected. However, in larger urban trees, nutrient problems often occur that are both difficult to diagnose and expensive to correct. Deficiencies can often be diagnosed by analyzing plant tissue and soil samples. These methods do have limitations in making accurate diagnoses, since drought, extreme wet weather, leaching, soil type, and pH may affect the validity of the tests.

Factors that regulate the amount of nutrients absorbed by tree roots are concentration of the nutrients, topsoil depth, texture and structure of the soil, type of subsoil, soil pH, and soil compaction. The greater the depth of the topsoil, the greater volume of soil with physical, chemical, and biological characteristics favorable for root growth. Soil texture and structure affect the water-holding capacity, aeration, and nutrient content. Heavy clay soils afford poor water drainage, aeration, and nutrient availability.

The subsoil is important because of its effect on the drainage of gravitational water from the topsoil. A tight heavy subsoil will cause frequent waterlogging of the topsoil during rainy periods. Soil compaction affects both aeration and water infiltration into, and percolation through, the topsoil. Root penetration and development are poor in heavy, compacted, poorly drained soils.

Soils in urban areas, particularly along streets and around homes, are often excellent examples of poor soil conservation and management. The refuse left from basements, foundations, storm sewers, and water- and gas-line excavations is usually spread over the surface. This type of deep subsoil is often heavy clay, variable in nutrients, and low or lacking in organic matter. It usually contains limited amounts of both nitrogen and potassium and can be deficient in several of the other essential elements.

The general symptoms on trees affected by nutrient deficiencies have been discussed by Smith *(1970)*. The nutrient most often lacking in plant growth is nitrogen. There is considerable evidence that under natural conditions most of the nitrogen in the soil accumulates in organic forms from the biological fixation of atmospheric nitrogen. The bulk of the nitrogen absorbed from the soil by plants is stored in decomposed plant material. Microorganisms in the soil must break down plant material into simple inorganic components before the nutrients are reused by trees. When nitrogen is lacking, it causes pale green foliage, stunted top growth, and yellowing or drying of the

older leaves, especially during droughts. Good fall color on maple, oak, and many other tree species is often an indication of nitrogen deficiency and general poor vigor. Maples and oaks that have been fertilized in the spring, and given supplemental watering during dry periods, usually remain green longer in the fall and do not develop good fall coloration.

Chlorosis occurs on several tree species due to the lack of iron, manganese, magnesium, boron, and zinc. The most common deficiency of pin oak, sweetgum, maple, baldcypress, hackberry, white oak, and several other deciduous or evergreen species is the lack of iron or manganese.

Symptoms of iron chlorosis develop on pin oak when the soil pH is 6.7 to slightly more than 7.0. Many pin oaks appear normal for years when not disturbed by construction or other soil disturbance. Lawn fertilization and watering with city water often change the soil pH after a few years. Many fertilizers contain large amounts of calcium carbonate. Although this chemical does move slowly through the soil, frequent applications of calcium carbonate over the years will change the soil pH.

Some pin oaks growing in nursery rows and along streets remain a normal green color while many others become chlorotic. This variation among pin oaks suggests that some genetic difference may occur and that it may be possible to select cultivars tolerant of high pH. Procedures for correcting iron chlorosis have been reported *(Schoeneweiss 1973, Neely 1973, Neely and Schoeneweiss 1974)*.

Stress Caused by Air and Soil Pollution

Nelson *(1967)* estimated that more than 50 percent of the American population live in areas of constant air pollution. All urban trees are living in constant soil or air pollution of one type or another.

Gaseous air pollutants, such as SO_2, halogen compounds, ozone, ethylene gas, and nitrogen oxides cause visible foliage injury to different tree species *(Brandt and Heck 1967, Sinclair and Costonis 1968, Heggestad 1968, U.S. Forest Service 1973)*. Under urban conditions, relatively few investigations have been made on the effects of long-term chronic exposure to low levels of pollutants of the air and soil. Long exposure to various pollutants can cause stresses that reduce growth and vigor.

Natural pollutants such as hydrocarbons from the conifers, methane gas from the marshes, hydrogen sulfide from decaying vegetation, air-borne soil particles, pollen, fungus spores, volcanic dust, and radiation have been in existence during the evolution of trees. For thousands of years, tree species have been naturally selected for surviving the environmental stresses caused by these pollutants.

Published reports indicate that 2,4-D and 2,4,5-T may cause extensive injury to foliage due to aerial drift of the spray and to volatile materials that evolve after application *(Goodwin and Niering 1962, Niering 1959, Phipps 1963)*. Much of the injury was believed to result from improper application and former use of highly volatile forms of the herbicides.

Neely and Crowley *(1974)* reported that, of 11 herbicides commonly used to control weeds in lawns, only dicamba consistently caused phytotoxic symptoms when applied to the soil. No phytotoxicity was observed with the use of bandane, benefin, bensulide, 2,4-D, DCPA, DSMA, siduron, silvex, 2,4,5-T, and trifluralin when applied at three times the recommended rate.

Visible chemical injury on nontarget plants is evident each year, and in 1975 over 10 percent of the tree and shrub specimens sent to the diagnostic laboratory of the Illinois Natural History Survey showed definite symptoms of chemical injury. A high percentage of the chemical injury resulted from the use of weed killers such as 2,4-D in lawn fertilizers and from surface spray applications. Much of the damage is apparently caused by applications that create fine particles easily carried by air movement to nontarget plants.

INFECTIOUS DISEASES

Many good books and circulars review ornamental- and shade-tree diseases for various parts of the country. Many of these publications cover both insect and disease problems. The bibliography lists a few useful as general references *(Carter 1972, Shurtleff 1962, Smith 1970, Wallner 1975, Hepting 1971, Pirone 1970 and 1972)*.

The infectious diseases are often more dramatic and cause specific symptoms that are more easily differentiated from one another than those caused by noninfectious agents. Infectious diseases are caused by fungi, bacteria, viruses, and mycoplasma. More is known about diseases caused by fungi and bacteria than about those caused by viruses and mycoplasma. This does not mean that the latter two agents are less important, but that they are highly specialized fields in which relatively few researchers have worked on specific tree problems.

Many of the important urban tree diseases caused by fungi and bacteria are not serious in forests and wooded areas, and economically important diseases of forests are often not serious in urban areas. White pine blister rust, chestnut blight, and oak wilt are considered serious diseases of the forest in areas where the affected species are the predominant species of the forest. Because of the lack of hosts or of efficient insect vectors, these diseases are usually of little concern in most urban areas.

Vascular Wilt Diseases

Oak wilt has caused loss of some oak trees in suburban areas of the Midwest where new homes have been constructed in stands of native oak. The recreational value of some parks and forest preserves has been lost due to the loss of oaks. Oak wilt is known to affect all species of oaks, but it is most serious among species of the red oak group. Oaks in urban areas do not appear to be threatened by this disease.

Many trees and shrubs are affected by Verticillium wilt, a vascular fungus disease. It is the only vascular disease that affects such a wide variety of unrelated annual and perennial plants. The disease is rare in forest stands, but is becoming increasingly prevalent in ornamental plantings, especially in temperate regions of the world. Presently, 60 tree and shrub species and varieties are known to be susceptible *(Himelick 1969)*. Since there is evidence that the fungus isolates differ in virulence to various hosts, the transporting of infected ornamental plants from one area to another may account for the appearance of the disease in areas where it has not been previously observed. It is likely that the indiscriminant movement of nursery stock from one region to another will eventually cause complete distribution of the more virulent strains to areas where they did not exist before. There appear to be differences in susceptibility within some tree species propagated from seeds—e.g., maple, redbud, and ash. However, the planting of a vegetatively propagated susceptible clone or variety could prove to be a serious problem in areas where the more virulent strains of the fungus occur.

Verticillium wilt symptoms can be difficult to diagnose on some of the less susceptible tree species. Trees weakened by the disease, because of the death of portions of the root system, may be more susceptible to the effects of other stress factors.

Leaf Diseases

Spray control is usually recommended for most leaf diseases to prevent loss in foliage and ornamental appearance. Loss of ornamental effect is often temporary, but loss of foliage, if severe, may have a long-term effect. Synthesis, movement, and storage of food reserves is lowered even in vigorously growing trees *(Parker 1970, Smith 1970)*. Older and less vigorous, slower-growing trees are more seriously affected, since the decrease in growth is often greater the following year. Awareness of the disease susceptibility of

various tree species to leaf diseases will permit proper timing of effective fungicide sprays. Improper timing of spray applications may make them worthless and expensive in time and money. Few leaf and canker diseases, except powdery mildew and scab, can be eradicated by fungicide spraying. Several leaf diseases are erratic in their severity and usually are important if heavy defoliation occurs early in the growing season for two or three consecutive years. Often it is more practical to apply water during drought periods than to spray. Unless trees are low in vigor, they will usually respond well to applications of fertilizer in the spring and supplemental watering during dry periods of the summer.

CONTROL OF INFECTIOUS TREE DISEASES

There are at least four major concepts of control for infectious tree diseases: exclusion, eradication, protection, and resistance. Each of these control procedures is important in limiting tree loss from infectious diseases.

Exclusion

Exclusion refers to control procedures that prevent the movement of plant pathogens or disease agents into areas where they are not known to exist. Seeds and vegetative parts used for reproductive purposes are often treated to prevent the introduction of undesirable organisms into new areas. When symptoms or other signs of infectious organisms are present, the infected plant material can be culled. Disease agents, such as viruses in the seed or other plant material, are easily transmitted in plant material used for propagation and, therefore, are difficult to control. Nursery inspections for certification and state quarantines have been effective in limiting the movement of certain insects and diseases to new areas of the country. United States quarantines are adopted to control the importing and exporting of plant materials, and these materials are subject to inspection and in some cases fumigation before they are shipped.

Eradication

Activities associated with removing or destroying all or parts of an infected tree constitute control by eradication. Destruction of diseased trees, removal of alternate hosts, and chemical therapy are procedures that may be used to control some of the infectious diseases we have in urban situations. Eradication of a canker disease on an individual infected tree is often the primary means of control; however, it may fail if the infectious organism has progressed into the trunk or if the tree is weakened and subject to multiple infections throughout the branches and twigs. Control of Dutch elm disease by eradication of diseased elm trees has contributed to the significant decrease in annual loss in most communities that also spray to control the insect vector. Control of chestnut blight by eradication has not been effective, and all such efforts to lessen tree losses have failed.

Removal of alternate hosts to rusts has not proved practical in urban situations simply because no one wants to destroy an ornamental plant until it is practically dead. If, however, more thought were given to planting, crabapples and hawthorns would be located at greater distances from susceptible junipers, and a reduction in the amount of infection on all hosts would be realized. The judicial use of rust-resistant varieties of crabapples and junipers would help to eliminate the problem.

Chemotherapy is a control method that may be used as an eradicant or a protectant. Various procedures have been used in testing chemicals that inhibit development of a pathogenic agent within a tree. Those procedures that have shown the greatest promise for internal therapy involve either soil injection or direct injection of chemicals into the vascular system. Although entomologists have recommended several systemic chemicals to

control insect pests, plant pathologists have only a few compounds that may be effective chemotherapeutants. There have been many disappointments in the research work with chemotherapeutants, particularly in the systemic control of vascular diseases such as Dutch elm disease, oak wilt, and Verticillium wilt. Research plant pathologists currently working on chemotherapy are still optimistic that compounds such as the solubilized forms of benomyl and TBZ (thiabendazole) may prove to be effective chemotherapeutants, particularly for Dutch elm disease control.

Protection

Fungicide and bactericide sprays often must be used to prevent ornamental loss of leaves and fruit. Complete control of a leaf disease by protective fungicides is seldom achieved, especially during those years when disease incidence is severe. Improper timing of spray application, use of the wrong fungicide, and excessive rain often result in failure to control many tree diseases effectively. Even with the limitations of time and knowledge, spray control should be used if the climatic conditions may be optimum for severe infection and heavy defoliation early in the growing season. I discourage the use of more than two applications of a protective spray, because the limited amount of added protection usually does not justify the added cost of labor and chemical.

Disease Resistance in Plants

Disease-resistant trees can be obtained in several ways. The most common methods used to produce resistant varieties are selection, hybridization, and induced mutations.

A. Selection for disease resistance

Trees resistant to pathogens and pests are likely to be found in regions where the plants originated or subsequently have been grown for a number of years. In such locations, a long association between pathogens and the tree species has occurred, with the consequent elimination of susceptible plant genotypes through natural selection. The relocation of naturally selected disease-resistant trees in other areas may prove that resistance no longer exists because of the presence of different races of the pathogen or different environmental conditions. The tolerance of certain tree species to disease may arise from imperfect synchronization of the pathogen and tree, as in diseases which occur in mature trees. Vigorous young trees may be able to replace diseased leaves or roots and so produce enough food reserves in spite of annually occurring infections. Some leaf diseases may fall into this category; precise knowledge of the injury they cause is lacking, and the injury may be more serious than is generally thought.

A limited list of tree varieties showing resistance to a few diseases was compiled by Stevenson and Jones *(1953)*. Although such a list may be of limited value in ornamental and shade tree breeding, other reports include additional tree species resistant or susceptible to tree diseases *(Gerhold and others 1966, Himelick, 1968, Himelick and Neely 1960, Neely and Himelick 1963, Nichols and Brewer 1973, Smith 1973)*.

B. Hybridization

The progeny from field-grown, disease-resistant plants may show a wide range of resistance and also be unduly susceptible to other pathogens or pests. In such cases a long-term program of plant breeding may be necessary to obtain satisfactory resistant varieties. As Smith *(1970)* pointed out, resistance mechanisms in plants are extremely diverse, and the problems associated with incorporating resistance in plants are complicated by the possibility that the fungus or bacterium can change genetically to circumvent the plant's defense.

Because adequate resistance cannot always be found in natural selections, other sources of resistance have to be used. This problem involves crossing the resis-

tant but perhaps otherwise undesirable trees with susceptible but commercially acceptable varieties in an effort to combine resistance and beauty. This combination has been sought in breeding for resistance to the Dutch elm disease. Crosses have been attempted between the susceptible American elm and certain native, Asiatic, and European elm species that are resistant to the disease *(Smalley and Kais 1966)*.

C. Induced mutations

Inducing mutations is a long-term approach to the problem of finding suitable resistance in tree selections that otherwise have desirable cultural characteristics. Irradiation and chemical mutations have been developed by treating tree seeds and young seedlings. The chances of obtaining resistant mutants would appear very slight unless large numbers of tree selections were tested and a very complicated screening program were designed to obtain the best selections.

A prominent plant pathologist, Dr. J. C. Walker, reviewed the problems and progress in controlling plant diseases by host resistance and the practical application of resistance to problems in horticulture and agriculture. In his summary Walker wrote, "By and large the development of resistant varieties must be looked upon as a continuing program. The potential variability of most pathogens (including viruses) will not permit any currently successful [plant] variety to remain resistant, for an indefinite period" *(Walker 1959)*. Generally his summary reflects the opinion of plant pathologists and breeders alike. This opinion is based on a long history of setbacks in the breeding of resistant varieties. Frequently new varieties have appeared with resistance that at first seemed adequate but later proved not to be long lasting. The resistance was matched with new or previously rare races of the pathogen and was lost. The development of new plant varieties is a continuing program.

In tree breeding and selection we have often stressed the tree species or variety as the principal factor concerned in disease resistance. In actuality three factors are involved and are referred to by Van der Plank *(1968)* as "the disease triangle. A more susceptible host, a more aggressive pathogen, and an environment more favorable to disease all increase disease. It is convenient to call host-pathogen-environment interactions the disease triangle." All three factors affect the rate of infection. The rate of infection summarizes the effects of the genetic resistance of the host, its age and size . . . , the abundance of pathogen inoculum, its virulence and aggressiveness . . . , and the environmental effects; e.g. the rainfall, relative humidity, air temperature, and all other relevant factors.

Before being released for large-scale propagation and planting, new disease-resistant varieties must be adequately tested as to disease resistance and all other desirable or undesirable characteristics. The tests should be carried out over several years and over the range of climatic and urban environmental conditions which the trees are likely to encounter. Their susceptibility to other pathogens and pests, their rate of growth, and their aesthetic qualities should be accurately assessed and recorded. The breeding and testing of resistant varieties of trees should be carried out on a worldwide basis so that maximum advantage can be taken of resistant varieties in as large an area as possible. With increasing understanding of the genetical basis of resistance to pathogens in trees and of virulence in pathogens, disease control by the propagation of resistant tree varieties will become more widespread in the ornamental- and shade-tree industry.

TREE SELECTION AND FUTURE MAINTENANCE

Urban tree selection has changed considerably during the past 30 to 50 years. Elm, pin oak, London plane, American sycamore, and Norway maple were for-

merly the most common species selected. All were relatively easy to transplant and grow and, therefore, represent the most common tree species lining our streets in many parts of the country. Each of these species has serious disease problems that now require high maintenance costs. To reduce these costs, a more scientific selection of tree species is needed.

Arborists, landscapers, and nurserymen realize the importance of proper tree selection in reducing future maintenance costs. Unfortunately, human emotions rather than basic tree information often influence the choices of many city officials as well as homeowners. The rapid loss of elms from Dutch elm disease caused tremendous expenditures to remove dead trees and replant denuded streets—expenditures that strained many municipal budgets. This was especially true in most cities and towns of the Midwest with populations of less than 100,000. Many midwestern cities lost 500 to 2,000 elms a year during the peak spread of Dutch elm disease in the early 1950's to late 1960's. It was not unusual for a moderate-sized city to spend over $100,000 a year removing trees and spraying for control of the elm bark beetle.

Very few of the smaller communities have a tree ordinance to control shade-tree replacement. In many midwestern communities, homeowners have replanted street trees and maintained them at their own expense. Unfortunately, tree selection was left to the discretion of the homeowner.

As an example, in 1950 approximately 52 percent of the total tree population in Urbana, Illinois, were elms *(Carter and Carter 1974)*. Only 15 of the original 4,235 elms are still alive. Many of the trees planted to replace the elms were planted by the homeowners. A 1975 survey of Urbana street trees showed that 80 percent of the tree population (7,322) are composed of 13 species. Five of these 13 species (37 percent) are now serious maintenance problems for the city. Two devastating ice storms in the past 15 years have damaged many silver maples and Siberian elms. The problems of the mimosa webworm and a leafhopper on honeylocust, iron chlorosis of pin oak, and sycamore anthracnose have made those species liabilities to the community.

Midwestern city arborists and homeowners are perplexed by the problems of selecting maintenance-free tree species. There are, in fact, no maintenance-free tree species; but some require less maintenance than others. Many tree species are relatively free of infectious-disease problems but are affected by insect and noninfectious-physiological-disease problems.

At least 10 species have been recommended in Illinois for replacing elms lost to Dutch elm disease. It was further recommended that municipalities avoid planting high percentages of only one or two species to avoid large losses if and when a serious disease or insect epidemic occurs. Experience over the past 25 years has proved that 10 tree species are not enough.

Nurseries are not always able to meet the demand for large numbers of one particular species of the size requested, and inflation has raised the cost of the more desirable species. Although supply and purchase cost are important factors in selecting suitable tree species, the real problem comes in maintaining inferior tree species during their useful life span under average urban environmental conditions.

Of the more than 300 tree species that will grow in most of Illinois, many are useful for ornamental purposes. Approximately 15 species have been widely planted. Table 1 lists species most frequently planted during the past 25 years and the disease and insect problems most commonly associated with them. With the exception of the crabapples and hawthorns, these species should be placed on a restricted list and used only in special cases where no other species can be substituted. Crabapples and hawthorns that are resistant or moderately susceptible to

Table 1.—Disease and insect problems of tree species most frequently planted in the Midwest

Tree species	Problems
Siberian and American elms	Elm leaf beetle, Dutch elm disease, wetwood, and ice-storm damage; phloem necrosis of American elm
Silver maple	Ice-storm damage
Honeylocust	Leafhopper damage, mimosa webworm, and Kaskaskia canker
Pin oak	Chlorosis
American sycamore	Anthracnose, leaf-feeding insects, and decline
White birch	Bronze birch borer
Crab (many species and cultivars) and hawthorn	Scab, rust, fire blight, and powdery mildew
London plane	Canker stain, leaf-feeding insects, frost cracks, and decline

the four diseases listed should be used *(Nichols and Brewer 1973, Smith 1973)*.

If a vascular disease, such as Verticillium wilt, were to become a serious problem in any one area of the country, it could not be eliminated by any known control measure. We will aparently have to live with the problem and hope that future resistant varieties are developed. Randomized planting of susceptible species and limiting each susceptible species to less than 5 percent of the total tree population should provide the most effective means of limiting future tree loss.

CONCLUSION

Stresses placed on urban trees by man equal all natural stresses. Many of the tree problems caused by infectious and noninfectious diseases can be substantially decreased by proper tree selection, planting, and maintenance. The public's desire for quick shade has resulted in the planting of many tree species that require considerable maintenance. We are constantly encountering new disease and insect problems. Many of these problems appear to be developing due to the planting of new tree selections and cultivars in areas where they have not been grown before under urban conditions. Relocating susceptible tree species in areas where infectious organisms exist permits a pathogenic relationship to develop. A natural selection will occur as the resistant trees will survive and the more susceptible trees will die, but this is a very expensive route to travel.

Disease control through development of resistant varieties is an area that needs concentrated and extensive research. The selection, propagation, and breeding of naturally disease-resistant varieties is the most efficient and inexpensive means of disease control. The millions of mature trees growing in our continental urban areas could be evaluated by well planned and coordinated efforts of scientists and other professionals.

The first line of defense against diseases and insect pests starts with the propagation, selection, and planting of tree species and cultivars that do not have chronic problems. Some tree-evaluation studies are presently under way, which will give valuable information on growth characteristics *(Chapin and Kozel 1975)*. Tree selection and evaluation studies should be initiated on a national basis. All aspects of selecting tree cultivars and varieties should be adequately considered and evaluated. Form, rate of growth, and ultimate size are important in proper landscaping. Future studies should include all disciplines involving trees—the professional fields of nursery management, horticulture, genetics, entomology, landscaping, and plant pathology. We must carefully evaluate all factors involved in the planting and maintenance of trees in the urban environment.

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IS HOST RESISTANCE A PRACTICAL GOAL FOR CONTROL OF SHADE-TREE INSECTS?

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ABSTRACT. Breeding for trees resistant to insects is an intriguing but difficult possibility. Some research is necessary in even determining that certain trees possess resistance to specific insects, not some form of pseudoresistance. In view of the pressure for research on other phases of breeding better shade trees, the search for and development of insect resistance will be of low priority. The use of insecticides will continue in the foreseeable future to have the primary role in controlling insect pests on shade trees.

THE IDEA OF UTILIZING natural resistance to insects as one method of developing better trees for metropolitan landscapes is intriguing and promising. The concept is biologically sound, environmentally constructive, and in practice would involve no outlay of operating funds or manpower. It would be an ideal ultimate solution to insect pest problems. But is this method attainable or feasible? If so, how and to what extent can it be achieved with shade or ornamental trees? If not, why not?; and how can valuable tree resources be protected and preserved?

The purpose of this discussion is to evaluate the concept of insect resistance in shade trees in an attempt to answer these questions. It will be of necessity a subjective analysis, since there is a paucity of literature on shade tree resistance to insects. Resistance in agricultural crop plants has been investigated for half a century with some successes. In forestry, research on resistance is more recent and less extensive. The most comprehensive review of the subject is the proceedings of a 1964 symposium on Breeding Pest Resistant Trees *(Gerhold and others 1966)*, including a thorough literature review of resistance to insects in forest trees *(Gerhold 1966)* and an analysis of the present status and future potential of insect resistance in forestry *(Callaham 1966)*.

Although 11 years have elapsed since that symposium, and more people are exploring insect resistance in forest trees, the subject is still in the pioneering stage. Virtually no research has been done with insect resistance in shade trees. In general, there is an urgent need for much more extensive research on shade-tree entomology and the development of a better strategy for protecting ornamental trees from insects. Pursuing the goal of

insect resistance will require long, extensive, and costly experiments.

Insect depredation is a major stress factor for shade trees, not only as a direct threat to health, vigor, and survival, but also when it predisposes trees to other stresses or is superimposed on them. Insect pests occur and multiply wherever trees grow, but it often appears that there are more kinds of pests at higher population levels on urban trees than under forest conditions. Yet, even this phenomenon has not been studied, nor has the economic impact of losses and damage or even the cost of control of shade-tree insects been assessed or tabulated. The monetary value of shade trees themselves is controversial. Thus it is difficult to show in economic terms how urgent the need is for adequate basic and applied research on tree insects even though it is obvious to those who work with them.

Existing methods of insect suppression on shade trees rely primarily on toxicants that are considered hazardous, objectionable to the public, unfavorable to the environment, expensive, and time-consuming to apply. Insect-control measures have been applied intensively to shade trees. Major pests usually require the application of pesticides annually. Minor pests are important and are frequently controlled when they increase to seriously damaging levels in very critical local situations. Moreover, people usually are not willing to tolerate even low populations of pests on valuable landscape plants.

Even with intensive use of insecticides, shade tree insects are highly destructive. Despite on-going control programs for major pests over the past 30 to 50 years, the transmission of Dutch elm disease by elm bark beetles has decimated our elms. The red pine scale has eliminated the use of red pine for watershed protection and ornamental plantings south of its natural range. Honeylocust has become pest-ridden since its general acceptance in widespread landscape use. Pine tip moth is still a scourge of two- and three-needled pines. White peach scale has raised havoc with flowering cherry trees developed for street and park plantings. The gypsy moth has killed thousands of oaks and other trees in the Northeast. During the 1960s in the Buffalo-Niagara Falls area, horned oak gall killed hundreds of pin oak trees. In Virginia and in Philadelphia the hemlock woolly aphid has appeared recently and is spreading. There are many other examples of insect depredation that could be cited, most of which have been given little attention publicly.

There is, therefore, ample justification for investigating new ways to minimize both the destructiveness of insect pests and the widespread use of toxicants. Insect-resistant trees would provide one ideal answer. Considerable research work on agricultural crops has shown that insect resistance can be an effective means of controlling insects. Painter *(1966)* cited a number of successful examples: Hessian fly on wheat, European corn borer, corn earworm, and spotted alfalfa aphid. Gerhold *(1966)* has reviewed and summarized indications of insect resistance and resistance mechanisms that have been reported for forest trees, and Callaham *(1966)* has evaluated their potential.

Theoretically and practically, insect resistance found in forest trees should be equally effective in shade trees. However, most of the forest trees that have been studied, such as black locust, conifers, poplar, walnut, and willow, are avoided or used only occasionally as ornamental trees. Further, it is doubtful that successes like those with agricultural crops could be achieved as rapidly with forest or shade trees. Nonetheless, past achievements have contributed much to our understanding of basic principles, factors and mechanisms of resistance, and research methods. There is an excellent opportunity to explore and investigate this new approach to insect control.

DEFINING RESISTANCE

Insect resistance in its entirety has been treated thoroughly by Painter *(1951)*. He defined resistance as a threefold mechanism. One or a combination of any three elements is present in most cases of resistance that have been well-studied: (1) *non-preference*, plants not selected by insects for oviposition, for feeding, or for shelter; (2) *antibiosis*, an adverse effect of the plant on the insect or on its biology; and (3) *tolerance*, the ability of the plant to withstand infestation, recover, or repair itself to health and vigor.

It is important to distinguish between resistance and pseudoresistance. Pseudoresistance is defined *(Painter 1951)* as apparent resistance in potentially susceptible host plants resulting from (1) *host evasion*, where, for example, the host passes through its susceptible stage at a time when the insects are not active; (2) *induced resistance*, exemplified by growing the host under conditions where insects are not likely to attack it, because they prefer to feed on other available plants; and (3) *escape*, such as a lack of infestation in an ordinarily susceptible host due to temporarily low populations of the pest in the area.

Defining the terms of resistance is a much simpler task than defining resistance as it occurs in trees in nature. Throughout the history of entomology, workers have studied and compiled host-preference lists. Alternate- and multiple-host relationships have been described and related to anatomical, physiological, and biochemical characteristics of plants. Yet there are few records of even apparent resistance to insects in shade trees. The lack is due largely to science rejecting observations of plants *not* attacked as negative data unless compared to those that are attacked. In general, also, tree pests have been studied much less intensively than food-crop pests, so we still do not yet have sufficient understanding of the biology and habits of many shade-tree insects. Painter *(1966)* indicated that it is vitally important to have detailed knowledge about an insect's biology, especially feeding behavior and stimuli to which the insect reacts, to carry on a successful study of resistance.

Defining resistance in shade trees is a complex and difficult problem that requires careful integrated investigations, as the following examples illustrate.

It is a relatively common occurrence that certain individual spruce trees are free of spruce gall aphid even when their branches overlap and are intertwined with infested trees. I have observed this in Massachusetts and New York. Thielges and Campbell *(1972)* reported on studies in progress in Ohio on selecting and breeding spruce to avoid spruce gall aphid. From controlled crosses among three resistant and four susceptible trees, they hoped to test the hypothesis of single-gene control of aphid resistance. They suggested two possibilities to explain the resistance mechanism: (1) physical barriers to aphid stylet penetration on gall-free trees; and (2) chemical compounds produced by the plant in response to stylet penetration that were unfavorable to the aphids. They reported no significant differences between dates of growth initiation of galled and gall-free trees, concluding that gall-free trees are not "escapes" that grow at a time not favorable to the aphid.

However, I observed a situation to the contrary in New York, and it suggests pseudoresistance of the host-evasion type as defined by Painter. Of four large trees in one location, three were infested annually with many galls while one had none. Normally, on the one tree, bud break and new growth occurred later than on the three infested trees. In one of the 5 years of observation, those three trees produced no galls, and the gall-free tree became severely infested. The weather that spring was unusual. New growth of the three trees developed prior to the onset of insect activity, which occurred as the gall-free tree initiated new growth. Until that year the gall-free tree appeared

resistant. This type of resistance, nonetheless, might have some practical value in regulating spruce gall aphid populations.

Vivani *(1966)* cited an example of induced resistance. The leafroller *Byctisus populi* was found to prefer the thin-leaved poplars to the thick-leaved individuals where the two forms were growing together and the insects had a choice. However, when thick-leaved poplars were the only hosts available, they were readily infested by the leafroller. Growing the two types together induced insect "resistance" in the thick-leaved trees.

An example of "escape" pseudoresistance may be explained by mating and "brood" habits of the Japanese beetle. Where numerous kinds of highly susceptible hosts occur together and beetle populations are not high, certain trees may be damaged severely while others escape or have very few beetles. This does not necessarily occur on the same trees each year. Trees appear to be colonized initially at random by the beetles. They attract increasing numbers of adults to their host trees while nearby susceptible plants not occupied are ignored. Thus in any given year those trees that escape infestation might appear to be resistant.

There may be many instances where true genetic resistance to shade-tree insects is exhibited in nature. But they are seldom reported or sufficiently documented. For example, in a devastating infestation of pin and red oaks by horned oak gall in the Buffalo-Niagara Falls area of New York in the 1960s, I observed one live pin oak completely devoid of galls growing among many other oaks dying from contiguous gall formations along all branches and twigs. This tree may have manifested natural resistance to horned oak gall. Painter *(1966)* has stressed that any evidence of resistance in trees will certainly be found during extensive insect outbreaks. For substantiation, however, very careful investigations would be necessary to demonstrate true genetically controlled resistance.

It may be that insect resistance in trees is more real than apparent. Gerhold *(1966)* stated, "the existence of heritable insect resistance (in forest trees) can hardly be doubted, and one gets the impression it can be discovered in any species if only the search is diligent enough"; but he added, "In most cases, the degree of usefulness has yet to be demonstrated, largely because such long and extensive experiments are required." With shade trees, we are still in the earliest stages of finding and identifying insect resistance. Thus, it is most difficult to predict the feasibility of utilizing this as an effective tool in the foreseeable future. I am inclined toward the view of Vivani *(1966)*: "the chance of selecting improved trees for insect resistance is indeed less than it would seem to be on the basis of preliminary observation and consideration."

PROBLEMS IN DEVELOPING RESISTANCE

One limiting factor in finding natural insect resistance in existing shade-tree plantings is horticultural diversity. A wide collection of genera, species, varieties, and cultivars is normal for landscape plantings, including exotic as well as native trees. There are relatively few individuals of any one type to express the genetic potential of the species. Unless the resistance is genetically dominant, occurring in many individuals, it is less likely to be found in existing trees. In contrast, there is more genetic and less horticultural diversity represented in agricultural crop plants and forest trees than in shade trees. Forests and woodlands contain mixtures of mostly native species in stands of many individuals. Forest production tends toward a monoculture of thousands or even millions of seedlings of a species.

In utilizing resistance, once discovered, resistant trees could supplant entire forest stands, but only a relatively small percentage of the total plant materials in

ornamental plantings. However, shade trees have an advantage with the increasing use of selected cultivars. Where insect resistance can be developed, it could be perpetuated indefinitely by vegetative propagation. This is a strong argument for finding and developing resistance even though it would solve only one or a few problems in a vast complex of many. In protecting shade trees, every means of preventing insect depredation is needed. Resistance could be utilized and could help, although it may not be generally applicable as a method of controlling shade-tree insects nor measurably reducing the overall use of toxicants.

A second problem in developing insect resistance in shade trees is the diversity in the insect fauna. Each kind of shade tree has a complex of major and minor pests associated with it. Trees such as elm and oak, which have been grown widely for centuries, have long lists of associated pests. As new trees come into general use, the list of pests grows with time and the number of plantings. Thornless honeylocust serves as a good example. Initially it was relatively pest-free, but common problems now include mimosa webworm, pod gall midge, honeylocust mite, thornbug, an eriophyid mite, and, more recently, honeylocust plant bug. Developing resistant trees against major pests case by case is helpful, but it is safe to assume that trees resistant to one pest may be susceptible to other pests. Borrowing an example from plant-disease studies, elms selected and propagated for resistance to Dutch elm disease have been all but eliminated by phloem necrosis where it has occurred.

Another problem in studying resistance is the fluctuation of major and minor pests of shade trees in time or space. They may fluctuate also due to changes in cultural practices. For example, European elm scale was a serious problem on elm prior to the use of DDT for elm leaf beetle and elm bark beetle control, yet was almost nonexistent on sprayed trees until DDT was banned. At the same time, the use of DDT resulted in severe damage by mites and aphids, which were minor pests prior to the DDT era.

Insect pests also fluctuate due to the kinds of trees that are planted. On new plant introductions, endemic or even rare pests may increase to become major problems. For example, when red pine was planted south of its natural range in Connecticut, New York, and New Jersey, the red pine scale developed to devastating proportions. No pesticidal control was found or developed, and red pine was eliminated by cutting and burning. In California, Indian laurel fig was introduced by the nursery trade as an ideal tree for urban planting. Subsequently the Cuban laurel thrips become a problem. It was 3 years before control measures were developed *(Bell 1969)*. Many more similar examples could be cited.

Fluctuations in the distribution and spread of endemic species will occur as man continues to transport them to new geographical habitats throughout the world; thus, new pest problems can be expected on already existing plants in any given area. The rate of fluctuation could certainly be expected to change more rapidly than the long slow process of developing insect resistance pest by pest and host by host. A period of many years and a great deal of research are required for implementation of insect resistance to displace significantly the need for insecticides. However, over an extended period of time, the development of insect resistance could alleviate some of the pest problems that afflict shade trees and eventually reduce some uses of chemicals.

A theoretical consideration in a study of resistance is the genetic ability that insect populations have to adapt and evolve their physiology and behavior. Over the 100- to 200-year lifespan of some shade trees, such evolution is likely to be expressed. Should resistance to one species of insect be established genetically within a host plant, vegetative propagation of the cultivar would theoretically preserve the genetic resistance in the tree.

The insect, however, living on other nonresistant individuals of the host, would genetically have the capability for change and adaptability, suggesting that the resistance in the tree might be of limited duration. However, Painter *(1951)* has cited cases to indicate that resistance should be permanent. Yet Campbell *(1966)* reported an interesting study with the forest tent caterpillar, providing evidence that physiological-genetic diversities in feeding do occur in the Lepidoptera. Along with reference to earlier work on spruce budworm, he showed that large variations in certain physiological characters of the insect were controlled genetically and were fundamental to numerical fluctuations in the insect populations.

One of the most critical factors limiting the development of insect resistance as a practical approach to insect control is the lack of sufficient research resources. Current manpower and funding are minimal even for investigating existing insect problems *(Weidhaas 1972, Campbell 1974)*. It is essential to provide remedies for insects that are already causing damage and are a threat to established shade trees. Yet there is a need for long-range innovative research on basic problems and the development of new methods and approaches to pest problems.

The impact of the newly amended federal pesticide law (FIFRA) has greatly aggravated the situation. Many pests no longer can be treated with insecticides that have been used effectively and safely for many years. New control measures must be developed to fill the void. Thus existing research resources must be applied to solving immediate critical problems.Where then will the manpower and financial support be found to study the intricacies and complexities of insect resistance where applicable results can hardly be expected until some distant time in the future? Which agencies or institutions are willing to support the long-range research needed to develop resistance? More practically, who would be willing to commit a career to research that might require 15 to 50 years of effort to show meaningful results, when professional and peer status, salaries, and promotions are evaluated on the basis of prolific publication of immediately applicable results from 3- to 5-year research programs?

SUMMARY AND CONCLUSIONS

Theoretically, host resistance to insects is an ideal method for protecting long-lived valuable shade and ornamental trees in metropolitan landscapes. Realistically, it is a promising goal for the future much like the use of parasites and predators, pheromones, juvenile hormones, attractants and repellents, and certain cultural practices. Practically, in view of existing and foreseeable research resources, it is attainable only to the extent that a few individual cases of resistance may be developed and utilized in the future through on-going research programs.

There are indications that resistance to insects does occur in shade trees. There is evidence of resistance, and resistance mechanisms have been described, in forest trees. In agricultural production there have been some successes in applying host resistance. Therefore, there is promise of developing resistance to insects in shade trees. However, where host resistance has been successful in agriculture, the unit value of the crops has been small and the acreage large *(Painter 1951)*. With shade trees, the unit value is high and the acreage, or number of individual trees, is relatively low. In more than 50 years of research with agricultural crops, successes have been relatively few. Host resistance to shade-tree insects has yet to be discovered and described. The finding and development of resistance to the point where it can be applied in pest-management practice for shade trees is an extensive long-range research process.

Practically, utilization of insect resistance does not appear to be feasible as a major method of controlling insects nor a means of reducing measurably the over-

all use of toxicants. Current research resources for entomology are already woefully inadequate to meet the needs of ongoing programs and to solve immediate insect problems. Insect resistance has been historically of very low priority in tree-selection and breeding programs. Research efforts have been and now are aimed primarily at esthetic values of form, color, flowering, size, and the like; functional values such as shade, noise abatement, pollution abatement, and screening; and adaptation or tolerance to climatic, edaphic, and architectural influences. The diversity of plant materials and the vast array of insect species associated with them are awesome. Since insects are one of the more readily controllable stress elements in urban areas, perhaps assigning low priority to resistance to insects in research is appropriate and acceptable. If so, we must rely primarily on insecticides and continue to develop their effective and safe use. It is essential to protect and preserve existing trees and those better trees developed in tree selection and breeding research.

As arboricultural research moves forward, however, insect resistance should be explored and included in investigations wherever possible. Great strides have been made in genetics, biochemistry, ecology, population dynamics, and improved plant materials for landscapes. There is an opportunity, through existing integrated research programs, to explore insect resistance in shade trees and gradually acquire basic information. We hope that adequate research will be forthcoming to carry on the long-range development of insect resistance in the future as a supplemental method in pest management. In the meantime, indications and observations of potential insect resistance in shade trees should be recorded, studied, evaluated, and reported. Existing research programs on tree improvement, selection, and breeding should include observations and studies of potential resistance to insects. At least, when new varieties and cultivars are developed, they should be evaluated in relation to their susceptibility to major insect pests.

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A LANDSCAPE ARCHITECT'S VIEW OF BETTER TREES FOR URBAN SPACES

by PAUL GARDESCU, *Landscape Architect and President, Sasaki Associates, Inc., 64 Pleasant Street, Watertown, Mass.*

ABSTRACT. Urban landscape architecture has a strong tradition for the importance of planted open space as an integral part of the city. There is also a strong tradition relating the city landscape to the surrounding region through the use of indigenous plant material. Trees are used as a design material in creating landscaped space. Tree selection is made for overall effect rather than individual characteristics. Plant lists, a primary source of information for the landscape architect, in general do not include cultivars or clones. An overriding factor, however, is availability of quality material. The emphasis in providing better trees for urban spaces is on improved growth and handling of suitable trees rather than on development of additional cultivars.

IN DESIGNING WITH TREES for urban areas, the landscape architect draws on a tradition that underscores the importance of the planted landscape as a complement to the constructed urban world. There is also a strong tradition of recognizing the natural features of an area and of trees indigenous to a region. This tradition reaches beyond the mere use of planting for embellishment and fascination with the exotic by relating the city open space with that of the surrounding natural countryside.

The use of trees in the urban area is related to the nature of the space and activities that take place. These areas range from large parks or natural preserves to plazas and tops of structures. The sources of information about trees, the quality and quantity of available material, and the landscape construction industry strongly dictate the selection and use of trees.

Selection of particular tree species or cultivars is of secondary priority in the design process, coming after consideration of overall effect, creation of site conditions that mollify the horticultural drawbacks of urban sites, and the obtaining of well-grown material.

As a general thesis, I propose that using better trees for urban areas involves, first, better growing and handling of known varieties, and second, the development of new cultivars.

A landscape architect looks at trees in the city from a point of view somewhat different from those of the horticulturist and the arborist. In large part this stems from the landscape architect's concern with space as a central element of de-

sign, trees being one of the materials to be used.

HERITAGE OF LANDSCAPE DESIGN

In making judgments, I find it interesting to compare views held 50 and 100 years ago. Consider the views of that mentor of American landscape architects, Frederick Law Olmsted. A hundred years ago this designer of Central Park proclaimed the major role that landscaped parks, drives, and streets had in creating a beneficial urban world. In 1870 he wrote:

> "The park should, as far as possible, complement the town. Openness is the one thing you cannot get in buildings... We want a ground to which people may easily go after their day's work is done, and where they may stroll for an hour, seeing, hearing, and feeling nothing of the bustle and jar of the streets, where they shall, in effect, find the city put far away from them. We want the greatest possible contrast with the streets and the shops and the rooms of the town which will be consistent with convenience and the preservation of good order and neatness. We want, especially, the greatest possible contrast with the restraining and confining conditions of the town, those conditions which compel us to walk circumspectly, watchfully, jealously, which compel us to look closely upon others, without sympathy. Practically, what we want most is a simple, broad, open space of clean greensward, with sufficient play of surface and a sufficient number of trees about it to supply a variety of light and shade. This we want as a central feature. We want depth of wood enough about it not only for comfort in hot weather, but to completely shut out the city from our landscapes."

The rural and pastoral landscape was not anti-urban in concept, but was conceived as a necessary foil to urban activity and, more important, such landscapes were to be integrated into the fabric of the city.

Related to this advocacy of public parks was a call for planted streets. Olmsted *(1870)* wrote:

> "The change both of scene and of air which would be obtained by people engaged for the most part in the necessarily confined interior commercial parts of the town, on passing into a street of this character after the trees had become stately and graceful, would be worth a good deal. If such streets were made still broader in some parts, with spacious malls, the advantage would be increased. If each of them were given the proper capacity, and laid out with laterals and connections in suitable directions to serve as a convenient trunk line of communication between two large districts of the town or the business centre and the suburbs, a very great number of people might thus be placed every day under influences counteracting those with which we desire to contend."

Going back a bit farther, we find that great horticulturist and landscape gardener, Andrew Jackson Downing, championing American trees for American cities. In promoting a knowledge of beautiful trees and plants, Downing *(1851)* called attention to: (1) "what private individuals may do"; (2) "what the nurserymen may do"; and (3) "what the Horticultural Societies may do." He also espoused an avoidance of those foreign fads, the "odorous ailanthuses and filthy poplars" *(1852)*. He praised the American elm and silver maple with these words *(1847)*:

> "They have, to recommend them, in the first place, great rapidity of growth; in the second place, the graceful forms which they assume; in the third place, abundance of fine foliage; and lastly, the capacity of adapting themselves to almost every soil where trees will thrive at all." He went on to say: "Select the finest indigenous tree or trees; such as the soil and climate of the place will bring to the highest perfection. Thus if it were a neighborhood where elm flourished peculiarly well, or the maple, or the beech, we would directly adopt the tree indicated."

The sugar maple, native oaks, tuliptree, linden and magnolia are all cited for "a grand and striking effect." Great thoughts, no fussing with purple- or yellow-leaved genetic sports, no meager apologies for trees to cower under the omnipotent power lines.

Both Olmsted and Downing thought large and laid claim to plan and plant landscapes that would have a grand scale as part of a city. They recognized the use of trees for form-giving and ornamental effect, and the need to balance these two aspects.

In present practice, this sense of the

urban scale is what often separates the professional and the amateur. The landscape architect may analyze a situation and conclude that it needs the unification of a line or group of dense-headed shade trees. The garden club or even the horticulturist might only see the chance to embellish an area with a collection of ornamental novelties.

RECENT LITERATURE ON DESIGN OF URBAN SPACES

If you cannot get hold of a good live landscape architect to declaim on the professional mysteries, there are several good discussions of the contemporary landscape architects' approach to design of urban spaces that put tree selection into perspective. Two outstanding books on the subject are Lawrence Halprin's *Cities (1972)* and Robert L. Zion's *Trees for Architecture and the Landscape (1968)*.

Halprin's book treats the whole gamut of urban landscape design. Green space is seen by him as contact with nature, which everyone should be able to enjoy, and open space as a key element in providing an environment for ". . . those chance occurrences and happenings which are so vital to be aware of—the strange and beautiful which no fixed, preconceived order can produce. A city is a complex series of events."

Halprin touches on the formal and naturalistic uses of trees and the special techniques employed in planting, protecting, and maintaining trees in paved spaces. He lists twelve trees for use in the city. Replete with photographs, Halprin's book is an excellent exposition of contemporary urban landscape design. It clearly illustrates the use of trees as a design material, and as only one of the many materials to be considered in the design of an urban space. Hence, it underscores a very basic attitude towards the selection of trees.

Robert Zion's book is—as its title, *Trees for Architecture and the Landscape*, notes—focused on trees. Though it only touches design issues, it is a complete compendium on tree selection. After illustrating the seasonal character of some 55 trees in (rural situations), he covers practical considerations, including protection of existing trees, buying and planting trees, and the special considerations for street trees, rooftop planting, and other special effects. He discusses design considerations noting:

> "If one general or all-inclusive counsel is to be set down here for the layman, it is this: *it is essential to keep the tree in its proper perspective*; it is not the essence of landscape architecture and should be regarded only as an embellishment—as furniture with which an outdoor room can be enhanced. Without denying the beauty and fascination of the tree in the landscape, the laymen should be cautioned against confusing the tree with the design itself."

Zion then provides design data for some 50 trees, many shown at commercial nursery size. A limited number of cultivars are noted in the discussion of species. The last section of Zion's book is a list of trees organized by states and classified by various design attributes. The classifications include "Trees for the City," categorized for usefulness by "For Wide Streets," "For Medium Streets," and "For Suburban Streets." The lists are extensive, although some selections are not commercially available. They give, however, a good sense of the very large range of material available even for the rigors of the city site.

In addition to the urban design considerations noted above, there are many studies on environmental considerations and on public policy dealing with trees. An example of the first is the recent *Plants/People and Environmental Quality*, by Gary Robinette *(1972)*, published by the U.S. Department of Interior. This includes an extensive bibliography and covers the whole range of environmental effects on and by trees. Surprisingly, however, it does not include lists of trees for urban areas. In the public policy domain there is the excellent monograph, *Trees in the City*, prepared by Charlotte Bingham for the American Society of Planning

Officials *(1968)*. It covers municipal regulations and planning as well as promotion of planting, and has a good but brief coverage of the public aspects.

LANDSCAPE ARCHITECTS' SELECTION OF TREES

This brief survey of design literature leads into a key factor of the basis for tree selection by landscape architects—that is, where does he get information? Obviously, landscape education lays a foundation, and particular office practice provides further guidance. As noted above, however, tree selection is but a small part of the many complex considerations in the design of urban landscape. Therefore, reference books, articles, and information from state agencies and private institutions form a significant source of specific additional information.

The sources of information are limited. Depending upon one's education, Donald Wyman's *Trees for American Gardens (1965)*, or other lists, are used for handy reference. There are also many special lists such as those published by power companies, directed at certain specific goals such as trees that are compatible with overhead power lines. Local state and city agencies and arboretums are consulted as to their recommendations. Our own office practice supplements this with field surveys of a metropolitan area to see what has been proven to do well and what shows chronic problems.

A useful way of reviewing the current basis for urban-tree selection is to compare a few of the current published lists. A detailed review of such lists will not only identify specific reccomendations but also reveal in part how material is categorized, hence, thought about. Size, form, soil tolerance, shade tolerance, hardiness, and various ornamental characteristics are classifications usually used. In my table showing brief comparisons of some available lists, these classifications have been omitted for brevity.

In comparing lists, we quickly see the trees commonly recognized as suitable for urban use and the vastly larger group of limited recommendation. Admittedly, my table mixes lists prepared for regions with ones with national coverage. Also, one list will include cultivars by name while another will note that selected cultivars should be used without giving specific names. Much of the more exotic material is, in fact, not commercially available. The purpose of such a tabular comparison, however, is to demonstrate the fairly wide range of material available for consideration and incidentally the diversity of opinion that is expressed through the recommendations in such lists.

In plant selection there are certain methodologies that imply that choices can be almost entirely a deductive process. The assumption is: if the input criteria are sufficient, there are one, two, or three trees that will come out of card-sorted characteristics. I happen to believe that selection for good planting design is much more an inductive and associative art, and that classification by characteristics can only be used as a first rough-sorting technique.

In my table the entries in the first column are from Donald Wyman's *Trees for American Gardens*, which is a standard reference because of the generally useful descriptions. Though it does list cultivars, the supply of these is limited. His cross-classification by form, color, special uses, etc. is helpful in reminding one of additional trees that might be considered. It is also a reference easily available. In my table only the "Trees that Withstand City Conditions" are included. His additional lists for planting along streets and in other areas provide more material for consideration, but I have arbitrarily omitted his recommendations for the other situations in this comparison.

Entries in the next column are from another extensive reference, the recent monograph *Transit Planting: A Manual* by The American Horticultural Society.

Table 1.—Number of species and clones recommended within selected genera as urban trees—by different authors

Genus	Number of species and clones[1] recommended by—							
	Wyman	Am. Hort. Soc.	Zion	Halprin	Taylor	Enright	Bartlett	Boston Edison
Abies	1	2	—	—	—	—	—	—
Acer	5	5	1	1	2	2	5	8
Aesculus	1	2	1	1	—	—	—	—
Ailanthus	1	—	1	1	1	1	—	—
Albizzia	1	—	—	—	—	—	—	—
Amelanchier	1	1	—	—	—	—	—	1
Aralia	1	—	—	—	—	—	—	—
Araucaria	—	1	—	—	—	—	—	—
Bauhinia	—	1	—	—	—	—	—	—
Betula	—	3	—	—	—	—	—	—
Brassaia	—	1	—	—	—	—	—	—
Carpinus	—	2	1	1	—	—	2	2
Carya	—	1	—	—	—	—	—	—
Catalpa	1	1	—	—	—	2	—	—
Celtis	1+	3	—	—	1	1	—	—
Cendrela	1	—	—	—	—	—	—	—
Cercis	—	—	—	—	—	1	—	1
Ceratonia	—	1	—	—	—	—	—	—
Cladrastis	—	—	—	—	—	—	—	1
Cornus	—	2	—	—	—	2	1	4
Crataegus	3	—	3	—	—	3	2	2
Diospyros	—	—	1	—	—	—	—	—
Elaeagnus	1	—	—	—	—	—	—	1
Euonymus	1	—	—	—	—	—	—	—
Ficus	—	1	—	—	—	—	—	—
Fraxinus	3	2	1	1	4	2	2	1
Ginkgo	1	1	1	1	1	1	2	—
Gleditsia	1	1	1	1	—	2	1	1
Gymnocladus	—	—	—	—	—	1	—	—
Halesia	—	1	—	—	—	—	—	1
Ilex	—	2	—	—	—	—	—	—
Juglans	—	1	—	—	—	—	—	—
Koelreuteria	1	2	—	—	—	—	1	—
Larix	—	2	—	—	—	—	—	—
Liquidambar	—	1	—	—	1	—	—	—
Liriodendron	—	—	—	—	1	—	—	—
Magnolia	3	2	—	—	—	1	—	—
Malus	1+	1+	1+	—	—	17	3	4
Melia	1	—	—	—	—	—	—	—
Metrosideros	—	1	—	—	—	—	—	—
Morus	—	—	1	—	—	—	—	—
Nyssa	—	—	—	—	—	—	—	1
Olea	—	1	—	—	—	—	—	—
Ostrya	—	1	—	—	—	—	1	1
Phellodendron	—	1	—	—	1	1	1	1
Picea	1	3	—	—	—	—	—	—
Pinus	—	5	—	—	—	—	—	—
Pittosporum	—	1	—	—	—	—	—	—
Platanus	1+	—	1	1	1	3	1	1
Populus	3	5	3	—	—	1	—	—
Prunus	—	4	—	—	—	2	2	2
Pyrus	—	1	1	—	—	1	1	—
Quercus	3	5	1	1	4	1	8	2
Rhamnus	1	1	—	—	—	—	—	—
Robinia	1	—	1	—	—	—	—	1
Salix	—	4	1	1	—	—	—	—
Sophora	1	1	—	—	—	—	1	1
Sorbus	—	—	—	—	—	—	—	2
Syringa	—	1	—	—	—	—	—	—
Tilia	2	2	1	1	3	1	2	2
Tsuga	1	—	—	—	—	—	—	—
Ulmus	5	2	1	—	2	3	1	—
Zelkova	—	1	1	1	—	—	1	1

[1] Where authors are indefinite but apparently recommend more than one species, 1+ is shown.

It lists trees, shrubs, and ground covers suitable for urban conditions, with classifications by climate zone as well as by size, growth rate, form, features, and special characteristics.

Following these are three short lists comprising recommendations of Zion, Halprin, and A. D. Taylor. Taylor's work, though over 50 years old, still is one of the most comprehensive and commonsense works on landscape gardening *(1921)*.

The next recommendations are from L. Enright's *Woody Plants for Landscape Use*, a typical working list useful for quick office reference *(1955)*.

The recommendations made in the *Street Trees Study for the District of Columbia*, by F. A. Bartlett Tree Expert Company, is an example of a list developed around the experience of a particular locality.

The final listing from *Trees in Your Community* is representative of handbooks provided by public service companies, and includes some species not strictly suitable for urban conditions.

These lists demonstrate somewhat differing approaches in tree selection. Taylor and Halprin list the best few. This is an approach used by our own office, and it is reinforced by the generally limited supply of quality nursery material. The American Horticultural Society, Wyman, and Zion provide extensive lists and, as previously mentioned, some selections are not readily available. Enright's and Bartlett's lists are perhaps mid-range, and typify working lists used in the practice. All lists, of course, reflect selections in response to the horticultural problems of urban areas. There is a lack of usable evergreens. There is the lack of an equivalent for a large canopy tree to replace the American elm (Zion, like Downing, recognizes the design equivalency of the silver maple, provided the location is suitable to the weak-wood characteristic). The other feature worth noting is that, unlike much of the periodic literature, the lists generally do not name cultivars. Wyman discusses cultivars to a limited extent in his text, but generally does not cover clones and varieties. This has the effect, of course, of not suggesting the use of cultivars even when they are readily available.

AVAILABILITY OF QUALITY TREES

There is perhaps an even more fundamental problem. Availability and quality are factors overruling recommendations in the various lists.

In most urban landscape situations, larger material must be used not only because it is expected to provide immediate effect, but because it is less subject to vandalism than small material. In addition, because maintenance by knowledgeable staff is very hard to get, trees that require a minimum of care need to be selected. Hence, trees of neat or predictable habit and well-formed through good nursery handling are mandatory.

Contractors' opinions are sought, and nurseries are checked both for information and for available stock. An early lesson is that the best academic advice is no help if no one can supply a given species in the size desired. The design process often requires contracting for trees that may be planted for one to several years later. This creates additional problems whether one wishes to obtain matched specimens or ornamental specimens.

However, in the selection process, the overall effect is most often of first priority, and not the use of a specific tree. At this point landscape architects can make arborists and horticulturists wince by their apparently casual attitude toward developed clones or even species—because the desire for matched blocks or for a well-formed tree (achieved through good nursery practices) often overrides considerations even of species selection.

I have seen professional park people bewildered by a landscape architect switching, for example, from maple to oak for a street planting because available maples were narrow, crowded, and poorly

branched while there existed a well-branched, evenly matched block of oaks. In addition, the need to get large quantities of sizable trees through public bidding thwarts the consideration of using selected clones or varieties. This does not mean that the landscape architect is indifferent to the selection of better trees, but that he often has other things of greater importance to consider.

It is hard to emphasize sufficiently the problems of good nursery practice. Rapid turnover is a key element to commercial success, hence the large volume of builders' plants. These are the quick-growing, easy-to-propagate materials. On the other hand, it is disheartening to see beeches or tea crabapples so butchered by unskilled pruning that Norway maples or 'Almey' crabapples become the best selection of the day.

In a way there remains the need to develop trees with good form and naturally balanced habit of branching, both of formal and informal character. As an example, honey locusts not prone to narrow-crotched double-leaders would provide many more quality trees. But when one sees a good ornamental pruned to branch from one place like a pollarded willow, it eclipses all thought of developing better forms of trees, and underscores the need to get better nursery practice.

Likewise, nursery practice often leaves only a few trees of medium to large size that are not stunted by crowding. If the project warrants large material, there is often the problem that the only sources are the culls left over as blocks were sold. This type of problem becomes a major consideration in the actual execution of the work.

CONCLUSION

In summary, this landscape architect's view is that—while there is obviously the desire to develop new cultivars—there is a far greater need to grow and market good-quality stock of already known species and cultivars. This is said to emphasize where the problems lie in supplying and selecting trees for urban landscapes.

One last aspect is worth noting. There is very little practical documentation dealing with special urban problems of tree growth. As an example, while container planting has been done for centuries, there is little applied research dealing with root-pruning or other maintenance techniques for trees in contained areas. Another problem deals with limited soil depth such as is encountered when planting over structures. Issues of providing a separate layer of drainage material or the use of a specially designed mix for areas as shallow as 12 to 18 inches could be immeasurably clarified by practical field research. This suggests that there is a special branch of urban horticulture that is in great need of collaboration among landscape architects, arborists, and horticulturists.

Urban areas must be planned and designed so they are hospitable to the growth of plants. Trees that will flourish or at least thrive under urban conditions must be identified, and their proper propagation and growth must be encouraged. Effective use of trees at an urban scale will continue to derive from a detailed experience with what will prosper, but their use will give us that experience with nature we all should have the opportunity to enjoy.

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DESIGN CONSIDERATIONS IN THE SELECTION OF CULTIVARS FOR METROPOLITAN HIGHWAYS

by JOHN J. RYAN, *Director, Landscaping Bureau, New York Department of Transportation, Albany, New York*

ABSTRACT. The role of the highway landscape designer in developing appropriate plans for tree planting along metropolitan highways is discussed. The need to determine design objectives for each project is emphasized, and the design and visual considerations that must be taken in account for such a determination are explored.

THE NEED FOR TREES

THERE IS A NEED for beauty in our lives that is just as essential to our spiritual and mental well-being as proper nutrition and clean air are to our physical well-being.

Thomas Jefferson, a man of wide-ranging interests, said: "Communities should be planned with an eye to the effect made on the human spirit by being continually surrounded by a maximum of beauty." This is a wonderful guide for us in our efforts to ensure that trees make a major contribution to beauty in our communities.

While trees are but one of the many things that hold beauty for mankind, they are undoubtedly one of the most important. They are beautiful and effective in various ways all seasons of the year. We can feel a relationship with trees—and a large tree doesn't overwhelm us the way a large or tall building does, because trees are on a human scale.

One of the many desirable attributes of a tree is its summer shade. This is different from the shade of anything else. It is constantly changing and has a filtered, light quality of immense esthetic appeal —particularly in urban areas where shade is often the heavy, solid shade cast by buildings.

In winter, the structure of the deciduous tree is revealed. You can see the trunk, the branches, the minor branches, and the twigs. Together they present a beautiful outline against the sky. One of winter's most delightful sights is a tree with snow lodged on its branches and twigs.

In spring, all deciduous trees have an appealing cover of unfurling, light green leaves. Then people are particularly glad to see this never-failing indicator of real spring. In the autumn, most deciduous trees indicate the passing of the season by changes in leaf color, some of which are spectacular and a source of joy.

THE ROLE OF THE HIGHWAY LANDSCAPE DESIGNER

While developing an outline for this paper, I found that I couldn't present a well-rounded view of the highway landscape designer's function without straying into other fields or disciplines. I do not apologize for this. I believe that this is essential to demonstrate that solutions of the problems we are discussing are facilitated by an understanding of, and collaboration with, other relevant fields and disciplines. We are engaged in what must be considered as a team effort, and all of the several professional fields involved have important contributions to make.

The highway landscape designer should have, as his major objective, the esthetic improvement of the highway right-of-way and its adjacent areas. Beauty should be consciously sought, and appropriate design decisions made, in light of this objective. While trees will be of primary importance in these efforts, the providing of adequate space in which to plant is of equal importance.

In addition to concern for landscape matters, the highway landscape designer may also contribute to the highway design in such matters as the amount of right-of-way needed for effective landscape treatment, the slope ratio of cuts or fills, the treatment of retaining walls, the retention of parcels unneeded for actual highway construction and similar problems. Occasionally there will be an opportunity to preserve existing mature trees and so retain major landscape components.

The highway landscape designer must keep eight basic considerations in mind. All, with the exception of the first, are of equal importance in arriving at an optimum solution.

1. The overriding consideration in any highway landscape work is the *safety* of the highway user. This consideration is reflected by the appropriate setbacks of trees for the several classes of highways of varying legal speed limits, vertical and horizontal sight distances, and related engineering matters.
2. The designer is usually working in what might be called a horticulturally hostile environment and must do whatever is possible to lessen its influence.
3. The motorist using the highway who sees, or more accurately is aware of, the highway landscape treatment is driving between 30 and 55 mph and cannot be expected to be sensitive to fine detail or subtle effects. What he sees or is aware of are masses of trees or foliage and the space between the roadway and the planting. It would be doing the motorist a disservice to distract his attention with a spectacular floral display, although touches of color add to the subliminal effect of the landscape. In contrast, landscaping of rest areas can give greater attention to detailed effects.
4. The effect of the landscape work on the residents adjacent to the urban highway, or on the people employed along the area, must be taken into account. The pedestrians who use the sidewalks along the highway or on adjoining streets are also affected by the landscape development.
5. The designer must consider and evaluate the needs and potentialities of the area he is working on. Often the trees and other landscape elements comprise the only landscape in the area and are extremely important because of this.
6. The designer should consider alternate concepts for the landscape treatment of the highway right-of-way.
7. Appropriate contacts with the local governmental units must be made so that plans are developed with their knowledge and cooperation.
8. The project must be oriented to people —whether motorists, pedestrians, or adjacent residents.

Hopefully, as the above considerations are studied and determinations made, the designer will coincidentally start to develop a rational system for the selection of trees for the project rather than turning to lists or depending on personal likes or dislikes.

GOVERNMENT POLICY DECISIONS AND FUNDING

All present here today are undoubtedly in favor of planting our urban highways. We can talk and talk, but nothing is going to happen until the appropriate government unit adopts and implements a policy of landscape development. A number, probably the majority, of the government units who build urban highways have already developed a policy of highway landscape development. When federal aid is involved, appropriate planting is encouraged by the Federal Government, but it is still up to the local government unit to decide how to use its highway funds.

Where there is no policy on the matter, and planting is not done, the community involved should demand a policy of appropriate landscape development and implementation of that policy. This policy should also provide for maintenance as well as for capital construction.

The funding of the work varies with the individual projects, and the only hard and fast suggestion which can be made is that the landscape development be funded in the same manner as the highway.

The project budget is best determined after some early preliminary planning. This will insure that there will be adequate funding for the level of development sought. Except in very unusual situations, no advanced or detailed planning should be done until the sources and amount of funding has been determined.

RELATIONSHIP BETWEEN CLASSES OF HIGHWAYS

In the context of this discussion, the highway landscape designer must deal with two basic classes of highways: the suburban highway, and the urban expressway or arterial together with its service roads. The importance of the urban highways is overriding, but there must be recognition of the necessity for appropriate landscape treatment of the suburban highways and of portions of rural roads. The need for continuity of design between the two classes of highways must be recognized. This transition zone requires special recognition and treatment.

In the majority of situations along rural highways leading into the suburban and urban highways, there is no need for planting—except perhaps at interchanges and a few special situations. Proper mowing patterns and the natural regeneration of woody plants will provide exactly what is best. The most important thing here, and in urban areas too, is to remember that nature has veto power over anything we do.

DESIGN AND VISUAL CONSIDERATIONS

After the decision to provide landscaping, the development of design concept alternatives should be the starting point of design for all projects. Occasionally this study will indicate that no planting is feasible for part or all of a project—due to costs, extremely harsh or hostile environment, or the potential for natural regeneration.

The designer should determine the effect he wishes to create on the site available to him and assemble his objectives and means of achieving them in written form supplemented by sketches, partial plans, and the like.

The great majority of urban arterials are at ground level, but a small and important percentage of the major arterials in the urban areas are either roadways

depressed below the level of the adjacent land or roadways elevated on columns or on fill. Usually both types, depressed and elevated, will have flanking service roads which are at ground level. All three categories—depressed, elevated, and ground level—call for somewhat different design approaches.

Sometimes in the depressed sections the combination of heat-reflecting retaining walls, lack of adequate space for planting, and steep slopes make the planting of trees impossible except at interchanges and along service roads. In such situations, the planting of the interchanges and service roads should be heavy to be sure that a definite landscape effect is achieved.

Where there is an elevated highway or interchange on piers or on fill, it is essential that the designer determine the amount of sunlight the plants will receive, especially during the growing season. On some projects this can be done by simple observation, but when the planting of a complex interchange is being considered, accurate information is needed. This information can be obtained by preparing a shadowgraph from sun-control data in such architectural references as Ramsey and Sleeper *(1970)*. A shadowgraph can be prepared for any time of day, any day of the year, and at any location to show the shadow cast by any object. Such shadowgraphs will often yield surprises, and you may find that it is possible to plant in the middle of a complex interchange because there is enough sunlight for plants to thrive.

The planting of trees on one side of the service roads is, for the most part, straightforward street-tree planting. Often there is considerable space between the service road and the main highway, which can be planted and which will be effective both from the man highway and from the service road. In such cases, the planting between the service road and the highway can be informal and heavy.

Often the same kind of trees are used for considerable length along the service road. There is no sound design reason to do this in every case. The designer should consider varying the species—from block to block or as necessary—to obtain a more interesting landscape effect.

Often there will be parcels along a major urban highway that are unused for highway purposes. Where these occur, they form an opportunity to design a small park or an open landscaped space with enough trees to give a feeling of depth, instead of a single row of trees.

Sometimes it is possible to plant on private property by permit, and so greatly increase the landscape effect. The conditions under which this can be done vary greatly, but this work should be considered where possible.

One of the persistent misunderstandings about the planting of trees and other woody materials along highways is that such planting will greatly help in reducing traffic noise. Sometimes the highway landscape designer is requested to plant trees for this purpose. A research project conducted for the Highway Research Board *(Gordon et al. 1971)* indicates that such planting has little or no value unless the planting is at least 100 feet in depth, dense, and at least 15 feet tall. Under these circumstances there may be a maximum reduction of 5 decibels, although visual isolation of the source may reduce a person's awareness of the noise to a greater extent.

DESIGN CONSIDERATIONS IN TREE SELECTIONS

Often at this stage in a paper, one or several lists of trees are proposed for use in different situations. This offering of a predetermined list doesn't seem a professional approach to the problem. Also, the presentation of such a list would be particularly inappropriate for members of this audience who have as one of their main goals the development of new and better cultivars.

As no two projects or sites are identical, it is imperative that the designer

determine and assemble his own list for each project. The designer must keep his design objectives in mind in making his selection and choose those trees that will assist most in achieving the objectives.

While these comments are made on the assumption that the highway landscape designer doing a project has a sound background of knowledge and experience in using trees, there are bound to be instances in which the special expertise and knowledge of a professional arborist or similar expert should be sought. Cooperation and collaboration between the two fields of expertise are bound to be in the best interests of the project at hand.

The designer should not necessarily select or reject a new cultivar. He should discuss the matter with the apropriate expert and make a joint evaluation of the development, characteristics, and period of testing of the tree.

In actual practice it must be recognized that the designer is working on a specific project and that he must be pragmatic in his selection of trees. All of the experimentation and testing of new cultivars should have been done, so the project is not a testing field—except in the most unusual circumstances where it is clearly understood that the project is experimental in nature and where provisions have been made to replant the project if the experimental planting is not successful.

The following considerations are not necessarily in order of importance, because the relative importance will vary from project to project. The fundamental characteristics of the trees should be evaluated against the design requirements. However, the designer may choose to develop his own list—mental or written—of the characteristics he feels are important. The following characteristics are largely from a design viewpoint rather than from a horticultural viewpoint:

1. The anticipated size of the tree at various ages—say 5 years after planting, 10 years after planting, and at early maturity—as well as the effective life of the plant. It is essential to know this in order to carry out the designer's intent.
2. Deciduous or evergreen (coniferous or broadleaved).
3. Appearance and character of trees as related to trunk, branch and twig structure, and bark.
4. Density of shade. Important both from an appearance viewpoint and from the standpoint of whether planting grass, ground covers, or other plants under the trees will be possible.
5. The foliage color in spring, summer and fall, and the relative leaf-out and leaf-drop times. Great variation from species to species, and a characteristic of importance in certain projects.
6. Relative time of flowering, duration of period of bloom, and flower color of plants used in floral displays.
7. Fruit color, duration, and possible hazard or nuisance from tree fruits.
8. Location of overhead and underground utilities.
9. Size of material to be planted is sometimes limited by size of soil ball that can be handled—as on steep slopes and in narrow spaces between curb and sidewalk.
10. Capacity of tree to produce a branch and crown structure that provides adequate vertical clearance for pedestrians when used as a street tree and the eventual clearance as may be required on the street side for passenger cars and trucks. Some trees cannot provide such clearance without looking grotesque and misshapen when planted, although they may recover to a typical shape years after planting.
11. Availability of the trees in the sizes proposed. Size of tree may be guided, to some extent, by available funds.
12. Specification of nursery-grown trees meeting AAN (American Association of Nurserymen) Standards.

RESEARCH AND DEVELOPMENT

The need for better trees for metropolitan areas is undisputed. A research and development program for this purpose is very timely.

The highway landscape designers will have a continuing interest in the program, and should be consulted on needs, evaluations, and some aspects of testing under field conditions.

If trees are going to be specifically developed for the usually harsh conditions of metropolitan areas, it would seem desirable that such trees receive special cultural treatment and be readily identifiable. Consideration should be given to having a special or specification designation in the nursery industry that would ensure special root pruning, special top pruning, and selection for quality.

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ROLE OF CULTIVARS IN A ROADSIDE PLANTING AND MAINTENANCE PROGRAM

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ABSTRACT. Planting and maintaining roadsides requires flexibility in administration and operation. Financial and technical demands on these programs are ever-changing, and there is a continuing need for plants that, having specific qualities, will meet these changing demands. Controls and techniques of planting and maintenance are discussed, especially their effect on plant materials used. Existing rules and regulations can be modified to stimulate the use of cultivars, and an incentive program is proposed to stimulate their use.

SINCE THE INCEPTION of roadside planting programs more than 50 years ago, the persons in charge have been concerned with roadside esthetics and the types and sources of planting stock.

However, only in recent years has the highway engineer realized the overall significance of combining the engineering and esthetic qualities to produce an environmentally sound highway program. No longer is it a simple matter of designing and constructing an arterial highway between two points with consideration only for traffic demands. Curvilinear alignment in lieu of long tangent sections is now preferred as a means of adding beauty and fitting the highway into and not onto the landscape.

Much of the early roadside landscaping was justified on the basis of erosion control. Even as late as 1960 the solution to obtaining federal funds for highway landscaping was to stress erosion control, not beautification. Under this philosophy a cost/benefit ratio was feasible, and no agency could be condemned for spending public funds on beauty.

Recent studies, such as the one by Baker *et al. (1973)*, reveal the public's preference for trees, plantings, and a neat park-like appearance. Consequently, highway departments can now design, plant, and maintain roadsides for esthetic values without fear of public criticism.

Future travel modes are predicted to change drastically in the next 25 years *(Frost and Sullivan 1975)*. A decline in the use of the internal-combustion engine from the current high of 99 percent to a mere 14 percent by 1990 is forecast as the

diesel, Wankel, and other power plants come of age.

These authors also report that the use of mass transportation will increase and create a leveling-off of private auto use at approximately 118 million by 1990. These changes, I predict, will substantially alter the roadside atmosphere and permit the utilization of plants that have been considered too sensitive to roadside pollution.

Just which plants the designer may select for his roadside design depends considerably upon the policies of the specific state highway department. I shall briefly review current practices in the establishment and maintenance of roadside plantings, and offer some ideas about the role that cultivars may play in future roadside landscaping.

PRESENT PRACTICES OF HIGHWAY DEPARTMENTS

Planting Practices

All states have planting programs that are financed partly or wholly by federal funds. Programs under the Federal Aid Interstate Highway Act call for federal funding of 90 percent of the costs and state funding of 10 percent. Provisions of the 1965 Highway Beautification Act (Title III, Scenic Enhancement) provide for federal funding of 100 percent of the costs of vegetation establishment. There are also other ratios of financing that are not as attractive to the states. Under cooperative financing, the design and establishment of roadside plantings are closely reviewed and inspected by both federal and state agencies.

Pennsylvania has not restricted the roadside planting of trees to projects financed jointly or completely with Federal funds.

Each of Pennsylvania's 11 highway-engineering districts has a District Roadside Specialist. He directs the whole roadside program for his area—from design through establishment to maintenance. Through experience he acquires considerable knowledge that he uses in subsequent planting designs and in the selection of plants.

Most interstate and major-highway projects require detailed plans for the plantings, and these are prepared either by the Roadside Design Section of the Bureau of Design in the State (Harrisburg) office or by consulting landscape architects.

Unlike many states of the Northeast, Pennsylvania requires that roadside planting be contracted and established at the same time and under the same contract as construction of the road. There are the following administrative and operational advantages in this procedure.

1. Only one contract need be prepared and negotiated.
2. The details of proposed roadside treatments are presented and discussed in public hearings—not merely promised at hearings and then dropped because of indifference or financial problems of the administration, or for other reasons. The discussions may cause plans to be modified as needed and the changes incorporated into the construction contract. The value of such a procedure in this era of environmental awareness cannot be overemphasized.
3. The prime contractor invariably sublets the planting job, including the supplying of plants, to a qualified landscape contractor. The latter coordinates his planting and any other roadside operations with the road construction. Often, by the time the project is completed, many of the plants have been established for a year or more.
4. Planting operations do not require separate protection from traffic. In contrast, landscape plantings after road construction often delay or impede the travel of motorists.
5. When the highway is completed and opened, the landscaping treatment is often finished—thus providing the motorists more pleasing views than the barren wasteland of unlandscaped

roadsides that prevail until landscaping is completed under a separate contract.

Plantings after completion of highway construction and under separate contracts, which cover the entire project or a number of contiguous projects, also have certain advantages. These are:

1. The landscape designer can see the finished site conditions. Use and culture of the adjacent land may require screening or other changes in landscaping that may not have been anticipated. Such variations in desirable landscaping are almost impossible to design before the road is constructed unless the landscape designer fully understands highway plans giving profiles and cross-sections.
2. Contract execution and planting practices are somewhat more coordinated between landscape-oriented personnel —the landscape architect, landscape contractor, and landscape-inspection personnel. For example, there are probably fewer conflicts and delays in plant inspection, digging, storage, and establishment than when landscape contracts are sublet by prime contractors.
3. A period for plant establishment can be incorporated into the contract and used without delaying the completion of payment for highway construction.
4. Changes in planting stock or establishment methods can be negotiated directly with the prime contractor.

In Pennsylvania, plants for roadside plantings are inspected and "sealed" at nurseries by Regional Field Control Representatives before the plants are dug. Because there are only three such representatives in the state, nursery inspections are of high quality and uniformity. These representatives are given professional latitude to match nursery stock and planting sites—an invaluable procedure regardless of the contracting method. High-quality inspections at the nursery are important in preventing rejections of entire shipments of planting stock at planting sites.

Nursery inspection is also, I believe, the principal reason for increased plant survival since Pennsylvania adopted this procedure. Nursery inspectors can observe cultural practices and consider them in the selection of plants. They can reject as unsuitable for roadsides, plants that have been excessively fertilized, as indicated by their abnormal growth.

Digging practices are also a major concern. Though modern equipment for digging trees provides significant saving in labor and is of tremendous value to the nursery industry, it can jeopardize survival. I think that many plants, sites, or conditions are not adapted to such a digging technique. I believe that an evaluation of plants adaptable to mechanical digging is sorely needed. The nursery industry and equipment manufacturers should provide needed information on the results of different techniques and issue guides for digging specific stock under specific conditions. Perhaps the *AAN* (American Association of Nurserymen) *Nursery Standard* would be the appropriate outlet for publishing precautions and approved techniques in mechanical digging.

Nursery inspectors have the opportunity to discuss and review digging, balling, storing, and shipping techniques with nursery personnel. Unsatisfactory techniques can be determined then, and avoided, so later rejections may not occur and may not jeopardize the completion of scheduled plantings.

As I have learned much through discussions with nurserymen, I would urge all landscape designers to make at least one nursery inspection annually. Thus designers can become familiar with many of the new selections of plants for possible inclusion in subsequent designs and can also learn about changing techniques in producing nursery stock.

Standard forms, such as shown in figure 1, should be used for inspection reports to assure uniformity. If the nurs-

Figure 1.—Form used by the Pennsylvania Department of Transportation in inspection of plants, for roadside plantings, upon delivery to the planting site.

LD-6104 (8-72)
CC-0830-4800-0300

PLANT MATERIAL

INSPECTION REPORT

DISTRICT _____
COUNTY _____
SPECIFICATION YEAR (FORM 408) _____

Project or Agreement No. _____ Route _____ Section _____

Department Forces ☐ Contractor _____ Sub Contractor _____

Plant Material Supplier _____ Nursery _____

ITEM NO. 808__	PLANT NAME	SIZE	POTTED BARE ROOT B & B	QUANTITY				
				PLAN	This Delivery	ACCEPTED	Rejected (cause) (1-14)	Balance Due

Delivery _____ (Date) _____ (Time) Department Inspector _____ (Name and Title)

Date District Roadside Specialist Notified _____ Approved: _____ (Roadside Specialist)

NOTE: The Department Inspector shall complete this report in duplicate (front and back) for each shipment of material delivered. The District Roadside Specialist or his representative shall check this material and report before approving. The original copy shall be placed in the project file and serve as quality documentation. The duplicate copy shall be retained by the Roadside Specialist and be placed in District Roadside files for reference in conjunction with subsequent plant materials survival inspections.

PLANT MATERIALS CHECKLIST

AND/OR

CAUSE FOR REJECTION

YES	NO	
☐	☐	1. Is plant material covered with burlap, canvas or other covering to prevent windburn and drying out in transit?
☐	☐	2. Is "heating" or "sweating" by reason of tight packing or poor ventilation evident?
☐	☐	3. Was the root system, of bare root stock, protected by moist material such as straw, hay or other mulches during transit?
☐	☐	4. Is plant material properly identified by label?
☐	☐	5. Does the plant size agree with size indicated on label?
☐	☐	6. Are certificates attesting to insect or disease free plants furnished with this shipment, invoice, or order?
☐	☐	7. Is plant material free of broken branches, mechanical wounds or other latent defects?
☐	☐	8. Are Department metal seals, attesting to pre-inspection, affixed to the plant material?
☐	☐	9. Does the ball size or root system meet the minimum "American Standard for Nursery Stock" requirements?
☐	☐	10. Is the ball condition satisfactory?
☐	☐	11. Are the balling and burlapping or root protection devices adequate to prevent damage to plants during handling?
☐	☐	12. Were B&B plants handled by the ball during unloading and other handling operations?
☐	☐	13. Was all plant material promptly and properly stored after delivery?
☐	☐	14. Other condition(s) detrimental to plant survival noted as follows:

eryman receives a copy at the time of inspection, subsequent misunderstandings will be reduced, and better handling practices will be the result, as he is therefore aware of the causes for rejection.

The nursery industry is providing increased amounts of container-grown plants that permit extending the planting season for many species and cultivars. Such extended seasons improve the chances of meeting completion dates on projects. Consequently, plants that are adapted to container-growing rank high on any designer's list.

Modern shipping methods permit direct shipments from the nursery to the planting site with minimal handling. The practice of heeling-in near the planting site is reduced or eliminated on many projects, and thefts of stock from storage areas are also reduced. Theft and vandalism are particularly common in urban-planting projects. While barbed or thorny plants are less likely to be stolen or vandalized, they cause discomfort to the contractor's personnel during planting and subsequently to maintenance personnel who have to remove wind-blown debris lodged in the plants.

Before roadside trees are planted, site conditions should be thoroughly analyzed—in particular:

1. Underground and aerial utilities may not be situated as shown in original plans, and the "as-built" plans should be studied so any necessary changes in planting plans can be made.
2. Use of adjacent property may not be compatible with the selected species or its location, or the planting or preference of the adjacent-property owner may warrant a change in the planting plan.
3. Changes in soil conditions or water table, as the result of construction activities, may make desirable a considerable modification of the planting plan.

In my opinion—based on analyzing probable causes of mortality—more trees have died in roadside landscaping from too deep planting than from any other single factor. There are admittedly several differing views on the proper depth for best survival. Alban and Reisch *(1973)* noted that heavy clay soils, especially in fills or under compaction, have extremely poor drainage. They recommend that in such conditions trees should be planted so one-third to one-half of the ball depth is above existing ground level; the trees should be adequately guyed; and the soil should be adequately mulched to prevent drying of roots.

Pirone *(1972)* stated that: "Experienced arborists have found that if a tree is set a bit higher in its new location than in its former one, the chances of continued good growth are increased. It is a well known fact that trees set too deeply will not thrive and may even die within a few years." However, where planting sites consist mostly of loose rock or other coarse fill, creating extremely dry conditions, I have seen successful plantings in which the tops of the root balls were set 6 inches below the finished grade. Those sites do not represent normal planting conditions. I would recommend setting trees 2 inches higher than they stood in the nursery and constructing an earthen cup of backfill mix to retain water during watering operations.

Intensive inspection and strict enforcement of contracts through the period of guarantee are highly important. Landscape designers, nurserymen, and inspectors have spent time, effort, and money in the selection of high-quality plants. Planting plans have been modified as required to provide suitable conditions for planting stock. Individual trees should consequently be planted, fertilized, watered, pruned, mulched, wrapped, and guyed as specified in the contract for the species and size of tree—if plantings are to be successful. Detailed specifications for these practices vary considerably among states, agencies, and municipalities; but in one form or another the

practices considered desirable are specified for each planting project.

Considerable emphasis has rightly been placed in recent years on the need for a 3-year plant establishment period in every contract. Most arborists recognize this period of time as critical for plant survival. This 3-year period for establishment has not been adopted because of administrative problems. Unfortunately planting contracts still provide for only one growing season or a 12-month period, after planting, as the plant-establishment period. Most agencies consider any needed care or replacement, after this period, as maintenance. Problems include adequate definitions of plant replacement and care. Such items as watering, weeding, and application of insecticide are difficult to define adequately. Too often the terms "as required", "as directed", or "as needed" are used to define the frequency of treatment. Contractors therefore are guided by past experience with the particular agency, and they bid and perform accordingly. However, contracts providing separate items of plant care, such as watering, can result in increased plant survival. Contracts should, of course, require that all watering within a project be completed within a specified period of time.

Maintenance

Maintenance of trees has always had low priority in the work programs of most administrators of highway programs. Consequently, budgets for tree maintenance are always inadequate.

Only when an epidemic that causes public concern develops, can adequate funds for tree maintenance be obtained. Extensive damage by gypsy moth in northeastern Pennsylvania has created such concern and provided support for a protective program. However, some other insect infestations, particularly in low populations, have not created sufficient public concern for protective action.

To provide adequate maintenance, after the acceptance of planting projects, many state highway departments are adopting a Highway Maintenance Management System (HMMS). It includes (1) development of standards for performance and frequency, (2) planning and programming, and (3) reporting for comparing performance with production goals. Such a system is invaluable in the preparation of budgets and work programs and in the analysis of operation accomplishments or deficiencies.

Tree maintenance can be performed successfully either by agency personnel or under contract by plant-maintenance services. Most rural districts and their employees are quite familiar with agricultural activities, and as a rule their personnel are used in plant-maintenance programs. Plantings in urban and suburban areas are best maintained through contract services. The increasing benefits demanded and gained by municipal unions make fiscally prudent the use of contract personnel who can be secured, as required, for short periods of time and then released. Through the use of contract personnel, overhead expenses such as social security, unemployment benefits, life and medical insurance, and retirement programs are not a continuing drain on the limited funds for tree maintenance.

Lack of widespread public support for maintenance programs is one good reason why landscape designers should incorporate into the design and in planting contracts species, planting, and establishment techniques that assure maximum survival despite inadequate maintenance.

Watering and insect control are the two most important items in most maintenance programs. Watering is the more important. "On-call" watering equipment is an important requirement, but difficult to obtain when needed. Severe summer droughts of the 1960s were a test of many organizations to conduct successful programs of tree establishment and maintenance. Then many apparently successful plantings were riddled with dying trees. Consequently species such as oak, linden,

and honeylocust gained prominence as desirable roadside trees because of their high survival.

Mowing can cause high mortality of planted trees because most operators seem to want to mow as close to tree trunks as possible. This often creates wounds for the entrance of disease or insects and sometimes directly kills trees. Many agencies have reduced the amounts of mowing through a mow-line policy, partly to save money and partly to encourage natural reproduction of woody plants.

However, reduced mowing may lead to damage by meadow mice in patches of dense unmowed cover. Many thin-bark trees are completely girdled during the winter and soon die. Such damage is particularly common in rural interchanges. Where trees are to be established in unmown areas, species should be carefully considered. Crabapples, hawthorns, and thin-bark maples are choice foods and poor risks. Large trees with thick bark, such as red oak and white ash in the 2½- to 3-inch caliper size (diameter 6 inches above ground) have had relatively good survival in such areas. Annual use of rodenticide around such trees is hazardous to domestic animals and also expensive.

Maintaining an area clear of vegetation around individual trees seems to be the most effective method of controlling rodent damage. While herbicide spraying or treatment has been effective in destroying undesirable vegetation, many plantings have been destroyed by improper use. A single misapplication can destroy desirable plants, and the expense and effort of many years are lost. This can also result in justifiable public criticism. Proper herbicide application is a must.

Screening of Objectionable Views

State transportation departments use plant materials to screen visually offensive views—including their own storage yards. The Federal Highway Beautification Act of 1965 provided for the control of outdoor advertising devices and junkyards along all interstate and primary highways receiving federal aid. Under this act, billboards are to be purchased and removed except those in specifically permitted areas, and junkyards are to be removed or screened so the junk is not visible.

In using trees as screens, certain species or types have definite advantages. Evergreen plantings provide the most effective year-round screens. Around highway-storage yards, soil may be contaminated with salt; so successful establishment of a screen may necessitate establishing it on an uncontaminated mound of soil. Fast-growing but long-lived trees are the most desirable plants to use in screening junkyards. However, the species selected must be able to thrive under the pollutants from the nearby highway *and* from junkyard operations. In such situations narrow-growing plants may also be required to fit the available space.

Tree screens may be damaged or destroyed because they are effective. Trees within highway rights-of-way have been purposely cut, trimmed, sprayed, or otherwise destroyed to make visible adjacent billboards or business signs. In some states legislation is needed to provide better control of such damage. Severe penalties should be applied to apprehended individuals, and in many states they are.

POSSIBLE USE OF CULTIVARS ALONG HIGHWAYS

In a recent survey by Gerhold *et al. (1975)* under the Pinchot Institute program of the U.S. Forest Service, municipalities, counties, and state highway departments were contacted. The somewhat incomplete reports showed that 754,567 trees were planted by municipalities and highway departments of 16 northeastern states between 1968 and 1972. Highway departments planted

473,255 of these trees, or about 100,000 a year. Even a 10-percent evaluation of these trees, or about 10,000 a year, would provide much data on the relative value of different species and cultivars and would indicate needed research in tree improvement.

The Ohio Agricultural Research and Development Center at Wooster has conducted an evaluation program since 1966. As a result, Kozel *(1975)* identified 23 species and 63 cultivars that in his opinion possess sufficiently favorable qualities to justify their extensive use as street or park trees. However, more extensive evaluation programs covering the Northeast are needed to provide landscape designers and others with a sound basis for selecting specific trees for planting along highways.

I suggest that, through coordinated federal and state programs, incentives for planting and evaluating cultivars be developed. Possibly the Federal Highway Administration (FHWA) might encourage the use of a specific percentage of the project or program funds for this purpose—as it has for certain other favored projects. I also suggest that a prudent limit be set on the initial tests of cultivars offering promise. If, for example, a maximum of 10 percent were permitted, the amount of stock evaluated under demanding field conditions would be large enough to stimulate propagators and nurseries alike to increasing their activities.

Selections should provide, after adequate testing, a gamut of trees to meet varied conditions. Especially valuable would be species or cultivars that possess tolerance to poor drainage or to planting depth—factors that would increase their survival over most plants. Such selections would greatly aid all arborists—including those of us concerned with roadside plantings.

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SELECTION PRACTICES OF MUNICIPAL ARBORISTS

by HENRY D. GERHOLD *and* KIM C. STEINER, *respectively Professor and Assistant Professor, School of Forest Resources, The Pennsylvania State University, University Park, Pennsylvania.* *Journal Paper No. 4899 of the Pennsylvania Agricultural Experiment Station, authorized for publication July 21, 1975. Research supported by USDA Northeastern Forest Experiment Station through The Pinchot Institute Consortium for Environmental Forestry Studies.*

ABSTRACT. Selection of species or cultivars for municipal plantings involves complex social-political, managerial, architectural, biological, and commercial relationships. Various kinds of selection strategies may exist. A survey of arborists in the northeastern United States indicated that at least 17 characteristics of trees are considered in selecting species or clones for particular planting sites. The relative utility and availability of each type of information is compared. Personal experience was the main basis for selection, supplemented by various kinds of publications and nursery catalogs. Better information is needed—particularly about transplantability, maintenance problems, and resistance to air pollutants and deicing salts. Partial information is available on growth rate, general health, cold and drought tolerance, and disease and insect resistance. Ways to improve the selection of species and cultivars are suggested.

IN SELECTING TREES for planting, a municipal arborist may choose among hundreds of species and cultivars, each with its unique set of perhaps 20 characteristics. How can he cope with such a vast array of data? What would be the ideal way of finding the best tree for a particular site? How is the choice made, in actual practice?

An arborist's professional reputation depends to a great extent on his ability to recommend the best trees for various kinds of planting sites. Serious problems can result from faulty choices, and too often they do. Poor survival, sickly trees, maintenance problems, or excessive size may lead to strained budgets, complaints from taxpayers, or worse consequences. In contrast, wise selections bring amenities that may be enjoyed for generations.

Nurserymen who grow the trees and breeders who are developing superior cultivars also have a lot at stake in this matter. Their selection strategies are

directly related to those of the arborists *(Collins 1971, Santamour 1968)*. It is important for all three to understand the actual ways by which trees are chosen and purchased, and also to consider how the process might be improved.

The interpretive part of this report attempts to clear away some of the mysteries surrounding the planting choices that have beautified some communities and horrified others. The factual portion is based mainly on a survey of arborists and on related literature. A composite description is given of current practices of experienced arborists, and of the kinds of information they either use or wish they had available for use.

CONTEXTS OF THE SELECTION PROCESS

Several kinds of forces may influence the planting choices made by a municipal arborist or a street-tree commission. If such pressures are managed wisely, rational selections can be expected. But there are many pitfalls along the way. For a fuller understanding of the selection process, one should consider the contexts in which it occurs.

Social-Political Context

The underlying reason why trees are being chosen is that the residents of a community want them. The interested parties include nearby property owners, other taxpayers, and their public servants. In different communities or states there are various legal arrangements for such legitimate interests to be represented. The predominant role in making decisions may be assigned to a municipal arborist, a shade-tree commission, or property owners *(Boers and Shaw 1971)*. Most citizens seem content to leave tree selection to someone else, unless their active participation is encouraged in some way. Quite commonly the number of people who make the choices is very small, even as few as one. Therefore, it is quite possible for decisions to be autocratic, or else vulnerable to the persuasion of experts or crackpots.

Managerial Context

Money and other resources needed for tree work always seem to be scarce. Budgetary pressures favor the purchase of cheaper species or cultivars. But wise shoppers realize that quality should be considered along with price. Some of the more expensive trees may turn out to be real bargains if they have longer useful lives or require lower expenditures for pruning, spraying, or sidewalk repairs. Stanley and Crossman *(1973)* developed a method of economic analysis for street trees and reported different costs according to size classes. Kielbaso *(1971)* reported that an average expenditure for maintenance of each street tree was $2.47 per year. In a 50-year period this would amount to over $120, or over $500 at 5 percent interest. A $5 difference in purchase price could buy considerable savings, if invested wisely.

Architectural Context

Spatial relationships are very important in choosing trees that will be appropriate for aesthetic and functional purposes. These may include visual and psychological effects, pedestrian-traffic control, glare reduction, microclimate modification, acoustical control, and atmospheric purification *(Robinette 1972)*. Trees should complement their surroundings not only when they are young, but also after they have grown to their full height and spread. Size, form, texture, and color of trunk, branches, foliage, flowers, and fruit should receive attention. Possible interference with overhead wires, lighting, sidewalks, underground utilities, or the vision of drivers and pedestrians may be even more important. Many of the improved cultivars have been developed with such considerations in mind *(Kozel 1975, Wyman 1969)*. They should be used much more effectively than they have been previously.

Biological Context

The ability of trees to survive and remain healthy for many years after planting is paramount among all characteristics under consideration. Trees that cannot meet this criterion are practically useless. Environmental relationships of many kinds should be evaluated in selecting trees that are reasonably well adapted to city conditions *(Collins 1972, Flemer 1972a and 1972b, Mower 1974, Santamour 1968 and 1969, Seibert 1972, Snyder 1972, Spicer 1971)*. Reactions of trees to stresses caused by cold, heat, wind, drought, ice, toxic chemicals in air or soil, restricted root space, diseases, insects, and vandals are all important. The relative importance of each is greatly influenced by geographic location and also by type of planting site; for example, business district versus residential street. Environmental stresses generally have greater effects on those characteristics that are under weaker genetic control than on others. Differences in reactions tend to be greater among species, but considerable variation also exists within species.

It is the municipal arborist's responsibility to determine from all these kinds of biological information which species could be grown under particular conditions. He also must decide which of these species or cultivars are architecturally most desirable, and acceptable in the social-political context. If he can find his way through this complex maze without serious damage to his integrity and principles, it may be only slightly less than miraculous. But he still faces one more hurdle.

Commercial Context

The chosen tree must be found in the appropriate size at a nursery that can supply it at the right time, in good condition, and at a reasonable cost. This would present no great difficulty, if the arborist could place his order 10, 5, or even 2 years before the delivery date. Unfortunately, that seldom is feasible. So the nurserymen can only second-guess his customers of various types; and also his competitors, the weather, the economy, and labor conditions—to mention just a few of his problems. Then the arborist must make do with what is available when he is ready to place his order. If bids are required by his agency, the arborist will have even less control and is more likely to get inferior trees.

KINDS OF SELECTION STRATEGIES

In view of these manifold and difficult problems, it is not surprising to realize that arborists have developed different strategies for dealing with them. There are various indications that different strategies exist, but little definitive information about them *(Bradley 1969, Collins 1972, Scanlon 1965, Spicer 1971, Walter 1969)*. For this reason, much greater liberties are taken with the truth in this section than are to be expected in a scientific discourse. Our observations admittedly are based on hearsay and inferences, more than on solid facts.

"GAMES ARBORISTS PLAY" could serve as a subtitle. Games are described that are analogous to possible selection strategies. Some are played only by pseudo-arborists, but not by professional experts. The tongue-in-cheek descriptions are intended to have only some resemblance to reality. See if you can recognize the games, or anyone you know among the players.

"Blind Man's Bluff"

With blindfold in place, a player called the "Arborist" goes around in circles, searching for other players representing "Tree Species". Confounded by voices all around him, he turns hither and yon until he blunders into the most accessible species. He is required to explain his choice of species, and that's when "The Bluff" occurs. With a little imagination, some really wild, barely plausible excuses can be conjured up. When "The Bluff" fails,

which happens often, another player replaces the "Arborist".

If there are lots of players, several blindfolded "Arborists" may play at the same time, giving each other advice freely. This version is named "The Blind Leading The Blind".

"Architectural Classics"

A sophisticated puzzle that challenges your three-dimensional perceptual acuity. Multicolored pieces in geometric shapes resembling trees, streets, buildings, and utilities fit together in the most ingenious ways. After the puzzle has been assembled, alas, some of the tree pieces are apt to fall apart. Others expand excessively, because the biological material from which they are made tends to have dimensional instability. The manufacturer is attempting to correct these vexing defects.

"Don't Fool Around with Mother Nature"

A party game, not for beginning arborists, and not as seductive as it may sound. The format is similar to "Charades". The trick is to separate the facts from the myths about trees, so that the best solution can be recognized. The lead player, "Mother Nature", is full of tricks, and her clues often are ambiguous. Sometimes there are surprise endings. It takes real mental giants to play this one. Too often the trees turn out to be the giants, and the players, mental midgets.

"Arborists' Monopoly"

Consummate skill and experience are required to be successful in the arborists' version of "Monopoly". In this game investments are made in trees, instead of real estate. At the start, each arborist has ample funds, which are generously supplemented by $200 when he passes "Go" at budget time. Occasionally he has an opportunity to take a "Chance", with either hilarious or tragic consequences. As he gains in skill, he finds that wise investments improve his financial status, but a certain amount of luck is needed, too. Although risks must be taken, a spirit of reckless abandon can lead to bankruptcy. Sooner or later, most players learn that nearly every move early in the game involves an opportunity to make a good or bad decision, and that they must face the consequences later on. Some players cannot stand the strain, and are relieved when they are instructed, "Go Directly to Jail".

These games are, of course, full of fallacies which are to be avoided. Choosing the proper tree should not be taken lightly. Nevertheless, selection does require skill and strategy, and it can bring enjoyment, just as in games. Our challenge is to invent a better way of playing the game. The key to improving this decision-making process is to obtain more extensive and reliable information and to develop better strategies for using pertinent information.

INFORMATION USED IN SELECTION SYSTEMS

Arborists have accumulated a wealth of practical experience related to selection. Much of this has not been reduced to a written form. In an attempt to tap this information, a survey of 93 municipal and highway arborists in 13 northeastern states was conducted in 1974. Its purpose was to learn about the types of information arborists use, in order to improve the process by which species and cultivars are selected for planting. The same questionnaire used for this purpose also asked for opinions on suitability of the more important species for various types of planting sites, and on their characteristics.

Information Types and Sources

Planting-site characteristics and tree characteristics are the two main kinds of information to be considered. Some site characteristics are used more commonly than others (table 1). Growing-space restrictions, both above and below ground, greatly limit the choices in many situations *(Boers and Shaw 1971)*. Prox-

Table 1.—Site characteristics used in selecting species for planting

Characteristics	Used by respondents
	Percent
Growing-space restrictions	97
Distance to paved areas	94
Soil characteristics	69
Pest occurrence in locality	52
Distance to pollution sources	47
Microclimate	31

imity to other trees, streets, sidewalks, buildings, and utility lines all affect the size and shape of crowns and root systems for which there is space. Nearly all arborists in the survey take account of space restrictions. Soil data, used by 69 percent, presumably may include texture, acidity, nutrients, moisture conditions, or aeration. The risk of disease, insect, or pollutant injuries is utilized by about half of the arborists, while only 31 percent are concerned about the microclimate. These types of data are obtained from inspections of planting sites, or are retrieved later from records kept in the office (table 2). The functions that trees are intended to serve can conveniently be considered when the planting site is inspected. In some municipalities the data are transformed into a master planting plan.

Having surveyed the planting site, the arborist then must decide which kind of tree is best suited to grow there and serve its intended purpose. His personal judgment, experience, and retention of facts take on greater importance than published information at this point. Personal experience was the most important source of information for arborists in the survey (table 3). The experience and preferences of others also were influential. Data in government publications, nursery catalogues, professional publications such as *Arborists News* (now *Journal of Arboriculture*) and *American Nurseryman*, or scientific journals such as *Forest Science* or *HortScience* are commonly used too.

There are at least 17 important tree characteristics that may be considered (table 4). Arborists indicated that nearly every characteristic that we listed is useful. Our survey results are in good agreement with a nationwide survey *(Bassett and Lawrence 1975)*, which found that diseases, insects, and maintenance are the three most pressing problems. Other traits such as transplantability, soil requirements, and shade tolerance may be important too, but they were not included specifically.

The relative need for additional or better information on certain traits is indicated by the difference between their utility and their availability (table 4). The greatest needs pertain to air-pollution resistance, survival records,

Table 2.—Types of records kept by municipal and highway tree planters

Type of record	Kept by respondents
	Percent
Planting location	91
Planting-site characteristics	21
Species	83
Cultivar, clone	44
Number of trees	77
Size of trees	76
Survival after 1 year	47
Survival after 2 years	33
Survival beyond 2 years	29
Causes of mortality	32
Pest occurrence	30
Cultural treatments	20
Maintenance operations	63

Table 3.—Value of different information sources in selecting species for planting

Source	Mean value[a]
Personal experience	2.7
Experience and preference of others	2.3
Nursery catalogs	2.2
Professional publications[b]	2.2
Scientific journals[c]	1.6
Government publications	2.4
Other	1.4

[a] Scale: 1 = not important to 3 = very important.
[b] Mentioned most: Arborists News; Int. Shade Tree Conf. Proc., Am. Nurseryman.
[c] Mentioned most: HortScience; For. Sci.

Table 4.—Tree characteristics that are useful for selection

[In percent of respondents]

Type of information	Respondents said information—		Index of need[a]
	—is useful	—is available	
Air-pollutant resistance	87	20	67
Records of survival elsewhere	90	28	62
Deicing salt tolerance	87	25	62
Maintenance problems	95	41	54
Drought tolerance	87	37	50
General health	85	46	39
Insect resistance	93	54	39
Growth rate	89	53	36
Disease resistance	96	60	36
Cold tolerance	80	48	32
Availability from nurseries	91	62	29
Adaptive traits of rootstocks	38	11	27
Branching habit	85	73	12
Crown size	87	81	6
Crown shape	86	85	1
Fruit traits	79	81	−2
Flower traits	79	82	−3
Leaf traits	76	80	−4

[a] Index of need = Useful minus Available.

deicing-salt tolerance, maintenance problems, and drought tolerance. Somewhat better but still inadequate information exists on general health, insect resistance, growth rate, disease resistance, cold tolerance, availability from nurseries, and rootstock adaptiveness. Adequate information is available on traits related to appearance and size.

Information Applications

The way in which information on each tree characteristic is used varies according to the biological, architectural, and managerial contexts in which it is considered. It also differs if the choice is being made among species, as compared to cultivars of a single species (table 5). Most commercial cultivars are clones budded on seedling rootstock. Arborists are more discriminating in choosing among species than cultivars within species. Also, greater attention is paid to appearance and dimensions of cultivars than their adaptiveness to environmental conditions. These tendencies probably reflect the greater amount of variation among species, the traits for which most cultivars were selected, and the availability of better information to guide choices in these two respects.

In assessing the importance of a particular characteristic, one should remem-

Table 5.—Use of genetic variation in tree characteristics for selecting species or cultivars

Characteristics	Percent of respondents who utilize variation among—	
	Some or all species	Cultivars in some or all species
Crown size	95	75
Crown shape	94	76
Leaf size or color	88	67
Flower coloring or timing	80	63
Fruit size, color, etc.	83	65
Branching habit	97	79
Rooting habit	95	62
Trunk straightness or color	92	71
Cold tolerance	90	61
Drought tolerance	91	61
Salt tolerance	85	58
Air-pollution resistance	73	49
Insect resistance	94	65
Disease resistance	98	68

ber that it is not independent of the other traits associated with it in a species or cultivar. The characteristics in which a species is weakest are the ones most likely to lead to its rejection by an arborist. These are also the traits that breeders should consider improving, though not necessarily those that will respond best to improvement efforts.

IMPROVING SELECTION SYSTEMS

Let us return to a question raised earlier. How can arborists cope with such a mass of data, interpreting it in various contexts, and do a better job of it? The tempting answer is to refer it to a computer. This may become possible, if adequate programs are written and better data are obtained. The process could at least be simplified, though we believe an arborist's judgment will still be required in making final decisions.

A more immediate improvement might be realized by using the collective wisdom of experienced arborists and organizing data so they can be utilized more effectively—despite their imperfections and inaccuracies. Therefore we have started to compile a table that summarizes the reputations of the more commonly planted species and cultivars in terms of size and appearance, maintenance characteristics, and performance under various kinds of site conditions. The information is based on several publications of experts *(Chapin and Kozel 1975, Enright 1955, Flemer 1972a, Kozel 1974 and 1975, Lewis 1965 and 1971, N.J. Fed. Shade Tree Comm. 1974, Scanlon 1965, Snyder 1972, Wyman 1965 and 1969)* and on the survey of arborists which we conducted.

The tabulated information may be used in various ways. Experienced arborists may use it as a check list, or to compare their opinions with those of others. Beginning arborists or novices can use the summary of conventional knowledge to supplement what they have learned from books, as a temporary substitute for professional experience. Tree breeders and researchers can identify species and characteristics in which genetic improvements would be useful or for which information is lacking.

The arrangement of data on species and cultivars should enable the user to employ his own strategy for sorting out the trees he wants. They should be listed without subdivision into categories such as size or hardiness zone. This will free the user to design his own search procedure. He can decide on the sequence in which different kinds of data will be considered, according to the meaning they hold for him. The most appropriate candidates for a particular use can be located by considering different variables in succession. The final choice can be made through a blending of science, art, and experience, which can be unique for each user.

A final word of caution is needed about imperfections in the data that are available. The performance of trees under city conditions varies greatly. Such variations have been noted subjectively, but objective measurements are scarce. There is a great need for more scientific data to develop improved selection guides. Arborists in our survey have clearly recognized this need. Many of them are already engaged in cooperative projects that aim to provide the information that will permit arborists and breeders to select more effectively.

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NURSERY GROWING PRACTICES AS RELATED TO SELECTION AND PRODUCTION OF MUNICIPAL TREES

by WILLIAM H. COLLINS, *Staff Horticulturist, Cole Nursery Co., Inc., Circleville, Ohio*

ABSTRACT. The commercial production and selection of trees for municipal plantings are traced from the early phase to the current propagation and cultural techniques that commercial nurseries are now using. Street-tree production is a long cycle, usually 3 to 5 years from the time 5- to 7-foot seedlings (liners) are spaced and planted in nursery rows. Clones provide municipal buyers with trees of known desirable characteristics and without the undesirable variability of seedlings. However, 6 to 15 years are needed to evaluate a clone, and many promising selections fail to meet acceptable standards for various reasons. Improved means of vegetative reproduction, especially "own-root" propagation, are sadly needed to permit the more efficient production of desirable clones of various species.

VOLUME PRODUCTION OF TREES for municipal planting is a specialized phase of the nursery business. The kinds suitable for street-tree planting are limited. Their production involves some specific cultural practices that begin with propagation techniques and end with refinements in digging and storage methods.

As would be expected in a free-enterprise business, no two firms of wholesale growers use the same production methods, grow the same kinds, or supply the same markets. However, most of them have at least two things in common: (1) their procedures in growing, grading, and selling are geared to meeting or exceeding industry standards (American Association of Nurserymen 1973); and (2) the nurseries strive to annually supply municipal and other buyers with the numbers, kinds, and sizes of stock required.

Many of us recall that the trees formerly grown by nurseries for all of their trade, including the municipal market, were of seedling origin. Then production practices were largely confined to selection of seed source, spacing of stock, its training and shaping, the frequency of transplanting, and digging and storage methods. As professionally trained arborists and foresters gained the responsibility of personnel and budgets, the planting programs of their predecessors showed some failings: municipal trees too large at maturity for the site, a lack of variety in species, and poor tree structure

resulting from inadequate training and shaping.

Interested growers and municipal planters gradually learned that both groups would benefit by exchange of information. Then began what continues to be a mutually advantageous arrangement: the nurseryman's personal observations of tree growth on city streets and highways, and municipal arborists' visits to nurseries, sometimes on field days, to see improved modifications in nursery practices. Goal of the interchange is, of course, to provide proper kinds, sizes, and shapes of trees for municipal plantings.

Both groups have one hurdle or barrier in common, the economic one. For the nurseryman, the price per tree is set largely by the cost of production. For the city arborist, landscape architect, or other buyer, the budget limits the number of trees meeting certain specifications that can be purchased. As a nurseryman, I welcome the opportunity to discuss some of the procedures and problems that contribute to the cost of producing this specialized nursery stock.

STREET-TREE PRODUCTION—A LONG CYCLE

Annually the nurseryman sets up a new production cycle to supply the needs of the specialized municipal market at a competitive price. He develops a schedule of individual timetables that cover the full line of trees and that indicate by year of harvest the quantities and sizes he will have available. Each cultural step is planned, so that as the trees in each block reach salable size, they are properly formed, pruned, and spaced. If the nurseryman has to dig the trees in one block a year sooner than scheduled, most of them will be "unsized"—smaller in height or diameter than called for in the minimum specifications. On the other hand, if the nurseryman has to allow the trees in a block to grow a year longer than planned, spacing both within and between rows will be undesirably close, trees may reach a larger than acceptable size, and production costs for that year have to be added to the selling price.

The production cycle varies with the growth rate of different kinds of trees

Table 1.—Average number of years required to produce street-tree stock from seedlings 5 to 7 feet tall or from 1-year-old whips of that size, by species or clone[1]

Species or clone	Type[2]	Years	Species or clone	Type[2]	Years
Acer campestre	S	3	*Fraxinus excelsior*	C	3
Acer platanoides	C	3	*Ginkgo biloba*	S	4-5
Acer rubrum	C	3		C	4-5
Acer saccharinum	S	3	*Gleditsia triacanthos inermis*	C	3
	C	3	*Liquidambar styraciflua*	S	4
Acer saccharum	S	4	*Malus* 'Snowdrift'	C	3
	C	3	*Ostrya virginiana*	S	4-5
Celtis occidentalis	S	3-4	*Platanus acerifolia*	C	2-3
Cercidiphyllum japonicum	S	4-5	*Pyrus calleryana*	C	3
Crataegus lavallei (tree form)	C	3-4	*Quercus rubra (Q. borealis)*	S	4
Crataegus phaenopyrum (tree form)	C	3-4	*Quercus palustris*	S	4
Fraxinus americana	C	3		C	4
Fraxinus pennsylvanica lanceolata	C	3	*Zelkova serrata*	C	3

[1] To minimize variables in the above comparison, the years listed are the average number required to grow street-tree types to a caliper of 1¼ to 1¾ inches from liners or whips that are 5 to 7 feet tall. To these years add the average number of years required to grow liners (seedlings from seed) to the 5- to 7-foot size or to produce 1-year-old whips of that size that have 3-year-old roots.

[2] Type of stock produced: S = seedlings; C = clones.

(table 1). Only a series of the most favorable growing seasons permits the harvesting of even the fastest growing kinds in less than 3 years. These years do not include the time needed to grow seedlings to a height of 5 to 7 feet or to produce whips of budded varieties of the same height. These young trees, even though taller than usual, are commonly referred to as "liners" in the nursery trade. Planting of trees of this size permits the predictable harvesting of some street-tree types in sizes from 1¼ inch through 1¾-inch caliper in 3 years. Slower growing types may need 4 or 5 years to reach this minimal size range.

(A "whip" is an erect, usually straight and unbranched 1-year-old stem growing from a single bud, grafted [or more exactly, budded] the previous season at or near ground level on a suitable seedling understock. A "liner" [lining-out stock] includes all young plants of sizes suitable for planting in the nursery. In the case of street trees, the liners are sometimes relatively large trees. In recent years they are frequently 1-year whips of budded varieties up to 7 feet in height. They are "lined out" in the nursery, uniformly spaced to grow for two or more years before selling or transplanting again. Caliper is the diameter measured 6 inches above ground for trees up to and including 4 inches in diameter.)

Although some nurseries do engage in contract growing (in which the buyer agrees to take a specified number of trees of specific kinds and sizes in certain designated years), most sales to municipalities and other public agencies are by bids. Bid sales do not provide assurance to nurserymen that, as trees reach salable size, all of them will be sold on schedule.

Nurserymen cannot deviate from their production cycle, especially for trees grown to be sold as bare-root stock; and bare-root stock is the bulk of the governmental market. The buyer, like the nurseryman, has rising costs in labor, equipment, and supplies, but wishes for his budgeted dollars to purchase the maximum number of trees that meet specifications. Trees purchased as bare-root stock permit the buyer to plant more miles of street or to set out more replacements than if he buys stock with soil balls wrapped in burlap (B&B stock). Increasing use of bare-root stock seems likely in view of savings in cost and energy. Many more bare-root trees than B&B stock can be shipped in the same volume of space, and the resulting load weighs less and requires less use of fuel by the 40-foot truck vans that we use.

Should a municipal arborist find it necessary, he can obtain the maximum number of trees for his budgeted dollars if he modifies his preferred specifications so that he purchases:

1. A higher proportion of trees as bare-root stock.
2. Trees of a smaller, less costly size.
3. Species or cultivars that are less expensive than others of the same size.

Of course, the arborist has to judge whether the bare-root stock, smaller trees, or less costly species will give him and his community adequate survival and performance, and whether offsetting costs result.

ENTER THE CLONE

Possibly the biggest single factor that has permitted the grower to meet the needs of the municipal buyer is the advent of the clone (cultivar). It has permitted the nurseryman and the forester or arborist, together or individually, to zero in on selections that grow well in street and highway plantings (fig. 1). These selections increase the cost of planted trees little, if at all, especially if the clone has acceptable growth and significantly superior performance when compared to the previously grown seedling trees. And clones do not have the variation found in seedling stock (fig. 2).

An extensive period of testing and evaluation has usually preceded the suc-



Figure 1.—'Snowdrift' flowering crabapple trees planted in sidewalk cut-outs. Note that the form of these trees is uniform and provides sufficient clearance for vehicular and pedestrian traffic.

cess of the best clonal selections, ones that meet the production standards of the nurseryman and the performance standards of the city forester. Important production factors that the grower must consider are ease of propagation with high survival rates, uniformity of growth, superior structural form, superior resistance to pest injuries, and pronounced vigor. The last includes an improved rate of annual growth, high percentage of survival in transplanting, and quicker recovery after transplanting. Clones having these characteristics will give the buyer uniformly excellent performance.

Poor performance of a clone need not be blamed on the tree. The cultivar may be planted north of the recommended hardiness zones. Some planting sites permit neither seedlings of the particular species nor their clones to survive, yet alone to thrive. Such sites and conditions can be classified in a *TOO SERIES*: too

Figure 2.—A block of 'Cleveland' Norway maples in the nursery, ready for digging and street planting. Note their uniform appearance, typical of clones. This is one of several fine cultivars for street-tree planting having an upright habit but form typical of the species.



poorly drained, too wet, too dry, too hot, too windy, too polluted (air, soil, or both), too small in soil-surface area or soil volume, too shady, too poor in quality of backfill, too little in maintenance care. Selection of clones and species for good performance on specific sites is a subject on which experienced and knowledgeable growers and arborists can exchange information to their mutual advantage.

The subject of this portion of the symposium is "selection for adaption to cultural systems," a concise way of suggesting that—if the grower cannot offer a selection at a price profitable to him and acceptable to the buyer—then the selection will not be commercially available on a sustained basis. I believe there are many fine species and a goodly number of individually superior specimen trees that will never be propagated to reach the market in volume—just because growers believe the costs of production exceed prices that government agencies can pay.

However, 50 to 100 years hence, 1975 may be considered the threshold of discovering, developing, and utilizing the genetic potential in the trees around us. As we pinpoint needs, so can we pinpoint our efforts. Early prejudices and categories that placed trees in lists are now being gradually removed or discarded. Many untested species are now being considered for potential use as municipal shade trees.

ASPECTS OF SELECTION AND EVALUATION

General Aspects

In the past there was little motivation for a nurseryman's involvement in the selection, evaluation, propagation, and testing of ornamental and shade trees. The change came when a need developed in metropolitan areas for kinds of trees that thrive and grow well in inner-city and highway plantings. This need gave us the opportunity to select clones for specific uses and effects: environmental tolerance, durable and predictable fall color, unusual floral effect, multi-season beauty (because of flowers, foliage, and fruit), distinctive functional form—to name a few.

A program for selecting, evaluating, and propagating tree cultivars is costly and time-consuming. It is best undertaken by a large wholesale-grower firm that produces a full lines of trees and has other markets in addition to the very important government market.

Whether a new selection originates from in-house efforts or from an outside source, reputable growers attempt to determine that this selection is, in fact, superior to the presently available kinds, or that it is sufficiently different, unusual, or unique so a potential market might exist. Without going into detail, I'll state that selections from different genera and species do require varying numbers of years in the testing program before comparable appraisals can be made. Appraisals of a flowering crabapple, a willow, or a poplar can be made after fewer years of observation than are needed for an oak or a ginkgo.

Substantial evaluation of certain growth characteristics or some other aspects will have to be made. These include:

1. What is the most economical method of propagation that produces a high percentage of trees having the desired size and form in the shortest time?
2. Will the existing cultural systems, which the nursery firm has determined are best suited to its overall operation, provide suitable methods of propagation and culture for the new selection?
3. Will the selection fit in the line of stocks that the firm is currently growing—in this case largely for the government market?
4. If sales of the selection are stimulated by reasonable advertising and promotion programs, will they soon reach and maintain a needed minimum?

(Cole Nursery's minimum is 500 per year.)

5. Is the quality of the selection up to the firm's previous introductions?
6. Is the selection patentable if the firm decides to apply? Patenting a plant does not guarantee market acceptance, but it does indicate the firm's belief in a strong and sustained demand for the new tree.

Methods of Testing and Evaluation

There are many different successful programs in plant testing. The diversity is due to the fact that each business or agency has to tailor its program to fit its personnel, funding, land, and propagation facilities.

There are a few truisms I should mention:

- Extensive knowledge of a wide variety of woody plants is helpful.
- Familiarity with growth habits and environmental adaptabilities of the species and genera in the program helps in suggesting possibilities and in reducing poor leads.
- One can never know too much about propagation.
- Except for the hobbyist or plant specialist, the goal is market acceptability. Successful introductions of the past are paying for today's testing costs. Today's selections should pay tomorrow's bills.

Cole's Evaluation Procedure

For each tree brought into Cole's program, a Test Plant Sheet (fig. 3) is filled out and placed in a loose-leaf binder, and it becomes the permanent record of the selection. Color slides of the selection are placed in transparent slide-holders and kept in the notebook with the test sheet. All notes, clippings, and back-up information that relate to the selection are kept in a separate file folder. For selections presently under consideration but not yet brought into the program, information is accumulated until the item is either acquisitioned or dropped. The last statement frequently applies to specimen trees growing outside the nursery; and for these, additional years of observation may be needed before a decision can be reached.

At the first opportunity, initial propagation work is started—with the goal of one or two dozen progeny of the parent tree. If the selection is in the nursery, propagation insures against possible loss when the parent tree is moved to a test-plant area. If the selection is growing outside, permission is obtained to collect propagation material.

A delay can be costly. We have lost the opportunity to test several promising specimens because site clearance, road widening, or accidental injury resulted in their removal before propagating wood was secured.

We want to know at the earliest possible date the selection's normal growth rate, its flowering and fruiting habits, and the natural shape it will assume. Pruning is, therefore, minimal on trees selected in the nursery. It is also minimal on one or two of the first propagated progeny for a selection growing outside of the nursery.

Nothing is as valuable as a color-slide record in evaluating tree selections. Photographing is not started until the progeny have grown enough or matured enough to substantiate earlier judgments. To make color evaluations constant, we have used Kodachrome II film (now replaced by Kodachrome 25). It permits valid color comparisons between different selections in the same season and between trees of the same selection in different years. Decisions on the worthiness of a selection for introduction or patenting are usually made by a group of management, sales, and production personnel. The color slides, test-plant sheets, field observations, and in-depth discussions give them the necessary information.

Too early culling of competitive selections may be unwise, and the evaluation period may be lengthy. For example, from a group of competitive selections, the

Figure 3.—The form used by Cole Nursery Company, Inc., to record data concerning the selection and evaluation of individual clones.

TEST PLANT SHEET NO. _____ Date initially filled out _____

PLANT NAME _____ *(botanical)* _____ *(common)*

Acquisition Number _____ Other Names, No's _____

ANTICIPATED MARKET POTENTIAL

as rated, date _____ *(red)* ; as rated, date _____ *(blue)* ; as rated, date _____ *(green)*

REASONS PLANT SELECTED FOR TEST

(Below, Circle Most Appropriate Rating)

1. Hardiest rating (Zone 2, 3, 4, 5, 6, 7, 8)
2. General Adaptability (wide - average - minimal)
3. Ease of transplanting (easy - average - difficult)
4. Ease of culture (easy - average - difficult)
5. Growth rate (fast - average - slow)
6. Can sell (Either B&B - b.r.) (Mostly B&B - b.r.) (Only B&B - b.r.)
7. Item is presently (well known - fairly well known - little known)
8. Plant to compete with, or to replace _____
9. Anticipated duration of demand (Long - 10 yrs. or more, Average - 5-10 yrs., Short - 1-5 yrs.)
10. Plant considered a (Superior form of a standard item, Superior Form of a lesser known item, Novelty item)
11. Volume of sales anticipated in (Retail nurseries, Government Agencies, Landscape Contractors, Golf Courses, Cemeteries, Other - specify _____

HISTORY

1. Source and/or date of original information _____
2. Plant suggested by _____
3. Location Parent Plant, or Seed Source _____
4. Parent Plant property of _____
5. Authority for testing. Letter Agreement _____ Contract _____ Other (specify) _____
6. Pictures in file _____ Existing pics suitable for cat. _____ for advertising _____
   Color _____ Black & White _____
7. Plant Patentable _____
8. Remarks _____

PROPAGATION

(Fill in, or circle as required)

1. Parent plant purchased _____, or received_____, date_____ PO No._____
2. Parent location (after purchase) _____
3. Propagation material forwarded by - PP, UPS, CAR, TRUCK. by_____ *(name & address)*
   _____ *(Date)* _____, as HWC, SWC, SCIONS, SEED, GR. PLT.
4. Received, date _____, CONDITION: EX, GOOD, FAIR, POOR
5. Units received _____ Propagated (date) _____
6. Initial propagation by SWC, HWC, GR., BUD, SEED
   a. Understock used _____
   b. Understock source _____
   c. PO No. _____DATE _____ SIZE OR AGE_____
   d. Understock: Date (Potted) (Planted) _____
      Date (Grafted) (Budded) _____
8. Location, 1st prop. plants _____
9. Transplanted to_____date _____
   Transplanted to _____ date_____
10. Remarks _____

NOTE: Record as above, each successive attempted propagation. (After initial propagation/s, see R and D Book and/or Stock Books for further propagation records.)

CONCLUSION

Having been tested and scored (see Evaluation Sheets) for _____years, the plant

1. Should be eliminated from further testing because_____

   Plants propagated to date should be disposed of as follows_____

or 2. Should be increased and introduced as a non-patented item because _____

or 3. Patent application should be started because _____

   Patent application started - Date _____ By_____
   Patent Attorney_____
   Patent File No. _____
   Patent granted - Date _____Patent No. _____
   Patent Assigned to _____Date_____
   If plant introduced by other than above, specify _____
   If plant owned by other (s), patent assignment obtained by _____
   Date _____ from _____

REMARKS _____

number is reduced to four. In the initial propagation, the first one propagates poorly and is dropped. Progeny of the other three selections are lined out for growth comparisons in the field under the usual cultural practices for that particular species. By the end of the second growing season, progeny of the third selection are only half as tall as those of the other two selections, so the third one is dropped. At the end of this field test, the available data are reviewed, and the second selection is favored because its pattern of growth is somewhat more uniform than the progeny of the fourth. Past experience suggests holding competitive selections fairly long in evaluations because of mishaps such as mixup in identity, overwintering loss in cold storage, accidental grubbing, and poor survivals after too-late transplanting.

Commercial Propagation Test

The acid test for a selection that has scored high in the initial evaluation is propagating and growing it to salable size of a minimal commercial quantity. Here the selection is handled as if it were already added to the line; so it receives the same method of propagation, the same cultural practices (spacing, pruning, shaping, etc.), as other clones of the same species. If progeny of the selection do well in the mini-commercial propagation test, it is then considered for an addition to the line and for possible patenting.

Marketability: "The Head Chopper"

In spite of how promising selections are judged at the time they are added to the test program, most are dropped somewhere along the way. Reasons for eliminating them include one or more of the following:

1. Unsuccessful propagation from a parent tree not growing in the nursery.
2. Tree extremely difficult to propagate.
3. Seedling understock of that particular species not available for budding or grafting when propagation wood of the parent tree is available.
4. Susceptibility to a pest that was not previously observed.
5. Reports from cooperators indicate hardiness less than anticipated.
6. Unacceptable degree of incompatibility with seedling understock.
7. Growth rate of the first-propagated progeny too slow to be commercially acceptable.

Because a large part of the municipal market prefers to buy bare-root trees, a slow-growing but otherwise superior clone would not be competitive if it had to be offered for sale only as B&B stock—trees in such form costing 2 to 3 times more than bare-root trees of the same size.

Marketability is "the head chopper". From the time the evaluation of a selection is started, the one burning question that is repeatedly asked is: "Will this item be marketable in substantial, sustained numbers?"

Period of Evaluation

The period of evaluation is extremely variable. It is usually shorter for fast-growing trees than for slow-growing trees, for kinds that bloom and fruit early, for kinds that are easily propagated, as by budding, for kinds that are inherently pest-free, and for selections from species with which the firm has experienced a favorable record of production and marketing. For genera like *Malus* and *Crataegus* the period may be 6 to 8 years; for late-maturing genera like *Ginkgo* and *Quercus* 12 to 15 years; and for intermediate types 8 to 12 years.

However, there are other variables. If the parent tree is mature, the period may be shortened—because we can judge the probable shape of vegetatively reproduced progeny by it. However, if the parent selection is a relatively young seedling, the test period may have to be stretched out—especially if one of the main reasons for its selection is an assumed mature form.

PROBLEMS IN VEGETATIVE PROPAGATION

Graft Incompatibilities

Propagating vegetatively new clones of shade and ornamental trees provides opportunities in the volume production of species seldom reproduced other than by seed, but problems have developed in grafting (often budding, rather than use of a scion). Observed incompatibilities include:

1. A swelling or overgrowth near the point of union, usually on the graft just above the union.
2. Incomplete "knitting" of graft and understock so only a portion of the union appears normal. This may cause uneven increases in diameter at the point of union.
3. Partial incompatibilities that are relatively difficult to detect. One shows up as premature fall coloring on scattered trees in a nursery block, especially among red and silver maples. A check then usually shows poor or weak unions on affected trees, which are also usually somewhat smaller and less vigorous than unaffected trees. Affected trees are considered unsatisfactory and are grubbed out. Presumably some percentage of unaffected stems may also have an incompatibility that might show up later. For example, a small percentage of the 'Sovereign' pin oaks, originating from buds or grafts, have broken cleanly at the point of union under the stress of a severe wind or impact—even though the unions had nearly normal appearance.

   Another symptom of incompatibility is a more than normal amount of sprouting, often as basal suckers, of the understock below the union. This may be caused by a difference in vigor of the understock and of the graft; and it occurs most commonly in *Malus*, but also to varying degrees in *Pyrus* and *Crataegus*.

"Own-Rooted" Trees

"Own-rooted" progeny should be a mirror image of the parent tree, but be free of the problems of incompatibilities found in grafting. "Own-rooted" progeny form the best alternative for clones susceptible to graft incompatibilities.

Propagation of "own-rooted" trees usually means by softwood or hardwood cuttings, but for certain selections propagation might be by root pieces. I have observed that when trees of certain kinds are dug for B&B stock with a tree spade, new plants may develop from root ends if the holes are not backfilled. Tree spades sever roots smoothly. Sprouting from the exposed root ends occurs quite readily in *Gleditsia*, *Liquidambar*, *Malus*, and *Prunus maritima*.

Problems in "own-root" propagation include at least the following:

1. A larger amount of scion material is required for the same number of progeny than in budding or grafting.
2. Growth during the first year, and sometimes into the second or third years, lags behind that of grafted trees.
3. Trees that have slower growth during the early years are likely to be less well-formed than rapidly growing stems from other methods of propagation.
4. Age of the propagated tree affects transplanting success and rate of recovery. Other factors being equal, the younger the tree, the more likely it will transplant successfully as bare-root stock.

However, advances in "own-root" propagations are, I believe, sadly needed. Can the techniques of this propagation method be so improved that it could become economically competitive with budding?

CONCLUSION

In this paper I have pointed out the long cycle involved in shade-tree production and the even longer cycle involved in the selection and evaluation of shade trees. I stressed the need for improved methods of vegetative reproduction if clones that are difficult to propagate are to be selected, produced, and used. If a clone cannot be mass-produced at reasonable prices, even the most desirable one will receive limited, if any, acceptance in the trade. Hence the need for providing effective means of vegetative reproduction is often as important as the initial selection and evaluation of clones.

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WINTER INJURY TO CONTAINER-GROWN PLANTS

by FRANCIS R. GOUIN, *Associate Professor, Department of Horticulture, University of Maryland, College Park, Maryland 20742. (Scientific article No. A2156, contribution No. 5123, of the Maryland Agricultural Experiment Station.)*

ABSTRACT. The overwinter survival of woody ornamental plants growing in containers or in raised planters depends on the cold-hardiness of the roots and on the amount of protection from the cold that the roots receive. Temperatures at which roots of many ornamental plants are killed range from −5°C to −18°C. The temperatures at which roots are killed depend partly on the age and maturity of roots: old roots are more cold-hardy than young roots. Increasing the cold-hardiness of roots through the use of growth regulators or fertilizers seems impractical at present.

CONTAINER PRODUCTION of ornamental plants allows nurserymen to grow a greater number of plants per acre without significantly increasing labor cost over that required for field production. Because the media are modified for optimum growth of plants, ornamentals grow more uniformly in containers than under field cultivation, and plants reach marketable size in minimum time. Furthermore, plants growing in containers can be transplanted successfully almost any time of the year.

Most ornamental plants are adaptable to container production. However, plant height and spread are limited by the size of the containers used. Large upright plants can be grown in containers, but stability is a serious problem.

One of the major factors limiting the use of containers by the nursery industry of the Northeast is root damage when ornamentals are overwintered in containers. Until recently, most winter injury has been attributed to desiccation. To prevent desiccation, nurserymen have constructed inexpensive plastic-covered greenhouses to protect their plants from drying winds, scorching sun, and rapidly fluctuating temperatures. To reduce heat buildup during warm winter days and in the early spring, the greenhouses are either covered with white plastic or painted with white latex paint. However, even in the protection of these greenhouses, many species of ornamentals seldom survive most winters without symptons of winter injury. Although the symptoms may go unnoticed until early summer.

The difference in winter-hardiness of plants growing in the ground and of the same species growing in containers or

planters has been a difficult-to-resolve problem. Winter injury is seldom a problem in these species when the plants grow in the nursery field or landscape. In recent years several studies have demonstrated that winter injury of many species of plants growing in containers can be attributed to lack of root hardiness *(Gouin 1969; Havis 1972, 1974; Havis and others 1972; Mityga and Lanphear 1971).*

ROOT SUSCEPTIBILITY

It has been known that the roots of woody plants are not as cold-hardy as the above-ground portions. However, the differences in cold-hardiness between roots and stems or leaves have never been determined for ornamentals.

Because container-grown plants are grown above the surface of the ground, roots within the growing media are subjected to nearly the same low temperatures as the tops. Nurserymen and landscape contractors have generally overlooked this difference in cultural methods when selecting plants to be grown in containers.

In 1970 Havis published a list of 19 species of ornamentals and their root-killing temperatures. In 1974 he expanded this list to include 30 species (table 1). His list indicates great differences among species of ornamentals and the temperatures at which roots are killed.

Havis reported that different species may not show similar responses in stems and foliage to root injuries. Species of *Ilex*, *Daphne*, and *Cryptomeria* that had damaged roots maintained normal healthy foliage while under cool, moist conditions; but when they were ex-

Table 1.—Tolerance of plant roots in winter storage to low temperatures[1]

Species or cultivar	Safe temperature		Killing temperature	
	°F	°C	°F	°C
Magnolia soulangiana	26	(— 3)	23	(— 5)
Magnolia stellata	26	(— 3)	23	(— 5)
Cornus florida	24	(— 4)	20	(— 7)
Daphne cneorum	24	(— 4)	20	(— 7)
Ilex crenata 'Convexa'	24	(— 4)	20	(— 7)
Ilex crenata 'Hetzi'	24	(— 4)	20	(— 7)
Ilex opaca	24	(— 4)	20	(— 7)
Ilex crenata 'Stokes'	24	(— 4)	20	(— 7)
Cotoneaster horizontalis	22	(— 6)	18	(— 8)
Pyracantha coccinea	22	(— 6)	18	(— 8)
Cryptomeria japonica	20	(— 7)	16	(— 9)
Cotoneaster adpressa praecox	20	(— 7)	16	(— 9)
Viburnum carlesii	20	(— 7)	15	(— 9)
Cytisus praecox	20	(— 7)	15	(— 9)
Acer palmatum 'Atropurpureum'	17	(— 8)	14	(—10)
Taxus X media 'Nigra'	15	(— 9)	10	(—12)
Azalea 'Gibraltar'	15	(— 9)	10	(—12)
Azalea 'Hinodegiri'	15	(— 9)	10	(—12)
Kalmia latifolia	15	(— 9)	*	
Leucothoe catesbaei	15	(— 9)	*	
Mahonia aquifolium	15	(— 9)	*	
Pieris floribunda	15	(— 9)	*	
Pieris japonica	15	(— 9)	*	
Rhododendron carolinianum	15	(— 9)	*	
Rhododendron catawbiense	15	(— 9)	*	
Thuja occidentalis	15	(— 9)	*	
Euonymus fortunei 'Colorata'	10	(—12)	5	(—15)
Juniperus horizontalis 'Plumosa'	10	(—12)	0	(—18)
Juniperus horizontalis 'Douglasii'	10	(—12)	0	(—18)
Rhododendron 'PJM'	10	(—12)	0	(—18)

[1] From Havis (1974) and published here with his permission.
* Killing temperature of roots has not been determined, but safe temperature has been estimated from storage experiments

posed to warm, drying conditions, their leaves shriveled and died. *Cornus*, *Magnolia*, and *Viburnum* plants that had suffered root damage started to leaf out, or to develop new shoots, and then suddenly wilted and died. Root-damaged plants of *Cotoneaster* and *Pyracantha* looked normal for a few weeks, even in warm weather, and suddenly died just after new growth started. Root-damaged plants of *Taxus* and *Juniperus* remained apparently healthy but did not grow.

The age and maturity of roots affect their cold hardiness. Mityga and Lanphear *(1971)* found from their study of artificially hardened plants of *Taxus* X *media* 'Hatfieldii' that young roots (cream- to white-colored roots, including root tips) were killed at −3°C; secondary mature roots (dark red to brown roots immediately above young roots) were killed at −7°C; and primary mature roots (roots near the base of the stem) were killed at −11°C.

Winter-storage conditions can greatly modify root losses to cold temperatures. In a study of container-grown *Buxus sempervirens*, some plants were overwintered in an unheated plastic shelter, and other plants were protected by microfoam *(Gouin 1969, 1973)*. The latter plants, which had no visual injury to their root systems, produced more top growth during the following season than plants stored in the unheated plastic shelter, and they had dry and shriveled roots in the spring (fig. 1)—even though all plants had apparently healthy foliage. Similar treatments of *Ilex crenata* growing in containers also produced marked differences in the appearance of root systems in the spring. Roots of plants overwintered in the unheated plastic shelter looked black and water-soaked when the containers were removed from storage, whereas roots in the microfoam treatments were white and active (fig. 2) and similar in appearance to *Ilex* roots before winter storage.

ROOT INJURY AS IT AFFECTS SURVIVAL AND GROWTH

Differing extent of damage within root systems seems to be responsible for great differences in the growth of tops among container plants of the same species. Plants that have suffered extensive root damage from being overwintered without adequate protection are less likely to grow during the following spring

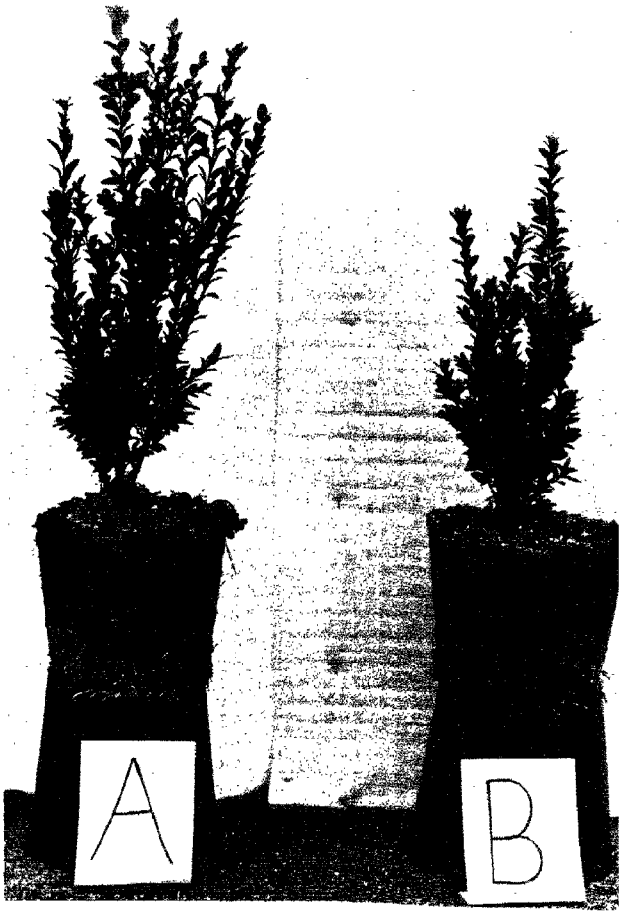


Figure 1.—Buxus sempervirens plants at the end of the second growing season. Plant A was protected from cold injury to its root system during the previous winter by the use of microfoam. Plant B was overwintered in an unheated, plastic-covered shelter; and its roots were damaged by cold.



Figure 2.—Plants of Ilex crenata overwintered in containers, but under different conditions. Plant on left was in an unheated, plastic-covered shelter: note the blackness of its roots and the lack of white root tips. Plant on right was overwintered under microfoam: note its active white roots, an indication that its root system was not damaged by cold.

than are plants that lose only their young roots. Plants that suffered no root-kill are more likely to resume normal top growth than are plants that lost either their young roots or both young roots and secondary mature roots. The poor and irregular growth resulting from root injury due to cold is often confused with that caused by damage in transplanting.

IMPORTANCE OF COLD-HARDINESS OF ROOTS

Plants selected for growing in containers or raised planters should have sufficiently cold-hardy roots. In fact, cold-hardiness of roots should receive primary consideration. Because different species of woody ornamental plants differ in cold-hardiness of roots, selections between species is possible. Less specific information is available on differences between species within genera and between geographic races within species. Presumably species or races growing in widely different climates, such as Florida and Maine, do differ in cold-hardiness of roots. However, from the limited information available (table 1), cold-hardiness of roots within species or races growing within a given climatic area seems to be similar.

The successful growing of ornamental plants in containers or raised planters in the Northeast depends on the proper selection of plants and on sufficient protection of roots during the winter months.

Plants must have sufficiently hardy root systems so most roots can survive the minimum temperatures occurring in unprotected containers, or the containers must be so protected that growing media stay above root-killing temperatures. In the spring of 1970, the City of Manchester, New Hampshire, planted fifty *Gleditsia triacanthos* 'Shademaster' trees (1¼ inch caliper) in concrete raised planters (4 feet in diameter) along its shopping district. Plants were so well cared for during the first growing season that they produced an abundance of new top growth. However, in the spring of 1971 not one of these trees was alive regardless of its location within the shopping district. The most probable cause of death was root kill from low temperatures. *Gleditsia triacanthos* is considered by Wyman *(1965)* to be hardy under air temperature of —10 to —20°F.

CULTURAL PRACTICES AND THEIR EFFECTS ON ROOT HARDINESS

According to present knowledge, most cultural practices do little to increase the cold-hardiness of roots. Neither additions of plant nutrients nor the use of chemical growth regulators increase the hardiness of roots of woody ornamentals *(Gouin 1969, Havis and others 1972, Mityga and Lanphear 1971)*. Altering the level of plant nutrients in the growing media above or below optimum levels for normal plant growth does not increase root hardiness. Neither foliar nor soil applications of plant growth regulators have increased the cold-hardiness of roots over winter.

Little is known about the mechanism of cold injury to roots of woody plants and the chemical or morphological factors that determine hardiness. If more information about these factors were known, it might be possible to alter cultural practices so as to increase root resistance to cold.

At present, cultural practices most commonly used in preventing root-killing temperatures in containers involve som form of protection. One method used b nurserymen in the Northeast is to irrigat containers biweekly or monthly durin the winter storage months. Such irriga tion not only delays the freezing of roo balls (because saturated root balls freez more slowly than dried ones); but als thaws, at least partially, root balls tha are frozen. Because the water tempera ture is above freezing, roots are subjecte to somewhat higher temperatures tha those in unirrigated containers.

An even more effective method of pro tection than irrigation is the use of micro foam covers. Microfoam is a white, pliable styrofoam-like packaging material, avail able in rolls 5 feet wide, 250 feet long and ¼ inch thick. It is light-weight, has a high insulating value, and reduces ligh intensity by about 50 percent.

To use microfoam for protecting con tainer stock overwinter, first water th plants thoroughly in late fall or earl winter and allow the containers to drai for 24 hours. Then in a well-drained are lay upright plants on their sides an leave spreading plants standing. Pack th plants tightly together, but expose a much of the foliage to light as possible Cover the plants with a layer of micro foam so that the edges touch the ground Several sheets may be taped together t form a wide blanket. Cover the micro foam with white polyethylene plastic an seal its edges to the ground with soil. Ir late winter or early spring, uncover th plants and stand upright those that were laid on their sides.

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CONTAINER TREES FOR USE IN LANDSCAPING

by WILLIAM FLEMER III, *President, Princeton Nurseries, Princeton, N.J., and Chairman of Advisory Council, U.S. National Arboretum, Washington, D.C.*

ABSTRACT. In planting trees, the current trend is to place increasing numbers in containers rather than in the ground. Conditions provided by containers are far from ideal: greater root hardiness is required than in trees planted in the ground. Methods and soil mixtures for improved growth in containers are described. Tree species especially suitable for planting in containers in the various climatic zones are briefly discussed, along with objectives for improving them for container use. Selection and breeding of new clones adapted to container growing are greatly needed.

THE USE OF TREES growing in containers as elements in landscape design is certainly not a new concept. They were a decorative feature of palace buildings in Egypt in the reign of Thutmose III (1430 B.C.), and the famous roof gardens of Babylon, built around 580 B.C., were one of the Seven Wonders of the ancient world. All of the vegetation in these "hanging gardens", as they were called, was grown in containers and container beds elevated one to several stories above the ground level.

An increasing number of city parks are in effect becoming container operations. More and more of the smaller city parks like Union Square in San Francisco and Mellon Square in Pittsburgh are giant container gardens on top of parking garages. In many places, to reduce construction costs, parks are stripped of topsoil, garages are built and roofed over; and then a deep layer of soil is placed on the concrete roof, and new vegetation is planted. This vegetation grows in what is actually a large container, with no access to subsoil water reservoirs as in natural soils.

CONTAINER GROWING

In the downtown areas of the modern city, most shade trees must be grown in containers. These may be concrete bowls or tubs placed upon the sidewalk, or they may be planting pits below the surface of the sidewalk. Even though the trees appear to be growing normally in soil, the area below the sidewalks is usually a maze of pipes, utility conduits, cellar space, or subways, with little soil.

Trees will not live forever in containers; but if the containers are large enough, several decades of successful growth can be obtained. There are bonsai trees living today that are 100 or more

years old. However, bonsai trees are so small that they can be removed from their bowls at frequent intervals to prune the roots, renovate the growing medium or replace it with new soil, and thus achieve the new root growth essential for the long life of any tree. Street trees growing in really large containers are so massive and heavy that the periodic drastic removal of trees and renovation of soil, essential steps in successful bonsai culture, are not possible. The best that can be accomplished—and it is very rarely done—is a partial removal of the container mix and replacement with new or enriched soil.

Proper Soil Mix

For this reason the nature of the soil mix in tree containers is of vital importance. To support a relatively long tree life, the soil mix must have certain properties, because it is all that the roots will have access to. They have nowhere else to go; they cannot grow down into the underlying pavement. This soil mix must have a porosity permitting the ready entrance of life-giving air and water and it must drain well enough to prevent stagnation. At the same time, the mix should retain a maximum of moisture without becoming waterlogged.

In such a mix, irrigation can be kept to a desirable minimum, and soil nutrients will not be leached out quickly. Humus, in the form of peat or similar organic substances, is the traditional material used to provide these essential properties in a soil mix for open ground. However, where trees are to be grown permanently in containers, a high proportion of humus in the mix is undesirable because it is soon used up by soil bacteria and fungi. As it disappears, the soil gradually subsides and compacts. A much more permanent substitute for humus as a soil conditioner is a porous inorganic material such as perlite or calcined clay particles. Vermiculite is also longer lasting than humus, but less permanent than the two mentioned above. Some humus content is valuable to promote growth after the tree is planted, but it should not exceed 10 percent of the volume of the mix.

One successful mix that has been tested widely is 45 percent (by volume) of sandy loam (Sassafras loam or a similar type), 10 percent sphagnum peat of a coarse grade, 25 percent horticultural-grade perlite, and 20 percent calcined clay particles (Turface or similar product). To this are added enough ground dolomitic limestone to bring the pH up to 6.0 if the soil is acid, superphosphate at a rate of 2 pounds per cubic yard of mix, and a small amount of fritted trace elements. If only a silt loam or clay loam is available as the soil component, it should be lightened by the addition and thorough incorporation of sand, or else the inorganic soil lighteners can be increased and the soil proportion decreased. If the available soil is strongly alkaline, the pH should be reduced by the addition of aluminum sulphate.

A good medium is essential for survival and continued growth of the trees. The failure of container-planted trees after a couple of seasons of growth has sometimes been blamed on a lack of hardiness of the species or clones used, when in reality rapid compaction of the soil in the containers was the cause.

Container Size

Another factor is the size of the container. The larger the containers, the better the survival and life expectancy of the trees planted in them. A general tendency is to choose containers that are too small. Trees grown in them rapidly reach a size at which there is very little leeway in watering. Defoliation or death of trees in small containers (2½ feet or less in diameter) can occur quickly in hot summer weather, especially if there is also a strong wind blowing. The older and larger the trees, the shorter the time they can survive without watering. In cold climates small containers freeze more rapidly and root temperatures drop much

lower than in large ones. The cold-hardiness of the roots of many trees and shrubs is much less than that of their aerial parts.

Root hardiness is the really critical factor, as many northern container nurserymen have learned to their sorrow. This factor has not been worked out for most trees, and much additional research is needed for clarification. It is safe to generalize that containers should be at least 3 feet in diameter and 2½ feet in depth and that, wherever space will permit, much larger containers should be used. Very tall narrow ones, besides being unstable in wind storms, freeze in rapidly from the sides. Very broad shallow ones, while stable and aesthetically pleasing, freeze inwardly very rapidly from the top and bottom, and they dry out with excessive speed in summer.

SELECTION OF TREES

Importance of Provenance and Species

The colder the climatic zone in which container planting of trees is undertaken, the greater are the difficulties of overwintering and the more limited is the list of varieties that will succeed. It is no accident that large-scale container production of nursery stock is limited to areas where winter freezes are rare or absent. In the selection of trees for container use, *provenance* is much more important than clonal selection. The geographical origin of tree races is a field to which foresters have paid far greater attention than have shade-tree producers. Foresters have done much research, but their efforts have been limited largely to species grown for timber or Christmas trees, mostly conifers such as loblolly and shortleaf pine, Norway spruce, Scotch pine, and Douglas-fir, which are not used for street-tree planting. In the field of ornamentals the surface has barely been scratched.

Trees and shrubs of foreign origin are a good example. Almost all of them have been propagated from a single origin, often an introduction dating back to the 19th century or earlier. Most of the Chinese and Japanese species came from sources close to major port cities, naturally enough, and little or no further exploration has been done for hardier or superior races. There is no question that in many cases far hardier races are waiting to be discovered and introduced. A good illustration is the Siberian elm *(Ulmus pumila)*. The first introduction was not winter-hardy in the prairie provinces of Canada. Later, a strain from a much colder area of the Amur River valley in China, raised by F. L. Skinner, proved to be fully hardy even at Dropmore, Manitoba, where the older strains were not.

Nor has research advanced appreciably farther in the case of our native woody ornamentals. Some tree species like *Cladrastis lutea* are very localized, with a restricted natural range. Many others, however, have an enormous geographical range such as American beech, northern red oak, and red maple, of which various races are native from Canada to Florida or Georgia. Red maples from the northern fringe of their range in Minnesota are among the hardiest of our broadleaf species, while those from the lower end of Florida are scarcely hardier than orange trees. For the Southern States, the provenance of shade trees is just as important as in the North, but heat tolerance is the important factor. Beech or hemlock propagated from New Hampshire seed grow feebly at best in low elevations of Alabama and the Carolinas. The same species grown from seed collected in Tennessee or Georgia make fine, vigorous specimens.

Container culture of landscape plants is relatively easy in areas with mild winters but increasingly difficult in successively colder zones. (Zones mentioned in this paper are those of Arnold Arboretum.) From Zone 6 north, it is increasingly likely that above-ground containers will freeze solid in winter, and furthermore that the soil temperature will drop

below 20°F, which appears to be the critical temperature for the root survival of many woody plants. For such areas, trees that are to be grown permanently in containers should be selected from northern races. Under natural conditions in Zone 5 the ground does freeze in winter, but it does not freeze very deep and the temperature within the frozen layer of the soil does not drop very low. In Zone 3 and the northern parts of Zone 4 the ground freezes on occasion to a depth of 3 or more feet and the soil temperature in the frozen part drops well below 20°F. Therefore in effect, a container tree in a severe winter in Zone 5 is really experiencing the winter root conditions of a much colder zone, and a race or clone originating from the latter will be much more likely to survive.

There is considerable evidence to indicate the importance of root hardiness as a factor for container landscaping. Exceptionally severe winters have played havoc with apple orchards in the northern states on several occasions. When there was little or no snow cover, the ground has frozen to great depths and entire orchards have been wiped out. In at least one instance, scions collected in the early spring, and bench-grafted on apple seedlings overwintered in protected storage, united and grew off normally, whereas the parent trees from which the scions were taken died as soon as the weather warmed up in late spring. It was the roots and not the trunk and branches that were killed. Experiences of this kind led to the use of the extremely hardy *Malus baccata* as an understock for northern orchards, and it is a preferred understock for ornamental crab apples destined for container culture.

From zone 7 south, cold-hardiness of the roots is not a serious problem. Winter protection may still be required for small ornamentals in 1- and 2-gallon cans. However, temperatures do not drop nearly so low as in the North, and freezes are of short duration. Plants of landscape size in large containers do not require protection because the large soil masses take a long time to freeze. Even if they do freeze, the soil temperature within such large containers does not drop to critical levels. Cultural problems are more likely to center on soil temperature during the summer months. As might be expected, races and clones of southern origin will perform much better than those from the far North. Unfortunately, although there has been some interest in selecting clones with superior cold resistance, little or no attention has been paid to selection for performance in the southern part of the range of most important trees.

In zone 9 and the southern parts of zone 8, the question of winter chilling requirements becomes interesting. *Cornus florida* seedlings grown from seed of Connecticut or New York races not only scorch badly in summer in these zones, but also break dormancy irregularly and poorly in the spring, whereas seedlings from local races grow normally. The original (and most widely grown) clone of *Cornus florida rubra* originated in Pennsylvania and will not thrive in Florida, although very southern races of *Cornus florida* are entirely satisfactory. Much work has been done on the dormancy behavior of the orchard peach *(Prunus persica)* and special clones with short-term chilling requirements have been selected for planting in southern orchards. Similar research is needed for shade and ornamental trees. Races of local origin are needed for successful landscape planting either in the open ground or in containers, races with short chilling requirements as a prelude to normal spring growth and with good tolerance of summer heat. From these adapted races clonal selections can be made for superior foliage, flowers, and branching habit. Many nursery growers and landscape designers are aware of the necessity to plant cold-hardy strains in northern zones, but few indeed realize that well-adapted southern strains are equally necessary for warm zones. The poor appearance of some landscape plant-

ings in the deep South is a result of neglecting this important factor.

Moisture stress is a problem with container trees, in inverse proportion to the size of the container used. Unless a careful maintenance program is followed—and this is much more the exception than the rule—soil moisture in containers will frequently approach the danger point. This is most troublesome during summer months when natural rainfall is undependable, daytime temperatures are high, and strong drying winds are frequent. Even if container trees are not killed outright, marginal scorching of the leaves is frequent, and partial defoliation may occur, both of which seriously mar the appearance of the trees.

In view of these problems, the logical approach is to select for container landscaping trees that are pioneer species ecologically and to avoid those that are climax species. The pioneer species are those that first colonize open land, and millennia of adaptation have conditioned them for surviving exposure to sun and wind. Thus, *Juniperis virginiana* or *J. scopulorum* will stand moisture stress that would kill *Tsuga canadensis*. Likewise *Quercus macrocarpa* or *Q. prinus* will thrive where *Acer saccharum* or *A. pensylvanicum* will not.

In the production of container trees for landscaping, provenance is just as important for drought-tolerance as it is for cold-hardiness. Trees like many of our native oaks and maples, which have a wide longitudinal range, from the humid East Coast to the edge of the dry Plains States, exhibit marked differences in moisture requirements. Races from the driest part of the species' range have a much greater potential for container use than races from areas with abundant natural rainfall. The former also tend to have a slower growth rate and smaller size at maturity, which extend their life and usefulness in the restricted soil of containers. They exhibit great clonal variation, and it is not difficult, in even the best geographical races, to select and propagate clones of marked superiority for container landscaping.

Resistance to Diseases and Insects

Natural resistance to insect pests and fungus diseases is desirable for all shade trees. It is even more important for trees destined for container use. Such trees are already struggling with adverse environmental conditions and do not have the reserves to survive an attack. The trees are usually located in enclosed courtyards, on raised roof gardens, or in other areas with poor access for spraying equipment. There is usually dense pedestrian traffic in such locations too, which means that spraying must be done during night hours if it is to be done at all. For these and other reasons, preventative maintenance is likely to be minimal, and natural resistance is especially desirable.

Enormous efforts—so far unsuccessful—have been made to find clones with natural resistance to spectacular lethal diseases like chestnut blight and Dutch elm disease. Much less attention, if any, has been paid to selection and breeding for resistance to nonlethal but disfiguring diseases and insects. There is great clonal variation in disease resistance. For example, *Malus* 'Hopa' is especially susceptible to defoliation from apple-scab disease *(Venturia inaequalis)*, whereas *Malus* 'Zumi Calocarpa' and clones of *Malus baccata* are virtually immune. Powdery mildew (*Sphaerotheca* sp.) badly disfigures the English oak *(Quercus robur)*, but occasional individuals occur that are free of it. Similarly there are occasional rare specimens of horsechestnut *(Aesculus hippocastanum)* that do not get the leaf blotch disease *(Guignardia aesculi)*, which defoliates the normal individuals by midsummer in many areas.

Marked resistance to insect pests is less frequently observed than resistance to fungus diseases, but it does occur. When the American elm was the largest selling species of all shade trees, our firm used to propagate a clone with exceptional resistance to the elm leaf beetle

(Pyrrhalta luteola), but we abandoned it when the Dutch elm disease stopped the planting of elms. When the Japanese beetle *(Popillia japonica)* reached the climax of its abundance in New Jersey 40 years ago, our firm selected and for a time propagated a clone of *Tilia cordata* that was virtually untouched by the pest.

The time is now ripe for serious attention to selection and breeding for natural resistance to insects and fungi.

SPECIES WARRANTING ATTENTION

Most of the following species were included in the American Horticultural Society's preliminary listing of trees that show special tolerance for urban growing conditions. The species are grouped arbitrarily under the coldest climatic zone in which they are reliably hardy, as a convenience for tree breeders who are working in these particular zones. However, the same species are very useful for container use in warmer climates.

Zone 2

Acer negundo (boxelder).—A poor choice wherever better maples are hardy, but useful for its extraordinary hardiness. Strains from the extreme northern edge of its range should be used for selection work.

Aesculus glabra (Ohio buckeye).—The hardiest of all the *Aesculus* species, free from leaf blotch disease, and some individuals show very good fall color. Can be hybridized with *A. hippocastanum* for a cross having much more showy flower trusses. The hybrids are very light fruiters, an advantage in a container tree.

Betula papyrifera (paper birch).—The best of all the white-barked birches for resistance to bronze birch borer. Seedling populations also exhibit wide variation in susceptibility to birch leaf miner, a difficult pest to control in the eastern part of the continent where it is native. Individual seedlings also vary in the age at which their bark turns white. Other qualities being equal, individuals that attain white bark early in life are superior for ornamental purposes.

Prunus maackii (Amur chokecherry).—One of the most ornamental of the small cherries, with polished yellow-brown bark. Selection objectives would include a more upright growth habit and larger racemes of flowers.

Prunus padus (European birdcherry).—The most showy-flowered of the very hardy cherries. There have been many European selections, two of which deserve re-introduction into the nursery trade after heat treatment to clean up virus problems. These are the variety "Watereri", which bears racemes of larger-than-normal flowers up to 8 inches in length, and 'plena', which bears semi-double flowers that last much longer than the single-flowered types.

Syringa amurensis japonica (S. reticulata) (Japanese tree-lilac).—A fine small tree bearing showy heads of white flowers in early summer. Seedlings vary in habit of growth and in size and density of the flower panicles. The cultivar 'Ivory Lace' from Canada is indicative of the improvement that even simple selection can produce.

Ulmus pumila 'Dropmore' (Dropmore Siberian elm).—This strain has remarkably superior hardiness in comparison with the species in general. A large seedling population of the Dropmore strain would yield some cultivars with greatly improved form since, like all elms, it is a very variable tree.

Zone 3

Acer ginnala (Amur maple).—One of the hardiest of all maples, with a clean habit and outstanding fall color. Most seedlings are very twiggy and tend to produce crooked trunks. Occasional individuals have marked apical dominance and produce straight trunks with fewer side branches, a form that can be readily pruned into standard tree form.

Celtis occidentalis (common hackberry). This species is particularly well

adapted to container use because its roots are very tolerant to cold. It has a great latitudinal range, and northern genotypes should be used. Selection should emphasize natural resistance to witches' broom, the scourge of the species.

Malus cultivars (crabapples).—Most are not winter-hardy north of zone 4, but *Malus baccata* and its descendants are much more cold-tolerant and also have the desirable trait of high resistance to apple-scab disease. Objectives should include double and hence sterile flowers, a wide range of colors, and natural resistance to both apple scab and fire blight.

Tilia americana (American linden).—Breeding should focus on dense crowns and smaller leaves. The clone 'Redmond' (erroneously reported to be a clone of *T. euchlora*) is an example of the latent potentialities of this very hardy tree.

Zone 4

Acer rubrum (red maple).—Almost all the good clones of red maple, except for the Arnold Arboretum clone 'columnare', are of Zone 5 or 6 origin. There is great need for trees with reliably red fall color, but with greater hardiness than 'October Glory' and 'Red Sunset', especially for container use. In selection, emphasize large and deep-red flowers for spring effect, as these vary enormously in half-sibling seedlings.

Aesculus hippocastanum (horsechestnut).—One of the most spectacular of the hardy trees when in flower. Breeding should concentrate on large floral trusses and freedom from leaf-blotch disease. Hybridization with other species can greatly increase the color range of the flowers, but the progeny should be ruthlessly culled for freedom from foliar diseases.

Amelanchier sp. (shadblow or serviceberry).—This genus has been badly neglected, but has great ornamental potential. Objectives would include double or at least semi-double flowers, a good non-fading pink clone, and selection for fall color, which is variable.

Zone 5

Pyrus calleryana (Callery pear).—New clones are coming on the market, but the species still has unrealized potential. Double flowers (which will extend the length of blooming display), improved winter hardiness, and more brilliant fall color are all important goals. Callery pear thrives in city conditions.

Sophora japonica (Pagodatree).—An exceedingly variable species. Improved growth habit, partial or preferably total sterility by means of double flowers, and the production of a better clone with violet flowers should be sought.

Zelkova serrata (Japanese zelkova).—The best selections are promising substitutes for American elm. Existing races come from a very limited—and by no means the most cold-hardy—provenance.

Zone 6

Corylus colurna (Turkish filbert).—A rare, but very fine tree, pyramidal in form, with clean foliage and marked resistance to drought. Seedlings vary considerably in shape and foliage, and the best forms are well worth selection and vegetative propagation.

Crataegus phaenopyrum (Washington hawthorn).—The best of all the *Crataegus* species for city use, it is very tolerant of city conditions, with first-rate flowers, foliage, and fruit. Not very variable, but superior individuals do occur. Breeding objectives would include adding color in the flowers, less pendant lower branches at maturity, and thornlessness.

Prunus cerasifera (myrobalan plum).—An excellent container plant, tolerant of confinement and resistant to drought. All named clones were selected for the deep color of their purple foliage. Cultivars with less purple foliage, more vigorous growth, and larger and more richly colored flowers would be a great improvement.

Maclura pomifera (Osageorange).—Tough, hardy, and very drought-tolerant. Dioecious, so only male clones should be

used. Selected clones have a fine erect branching habit and excellent lustrous foliage. The bark is handsome in winter.

Zone 7

Celtis australis (European hackberry).—An excellent shade tree, reaching noble stature on open ground, but also withstanding confinement. It is not subject to witches' broom. The species is very variable in the size and quality of foliage, as well as in growth form. No selection has been done.

Cupressus sempervirens (Italian cypress).—This evergreen thrives in conditions of heat and drought. The narrow form var. *stricta* is a showy accent plant, and the broadly spreading var. *horizontalis* makes a fine small shade tree.

Magnolia grandiflora (southern magnolia).—The finest evergreen flowering tree. Usually seedlings are planted, and quality of their flowers and foliage is very uneven. Some superior named clones of American origin are appearing, but the possibilities for improvement have been by no means exhausted.

Zone 8

Lagerstroemia indica (crapemyrtle).—The few best forms are unequalled as flowering trees in the South. Growing them with multiple stems greatly enhances the attractiveness of their bark. Street forms should be bred for rapidity of growth and freedom from powdery mildew fungus. Dr. Egolf's new creations are especially promising.

Prunus lusitanica (Portugal laurel).—This species varies considerably in the thickness of its foliage and resistance to winter burn. It has been grown in the middle South since colonial times, but no selection has been done in this country. It withstands heat and confinement, and the glossy foliage of the best forms is outstanding.

Zone 9

Bauhinia variegata (orchid tree).—The showiest of the genus, in both the normal purple and white forms. Selection should emphasize a more upright growth habit and larger flowers.

Ceratonia siliqua (carob tree).—A clean tree with remarkable resistance to heat and dry soil. Many forms are scrubby and contorted in shape, but good ones with superior foliage do occur and would form a parental nucleus for improvement.

Olea europeae (olive).—One of the best of all container trees on the West Coast. Breeding efforts have been limited largely to improving the species for orchard purposes, the diametric opposite of ornamental use. Improved form, foliage, and partial or complete sterility would be the proper goals for breeding ornamental olives.

Quercus virginiana (live oak).—A strong contender for the title of the best of all the evergreen oaks. Highly variable in leaf size, leaf gloss, duration of foliage retention, and branching habit. At present only mediocre seedling trees are planted.

Zone 10

Delonix regia (flamboyanttree).—The showiest of all flowering trees. Long-lasting in a big container, and tolerant of adversity.

Ficus retusa (Indianlaurel fig).—Very broad and spreading, handsome evergreen. Most trees observed in this country and Puerto Rico appear to be a single clone. Better forms may exist in its native region.

Jacaranda acutifolia (sharpleaf jacaranda).—Most jacarandas sold are of seedling origin, and they vary considerably in size of the floral truss, size and color of the flowers, and length of time the foliage is retained. The genus is tolerant of root confinement.

CONCLUSION

The species noted above are by no means the only possibilities for container use. However, they do include many well adapted to container growth and were selected because they have received little or no attention from ornamental tree breeders. In my opinion they warrant more work by tree breeders.

SELECTION AND BREEDING OF MAPLES FOR URBAN AREAS

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ABSTRACT. Among its approximately 150 species, the genus *Acer* offers diversity in size, form, color, and adaptability. Genetic improvement of maples for urban environments will require studies of intraspecific variation, interspecific hybridization, and tolerance to *Verticillium* wilt and environmental stresses. Breeding and selection with small exotic maples has been neglected, yet might rapidly yield improved cultivars of high value for urban plantings.

THE MAPLES may constitute the most important group of trees available for planting in metropolitan areas. Among about 150 species, the maples offer great diversity in size, shape, leaf and fruit characteristics, and leaf coloration *(Mulligan 1958; May 1961, 1962)*. Moreover, most of them are easy to transplant, are long-lived, and grow well in a variety of soil conditions *(Irwin 1973)*. Most of the Japanese, Chinese, and Himalayan species are shrubs or small round-headed trees—just the size so much in demand for urban plantings. The genus *Acer* offers a virtually untapped genetic resource.

The genus extends over a major part of the northern hemisphere, and is found in almost all countries north of the Equator to Alaska and Siberia *(May 1961, 1962)*. South of the equator, species have been reported in Sumatra and Java.

Mulligan *(1958)* gave their distribution as follows: China, 58 species; North America, 25 species; Japan, 16 species; Europe, 13 species; Taiwan, 11 species; southeastern, western, and northeastern Asia, 16 species; India and Burma, 6 species, and Korea, 5 species. The greatest diversity of species, or principal center of the genus, is found in the eastern Himalayan Mountains and western China.

CYTOLOGY

The basic chromosome number in the genus *Acer* is n = 13. Of the approximately 46 species examined for chromosome number, 42 have been reported as diploid *(Wright 1957, Mehra and others 1972)*. *Acer saccharinum, A. pseudoplatanus,* and *A. carpinifolium* are tetraploid *(Wright 1957)*. Santamour *(1965)* reported that trees of *A. rubrum* may exist as a hexaploid, octoploid, or septaploid. Aneuploid hybrids between red and silver maples are also possible.

TAXONOMY

The only comprehensive monographs of the genus are those of Pax *(1902)* and Murray *(1970)*. Pax listed 13 sections of the genus: *Platanoidea, Campestria, Saccharina, Spicata, Palmata, Glabra, Integrifolia, Indivisa, Macrantha, Lithocarpa, Rubra, Trifoliata,* and *Negundo.* Rehder *(1940, 1949)* later recognized only two sections, *Acer* and *Negundo.* Section *Acer* contained 13 series, which corresponded to 12 of Pax's sections plus Rehder's *Arguta.* Critchfield *(1971)* surveyed maples with medium-size or small leaves and grouped the species into four categories based on shoot growth and heterophylly. His findings agreed with the taxonomic classifications of Pax *(1902)* and Fang *(1966)*. He emphasized, however, that past failure to recognize and deal with heterophylly in *Acer* has imposed unnecessary restrictions on the scope and usefulness of maple classification.

Murray *(1970)* divided the genus *Acer* into seven subgenera, and these into lower sections and series. According to this scheme, the subgenus *Acer* contains most species and is split into 16 sections. Fowden and Pratt *(1973)* surveyed the occurrence of cyclopropylamino acids and examined their pattern of distribution against Murray's classification. The ability to synthesize these acids was restricted to the members of certain sections; and when several species from an individual series were analyzed, all showed a common pattern. One species, *A. distylum,* was characterized with a single ninhydrin-positive compound. Momotani *(1962)* had reported previously that *A. distylum* exhibited certain unique features of seed protein composition.

Ziegenfus and Clarkson *(1971)* used polyacrylamide disk electrophoresis, immuno-electrophoresis, and double diffusion to compare seven taxa of *Acer* native to eastern North America. The members of the section *Saccharina* were found to have close protein similarity. *A. negundo,* thought by several workers to be the most distinct of the maples, was found to have high protein similarity with the members of the section *Saccharina.* The traditional placement of *A. rubrum* and *A. saccharinum* in the same section was supported by the relatively high protein similarity of these taxa. Data obtained by serological techniques and disk electrophoresis were found to be complementary. Thus these chemical experiments confirmed morphological and genetic evaluations of the relationships among species.

INTRASPECIFIC VARIATION

Wide variation within a species allows for rapid genetic progress, because initial selection of the best populations gives a superior base from which advances can be made. The larger and more variable the array of phenotypes available for selection, the greater are the prospects for genetic improvement. It is important, therefore, to determine the magnitude of genetic variation within each maple species. Little research has been directed to this end, even though most maples grow over a wide range of habitats.

Sugar maple *(A. saccharum)* has been more intensively studied than any other maple species. Much of the research has uncovered considerable variation in timber quality *(Kriebel 1968)*. In a summary paper, Kriebel and Gabriel *(1969)* reported marked variation in winter hardiness, tolerance to summer heat and drought, chilling requirements, time of onset of dormancy, branching habit, growth rate, and sugar concentration. Narrow-crown types could be selected from Appalachian and northern origins. Drought-resistant genotypes of intermediate size and bushy crown could be made from trees native to southern Illinois and possibly southern Indiana. For the South, the Florida sugar maple (subspecies *floridanum)* offers excellent possibilities for selection of compact types of small size at maturity.

A red maple *(A. rubrum)* seed source and progeny test we have carried out at

Delaware, Ohio, has shown considerable variation in fruit traits, height growth, autumn coloration, time of flushing, and cold hardiness *(Townsend 1972, 1975)*. We have also uncovered significant variation in tolerance to drought *(Townsend and Roberts 1973)*, *Verticillium* wilt *(Townsend and Hock 1973)*, and air pollution *(Townsend and Dochinger 1974)*. Important information on adaptability of different seed-source progenies will be forthcoming from performance evaluation of progenies outplanted in Ohio, Indiana, Iowa, Michigan, Missouri, Wisconsin, and Minnesota. We also have established two urban plantings of red maple progenies, one in Cleveland and another in Pittsburgh, to determine which groups can best tolerate urban stresses.

Wright *(1949)* found pronounced genetic differences between wild trees of silver maple *(A. saccharinum)* growing in a limited geographic area. There were significant differences among progenies in the amount of winter-killing and in the number of branchlets that developed in the axils of uninjured leaves on the current year's growth.

Research related to intraspecific variation in other *Acer* species has been very limited. Demos and others *(1973)* grew *A. negundo* under both indoor and outdoor conditions. Seedlings were grown from seed collected from New York, Ohio, Tennessee, and Texas. Frost resistance increased as the length of the growing season at the seed origin decreased.

BREEDING

Little research has been concentrated in determining interspecific crossability patterns in *Acer*. Freeman *(1941)* produced *A. rubrum* x *saccharinum* hybrids. Wright *(1953)* attempted 35 different interspecific combinations. *A. platanoides* x *mayrii* and *A. platanoides* x *cappadocicum* grew vigorously after outplanting and showed hybrid vigor in their tenth year *(Wright 1962)*. *A. negundo* x *henryi* hybrids outgrew the female parent in the nursery, but later suffered winter dieback. Wright believed that in warm temperate climates this hybrid would be a promising ornamental because of its foliage, which remains pink or red during the summer.

Table 1 is a summary of reported hybridizations in the genus *Acer*. Many of the hybrids have been reported without essential morphological and biochemical data to verify hybridity. Albenski *(1946)* reported success in these crosses: *A. negundo* (♀) x *A. saccharinum* (♂), *A. negundo* (♀) x *A. platanoides* (♂), and *A. platanoides* (♀) x *A. negundo* (♂). However, insufficient information is given to conclude that true hybridity was present. As indicated in table 1, Zaikina *(1959)* reported success in eight crosses among nine species. Little evidence was given, however, to verify hybridity.

Genetic barriers to crossing seem to be present between species belonging to different sections. Many within-section crosses are possible. Wright *(1953)* reported that none of 24 attempted crosses between species belonging to different sections was successful.

Piatnisky *(1934)* ran experiments on selfing of 10 *Acer* species. Unfortunately, he did not germinate the seeds to determine the quality of seeds. For all species, a larger percentage of unfilled fruit developed from self- as compared to cross-pollination.

Inbreeding experiments with sugar maple have shown that there are significant differences between individual trees in self-fertility *(Kriebel and Gabriel 1969)*. Seed set in terms of numbers of flowers pollinated ranged from 8 to 27 percent. The close relation of percentage seed set after self- and cross-pollination of a given female parent indicated that self- and cross-sterility were associated.

The expression of agamocarpy is strong in sugar maple: fruit sets ranging from 36 to 94 percent were noted among unpollinated flowers of individual trees *(Gabriel 1967)*. However, less than 1 per-

Table 1.—Reported hybridizations in the genus Acer

Female parent	Male parent																	
	platanoides	*mayrii*	*cappadocicum*	*lobelii*	*campestre*	*monspessulanum*	*saccharum*	*macrophyllum*	*pseudoplatanus*	*tataricum*	*palmatum*	*japonicum*	*rufinerve*	*barbinerve*	*rubrum*	*saccharinum*	*henryi*	*negundo*
A. platanoides	..	S-5	S-5	S-4*	..	..	F-5	..	..	..	F-5	F-5	..	S-6	S-6 F-5	S-6	F-5	S-1, 6;F-5
A. lobelii	S-4*	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
A. miyabei	..	..	..	..	S-3	..	..	..	..	..	..	..	..	..	..	..	..	..
A. campestre	..	..	..	..	..	S-4*	..	..	S-4*	..	..	..	..	..	..	..	..	..
A. monspessulanum	..	..	..	..	S-4*	..	..	..	S-4*	S-4*	..	..	..	..	..	..	..	..
A. opalus	..	..	..	..	..	S-4*	..	..	..	..	..	..	..	..	..	..	..	..
A. saccharum	S-5	..	F-5	..	F-5	..	..	S-3	..	..	F-5	..	..	..	F-5	F-5	..	F-5
A. pseudoplatanus	S-6	..	..	..	S-4*	S-4*	..	..	..	..	..	..	..	..	..	..	..	..
A. buergerianum	..	..	..	..	..	..	..	..	..	..	F-5	..	..	..	..	..	..	..
A. tataricum	S-1	..	..	..	S-1	S-4*	..	..	..	..	..	..	..	..	..	..	..	S-1
A. palmatum	F-5	..	..	..	..	..	F-5	..	..	..	..	F-5	..	..	..	..	..	F-5
A. davidii	..	..	..	..	..	..	..	..	..	..	..	..	S-3	..	..	..	..	..
A. pensylvanicum	..	..	..	..	..	..	..	..	..	S-4*	..	..	..	..	..	..	..	..
A. rubrum	S-6 F-5	F-5	F-5	..	F-5	..	F-5	..	..	..	F-5	..	..	..	..	S-2,5	..	S-6 F-5
A. saccharinum	..	..	..	..	..	..	..	..	..	..	..	..	..	..	S-5	..	..	..
A. negundo	S-6,1	..	..	..	..	..	F-5	..	..	..	..	..	..	..	F-5	S-1 F-5	S-5	..

* Direction of cross unknown.
S = Success in obtaining hybrids.
F = Failure in obtaining hybrids.

1 = Albenski *(1946)*
2 = Freeman *(1941)*
3 = Mulligan *(1958)*
4 = Rehder *(1940)*
5 = Wright *(1953)*
6 = Zaikina *(1995)*

cent of the unpollinated flowers produced filled fruits.

Details of flower ecology and flower morphology of *Acer* have been described by Mottier *(1893)*, Taylor *(1920)*, Stout *(1938)*, and Hall *(1951)*.

For success in interspecific hybridizations, it is essential that we learn much more about sex conditions, time of flower ripening, pollen dissemination and storage, and receptivity in *Acer* species. Most maples can be control-pollinated by using porous or loosely woven bags. Kriebel and Gabriel *(1969)* have found that white cotton bags are suitable; flowers in dark-colored cloth or paper bags are killed by overheating. Pollen can be applied by using freshly opened anthers as pollinating brushes, or from a vial with a camel's hair brush.

SPECIES WITH IMPROVEMENT POTENTIAL

Many maple species seem to offer essential attributes for planting in metropolitan areas. The introduction and evaluation of exotic species need to be expanded. These species could be used in a selection program, and for hybridization with native and other exotic species. The potential of a species in most cases will be based on its climatic and edaphic requirements. However, the range of adaptability of an exotic species may be increased by hybridization with other species. To develop new maple cultivars of smaller sizes, the following exotics seem to offer the best opportunities for breeding and selection:

A. argutum—hempleaf maple. A small tree, it reaches a height of 25 feet.

A. buergerianum—trident maple. This species is becoming more and more popular as a street tree, and has performed well in Oregon *(Ticknor 1973)*.

A. campestre—hedge maple. This species is especially useful as a screen hedge on relatively dry soils. It is usually pest-free and stress-tolerant, and shows dark green summer foliage and excellent yellow fall color. Kozel *(1974)* highly recommends this tree for planting directly beneath utility lines, based on information derived from a shade-tree evaluation project.

A. capillipes—Kisogawa maple. According to Ticknor *(1973)*, this species has grown and colored well in Oregon. Its bark is green with white stripes, and it does better in open areas than striped maple *(A. pensylvanicum) (Mitchell 1972)*.

A. carpinifolium—hornbeam maple. The crown is vase-shaped. The leaves closely resemble those of hornbeam, and produce a dense, dark crown. It grows to a height of about 30 feet.

A. circinatum—vine maple. Harkness *(1955)* stated that this species has shown brilliant red fall color in Rochester, N.Y., and grows as a shrub on poor soil. This tree is especially suited for urban lots because of its small, compact size, and its ability to grow well in partially shaded locations. Stems commonly are much twisted and turned.

A. ginnala—Amur maple. Grows to about 20 feet in height and forms a dense-branching, upright, rounded crown. Reliably cold-hardy, it shows conspicuous red samaras in summer and rich red foliage in fall.

A. griseum—paperbark maple. This has light brown bark that separates into paper-thin flakes, revealing orange bark beneath. The chief obstacle to more widespread use is its difficulty in propagation *(Fordham 1969)*. Controlled-pollinations should be attempted to overcome the problem of undeveloped embryos.

A. nikoense—Nikko maple. One of the few maples having a vase-shaped form, this species is especially attractive from mid to late October, when its leaves turn rose-red.

A. spicatum—mountain maple. The fruit of this species is unique in displaying an autumnal coloration equal or even superior to that of the foliage. Also, it is extremely cold-hardy and tolerates partial shade.

The preceding list includes the most promising small maples. Of the larger maples, *A. macrophyllum, A. rubrum, A. saccharum*, and *A. platanoides* offer the wide range of variability essential for rapid genetic improvement.

SELECTION AND BREEDING STRATEGIES

The major objectives of any future research on maples should be: (1) to develop knowledge of the existing and potential variability of native and exotic species of value in metropolitan areas; (2) to provide information and create breeding material that will make possible the development of genetically improved genotypes; (3) to breed, select and release new and more adaptable, maple cultivars.

Approximately 170 cultivars of *Acer* have been selected. Most of these are phenotypes that appear to be exceptional in leaf coloration or tree form. Many are planted widely, and for good reasons *(Davis 1973, Kozel 1974)*. However, none of these has resulted from a scientific systematic program of selection and breeding. As a result, no one cultivar has proved itself above-average in disease or insect resistance, or as especially adaptable to urban stresses. These latter characteristics should be primary goals of an urban-tree improvement program.

It is essential that we investigate the intraspecific variation in the most promising maple species. Establishment of one-parent progeny tests representing a wide range of sources can form the basis for a breeding and selection program and enable recommendations to be made of the best seed sources for seed collection. For example, we at Delaware, Ohio, are planning to select the best clones of red maple from those half-sib families that show the best performance throughout the north-central U. S. We also plan intraspecific crosses between superior clones.

The full potential of interspecific hybridization needs to be explored. Several geographic seed sources of each species should be used to test species compatibility. Hybrids that are developed should be tested in different areas to determine their range of adaptability and usefulness.

Acer species should be screened and compared in their tolerance to *Verticillium* wilt, air pollutants, cold, drought, and salt. Basic information is becoming available on the relative ability of different maple species to tolerate salt *(Lumis and others 1975)*. Studies such as these are necessary before an effective *Acer* breeding and selection effort can begin. More must be learned about environmental modifications of tolerance to *Verticillium* wilt, and host-pathogen interactions should be explored *(Dwinell 1967)*.

Research in forest genetics has shown that some stem characters such as straightness and tapering are less dependent on the environment and are possibly controlled by a simpler gene complex than growth rate *(Johnsson 1960)*. Therefore, we may make faster genetic gain on stem or trunk properties than on growth rate. In many species examined to date, the tendency of the stem to grow straight is associated with the geographical origin of the seed.

It is important that, once developed, promising clones should be planted in metropolitan areas, to be tested for adaptability to the composite of stress factors present in the city. The urban-tree geneticist must take responsibility not only for developing better trees, but also for assuring that their superiority is retained under adverse conditions.

Also needed are studies related to floral morphology and dichogamy, and apomixis. Problems of vegetative propagation must be overcome if promising species such as paperbark maple are to be used in an improvement program. Selection and breeding should include the improvement of specific rootstocks that would enable

trees to grow in containers or urban areas where root-growing space is limited.

CONCLUSION

Genetic improvement of maples will require cooperation among geneticists in federal agencies, geneticists in universities, nurserymen, arborists, and other specialists. All species of maples constitute a large reservoir of diverse trees that can be used for planting in metropolitan areas. Highest priority should be given to selecting, breeding, and testing of genetically identified progenies and clones.

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CHAPTERS ON THE GENETIC IMPROVEMENT OF ELMS

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ABSTRACT. The development, goals, and newly released clones of the Dutch elm breeding program are described. The merits of clonal and seedling varieties are compared; the latter have some advantages for landscaping purposes. They also contribute to gene conservation. In preparing for future disease risks, however, variability *per se* is valuable, be it through clones or seedlings. The recent variation in the fungus *Ceratocystis ulmi* is discussed; and two types of resistance are described. The value of Asiatic elms is stressed. Reasons for the slow progress in the improvement of American elm are given, and research needs are mentioned.

ELM USED TO BE the favorite tree for urban use over large areas of the northern hemisphere. It would still be so, if the Dutch elm disease, caused by the fungus *Ceratocystis ulmi* and spread by various elm bark beetles, had not appeared. The disease wrought havoc among the elms of Europe, North America, and parts of Asia; so that elm was no longer safe for new plantings.

Breeding now should serve to give the elm back to the city and landscape forester, as a tool to beautify man's world. In this paper I do not intend to give a complete survey of elm-breeding programs, but rather to concentrate on some general aspects and on some questions of current interest.

PLOTTING A COURSE

Tree breeding is more than just research.

To be effective, a breeding program should constantly readjust its course by confronting the desirable and the attainable. The breeder should try to develop the full picture of each as completely as possible, and then confront the two. At the start of the Dutch elm breeding program around 1930, the goal considered desirable was to develop a clone that was resistant to Dutch elm disease, was fast growing, and had exactly the same shape as the existing and popular clone *U.* x *hollandica* 'Belgica'. Subsequently, we found quite feasible the production of resistant and fast-growing trees; but, surprisingly, the production of a clone with the shape of 'Belgica' has proved as yet unattainable.

One can also proceed by considering first what is achievable, and then find out whether that is desirable. Resistant, fast-growing trees with the shape of Siberian elm were within easy reach, but appeared

not desirable. Similarly, the production of a resistant, small compact elm proved attainable; and more or less to our surprise, city foresters found it desirable, so it was released under the name 'Groeneveld' *(Heybroek 1964)*.

Neither desirabilities nor attainabilities are fully known from the start. The desirability of exposure resistance in clones in Holland was realized only in the course of the program. It was, in fact, only realized after the first two released clones had proved to be failures in this respect. New demands arise with changes in use patterns of tree species. In our country, some need has arisen for elms fit for use in the new forests that are being created near the cities—on formerly agricultural land and in areas reclaimed from the sea. This use allows or requires a different set of properties in the candidate elm.

Experience can try to predict what is attainable. Research, however, can open up new, unthought-of possibilities. Santamour *(1972a, 1974)* showed that it is possible to hybridize fall- and spring-flowering elms so that it is now possible to utilize the disease resistance of the fall-flowering Chinese elm in many new combinations. The availability of new parent material from plant introductions may likewise open up new possibilities. The weighing of desirability against attainabilities and *vice versa* is therefore a continuous process and an important responsibility of the breeder: he should explore both.

The breeder should further try to quantify his wishes. He should try to find out what minimum level of resistance is required, or in other words, how susceptible a tree can be and still be acceptable for practical use. Though absolute resistance may be ideal, it may well happen that, in the absence of the ideal, a tree with no more than moderate resistance would be very welcome, too.

In our program, this led to the realization that we have use for several types of elm for different purposes. Requirements differ for these different types of use (table 1). Under open conditions in the coastal area, where salt-laden winds are frequent, a tree with relatively poor marks for several properties will do, provided it has a high resistance to exposure and to the fungus *Nectria cinnabarina*. The latter can be particularly noxious in that area. For an elm that should profitably be grown under forest conditions, shape and exposure resistance have a low priority; however, the tree should produce good-quality timber in a short time.

THE DUTCH PROGRAM AND ITS RECENT RELEASES

When Dr. Christine Buisman was first appointed to study the Dutch elm disease and to try to find solutions for it, she started by making a wide collection of clones and seedlings of elm from every available source in 1928-30. S. G. A. Doorenbos, Director of Parks in the

Table 1.—Minimum requirement for elm clones for different uses in the Netherlands (adapted from Heybroek 1966)

Property	Property rating by type of use[1]		
	General	Coastal areas	Forest for timber
Resistance to Dutch elm disease	2	3	2
Shape	3	4	4
Growth rate	3	4	1-2
Resistance to exposure	3	1	4
Resistance to *Nectria cinnabarina*	3	2	3
Timber quality	4	5	1-2

[1] Rating: 1 = very high/very good for the particular property; 2 = high/good; 3 = medium; 4 = low/poor; 5 = very low/very poor.

Hague, helped her. This material was screened for resistance by artificial inoculation with *C. ulmi*, the causal fungus, in the following years, 1930-36. Absolute resistance would have been preferred, but Dr. Buisman soon found that such resistance did not exist, and that the expression of disease symptoms could vary considerably from year to year. It appeared that resistance was only relative. Therefore, not every seedling or clone with some slight disease symptom was discarded. Though a high proportion of the original material was thrown away because of too severe reactions to the disease, quite a few plants or clones were kept that were not too badly diseased. In this respect, the program resembled that of Cornell University *(Sinclair and others 1974)*.

This policy proved to be right. When the elms started to flower and my predecessors decided to cross them and select among their offspring, a collection of elms with a fair degree of resistance was available, and crosses of these sometimes produced seedlings with a much higher degree of resistance than the parents and with a desirable growth-habit. It was only fortunate the parents had not been discarded. On the other hand, some of the most resistant selections gave a much poorer offspring. The 'Christine Buisman' elm transmitted little of its high resistance to its offspring. Similarly, offspring of the resistant Siberian elm were often disappointing as regards resistance, also generally had an undesirable shape, suffered some twig dieback, and were often incompatible with the commercially used rootstock.

In the scheme of figure 1, the development of the breeding program is exemplified, giving the pedigree of the newly released clone 'Plantyn'. Before its release, it was known as No. 496. This clone was selected in 1962 from a population of hybrid seedlings, made in 1954 from parents as shown. As the grafts showed quality in growth and resistance at an early date, the clone was soon used in crosses. A very good cross was made in 1965 with the equally promising clone 495 (ancestry shown), yielding fine clones that are presently under test. These clones thus belong to the F_3-generation.

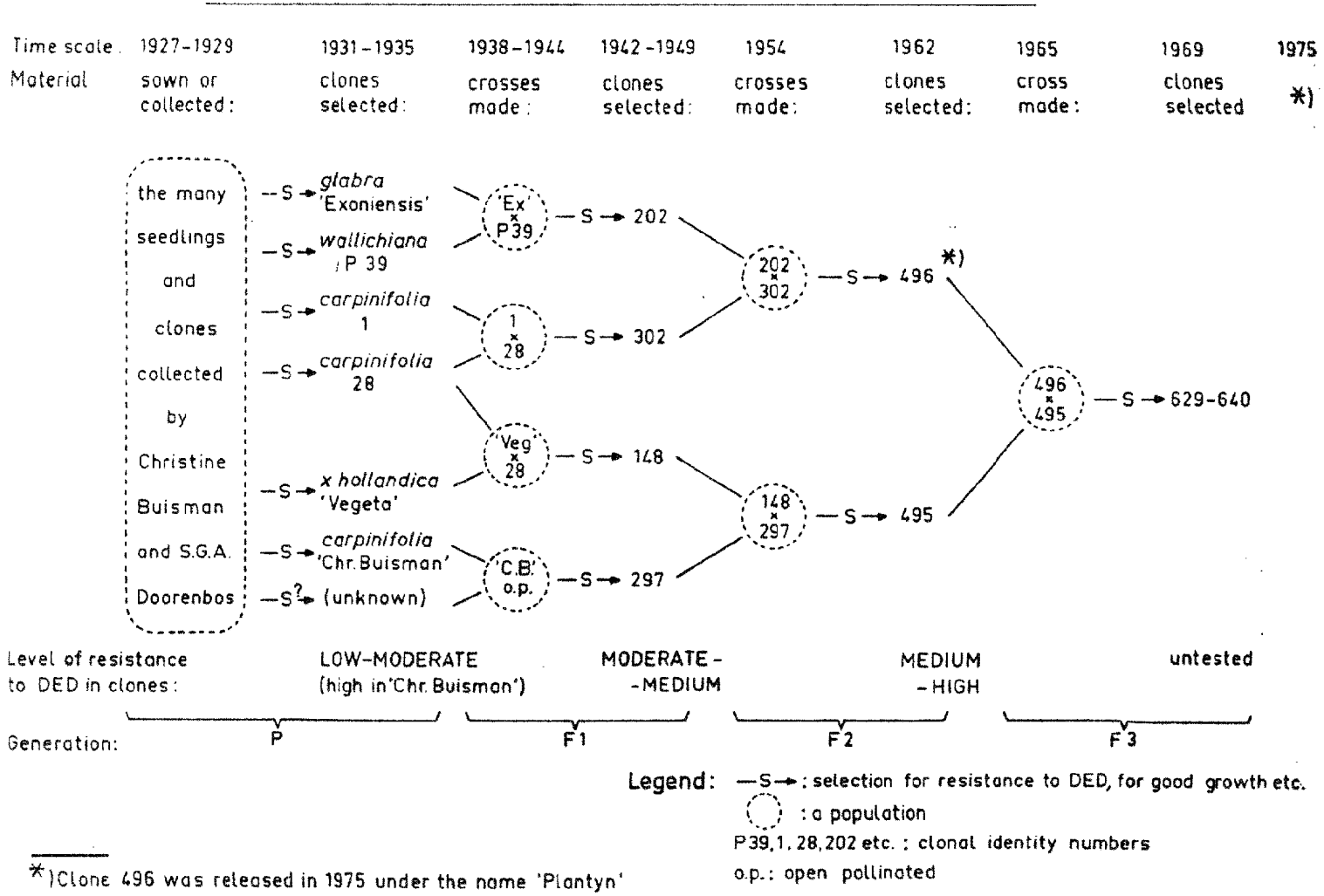
Completing the story of the 'Plantyn' elm, I can add that its grafts entered field tests as early as 1967. Now in 1975, it is represented in 24 replicated and randomized field tests, each containing many clones. These field tests are not designed to test for disease resistance, as that aspect is taken care of in the nursery. They should primarily allow us to get an idea about the growth, shape, and general health of the clones under varying conditions. Many of the tests are laid out in coastal areas, so that the clones can be tested for their exposure resistance.

In 1971, the 'Plantyn' and three other clones were up for release. Release was suspended, however, when it became clear in the same year that a different and vastly more aggressive strain of the Dutch elm disease fungus was rampant in Great Britain. Because that strain could not be expected to stay on the other side of the North Sea forever, the release of clones with an unknown degree of resistance against it would be most unwise.

Testing for resistance to the new strain was carried out in Britain, the United States, and Holland in exemplary international cooperation. Of the four candidates for release in 1971, two proved to be too susceptible to the new strain and had to be dropped.

Not without hesitation, we decided early in 1975 to release the two others to the trade, adding a third one that had not yet been considered in 1971. They were given the names 'Plantyn', 'Lobel', and 'Dodoens' (former clonal identity numbers 496, 454, and 494 respectively). Hesitations arose from the fact that even their level of resistance is no more than passable: in a few cases they have even been damaged badly by inoculation. However, they are far more resistant than

Figure 1.—Schematic development of the breeding program for the newly released elm clone 'Plantyn'.



*)Clone 496 was released in 1975 under the name 'Plantyn'

Table 2.—Properties of some old and new elm clones

Property	Property rating by clones[1]					
	'Belgica'	'Commelin'	'Groeneveld'	'Plantyn'	'Dodoens'	'Lobel'
Resistance to Dutch elm disease	5	4	3	3	3	3
Shape	1-3	2	2	2-3	3	2
Growth rate	1	1-2	4	2	2-3	2-3
Resistance to exposure	2	2	2-3	3?	2?	2?

[1] Ratings: see table 1.

the widely planted 'Commelin' elm, which they can replace. They are at least as resistant as the 'Groeneveld' elm, and superior to that clone in growth rate (table 2). Though not perfect, they are considerably better than the available cultivars. The nursery trade showed much interest: 71 nurserymen applied for propagating material and had to share the 30,000 available scions. In summer 1975 again, 30,000 buds were distributed to the nurserymen for bud grafting. The trees were named after persons: Rembert Dodoens and Mathias de Lobel were medical men and botanists from the Low Countries whose famous herbals were first printed in 1554 and 1570; Christoffel Plantyn encouraged them and printed the books.

Returning to the scheme in figure 1, I wish to point out that in this example a higher level of resistance was built up step by step over two generations and in three rounds of selection. In other examples, resistant material was found right away in the P-generation after one selection step, such as was the case with the released clones 'Christine Buisman' and 'Bea Schwarz'; or similarly in the F_1-generation, 'Groeneveld'. Moreover, the scheme is not representative of the program as a whole in that it does not show crosses of F_2 clones with clones of the P-generation, and these crosses have been common. Neither does it show the use of new parent material introduced or selected after 1955.

CLONES OR SEEDLINGS?

The Dutch breeding program, as discussed before, aims at producing clonal varieties for the trade. It can be questioned, however, whether that is wise. One can argue that massive plantings of one or two clones represent the accumulation of dangerous quantities of "fuel": just one spark, in the form of some new disease, might suffice to start an uncontrollable fire in the form of a devastating epidemic. From this viewpoint, planting clones would be preparing future catastrophies.

The Wisconsin elm-breeding program aims at producing seed-propagated elm materials (seedling varieties): for example, from the backcross *(U. pumila* x *japonica)* x *japonica*. A seedling population of elm in which less than 10 percent of the individuals are susceptible is regarded as acceptable for planting from a disease resistance point of view *(Lester and Smalley 1972; Lester 1975)*.

Seedling cultivars, that is populations of seedlings, certainly have some important advantages over clonal cultivars. Since in elm apparently both approaches to improvement are feasible to some extent, and since it is the explicit aim of this meeting to discuss breeding policy, further comparison of the two approaches seems desirable. For populations of seedlings in general, four important advantages can be mentioned:

1. Seedlings tend to be cheaper than

vegetatively propagated material. This is certainly the case in elm that is rather difficult to propagate by cuttings. Nearly all of the 200,000 selected elms that are planted in Holland annually are propagated by grafting, partly on seedlings of *Ulmus glabra*, partly on rootstocks of *U.* x *hollandica* 'Belgica', which themselves are produced by layering or from softwood cuttings. The use of rootstocks may entail problems of incompatibility.

2. Clonal plants, being genetically uniform, will produce a homogeneous plantation, while seedlings will develop into a plantation that shows a certain variation from tree to tree. For landscaping and for ornamental plantings, the second type is to be preferred for visual reasons in many cases. A clonal plantation, by its uniformity, can have a more formal, more artificial air. There is some danger of monotony. A plantation of seedlings, on the other hand, blends better in the landscape and tends to be less obtrusive; it looks more natural. It contains better and poorer trees; there is variation in shape, in color and structure, in leaf size and density, in branching pattern, in time of flowering, flushing, and leaf fall. It provides more detail and interest. The effect is that more emphasis falls on the individual trees, less on the plantation as a whole. Therefore, while missing trees can spoil the effect of a clonal plantation, they do relatively little harm to a seedling plantation. These considerations may sound like the subtleties of the specialist-landscape architect, but the differences mentioned are perceived by the layman as well. In the Netherlands there is some vague opposition against planting cottonwoods these days; this may be based more on a dislike of the monotony caused by the clonal plantings than on a dislike of the species itself.

   I do not mean that there are not situations where clonal plantations are appropriate and where they will give the desired effect. In some situations, either will do. Ideally, the planter should have both clones and seedling varieties at his disposal.

3. From the standpoint of the geneticist-breeder, the replacement of populations by clones means an impoverishment of the genetic variation, and genetic variation is the basis for future breeding work. Clones like *U.* x *hollandica* 'Belgica' have been so popular in the Netherlands during the last few centuries, that there are now only a few poor remnants of the original elm population in the country. For that reason, Dr. Buisman had to introduce the elm seedlings on which she based her program from abroad, mainly from France, where a wide genetic variation can still be found in the countryside. This meant also the introduction of some more susceptibility to frost and *Nectria cinnabarina* in the materials, because France has a milder climate than the Netherlands. For a breeder, planting populations means that material for his successor is being prepared *(Koster 1974)*. It is an act of gene conservation.

4. Seedling populations, through the inherent variation in their genetic constitution, are often suggested to safeguard against future disease risks. The idea would be that some "new" disease would find not a uniformly susceptible clone, but a mixture of more or less susceptible and resistant individuals, which would at least slow down the spread of the disease. Though there may be a grain of truth in this thesis, it is not generally true. Seedlings are not *per se* more resistant than clones. When a new disorder appears, it is a question of chance as to which material will prove to be the most resistant; it could just as well be that some clones would prove resistant. Or there might be no resistance at all; chestnut blight and Dutch elm disease in North America are examples of

diseases that met practically no resistance when sweeping through perfectly native seedling populations with full genetic variation. Planters of populations should not get a false sense of security in this respect.

On the other hand, no risk-conscious plant-breeder will feel tranquil if the culture of a species rests predominantly on one or two clones. He will realize that the only, if not perfect, defense against unknown maladies is in variety: it is just a question of common sense not to put all our eggs in one basket.

If genetic diversification is the goal, each contribution is welcome: not only the variation between the seedlings of one seedling-population, but also the variation between clones. The latter can be very big in cases like elm, where species hybrids of widely different composition can qualify for use as cultivars. That means there should be many usable clones available, if possible with a divergent genetic background. It is a technical matter of secondary importance whether these clones be employed in pure groups or as a clonal mixture. It does not affect their resistance. In agricultural crops, for special diseases and under highly specified conditions, there may be cases where a balanced mixture of very special susceptible lines will behave as a resistant population *(Browning and Frey 1969)*, but this certainly does not apply to any blind mixture, and no example has been given yet in which it worked for trees.

Summing up the above discussion, I believe both clonal and seedling cultivars are welcome, though they have sometimes different roles to play. The development of seedling cultivars is certainly to be welcomed wherever the opportunity arises. The more cultivars there are, the better. The limit will be imposed by the nurseryman who does not find it profitable to carry too many cultivars.

The seedling cultivar meets a different problem in the nursery trade. To a varying extent, it is often possible to recognize the promising seedlings having the better genotype in the nursery stage; they may have a better growth, larger leaves, a different branching angle, etc. Consciously or unconsciously, the nurseryman tends to select in this material. That means that some customer will receive the poorest remaining part of the population, unless it is destroyed. For the customer now, there are few means to be sure that the plants he receives belong to the top selection or to the average, instead of to the tail end. In the Netherlands, problems of this kind occur with some other species and so far have, in practice, proved difficult to solve.

Needless to say, a tree breeder needs a certain amount of luck to find parent trees that will produce a sufficiently homogeneous and resistant offspring of sufficient cultural value. Most trees depicted in figure 1, by their hybrid nature, will give offspring that are far too heterogeneous to be of any practical value. In other words, in breeding for the development of clones, one can make use of much parent-material that is unsuitable for the development of seedling cultivars. But, as I have already said, it is worthwhile to try to find or develop parent trees that are able to produce sufficiently homogeneous seedling progenies of good genetic quality.

VARIATION IN THE FUNGUS

Every handbook on breeding plants for disease resistance abounds with examples in which the breeder had produced a resistant variety that at a later stage turned susceptible after the fungus had apparently changed. While the variety could not be attacked by the formerly current type or types of the fungus, it proved susceptible to a new type of the same species of fungus that unexpectedly appeared. If this happens in annual crops 5 or 10 years after the new variety was released, it is serious enough; but the variety at least has produced a healthy

crop 4 to 9 times. In tree breeding, the same phenomenon would be devastating because even ornamental trees normally need 10 or more years before they really start to function, to say nothing of forest trees with their rotations of up to 100 years and more.

The theory tells us *(Van der Plank 1968)* that some cases of resistance (called vertical or specific resistance) are liable to such a breakdown caused by changes in the fungus. In another category of cases, resistance (called horizontal or general resistance) is suggested to be permanent. The difference would lie in the physiological and genetical basis of the resistance: resistances based on hypersensitivity of the host and on a single gene would normally fall in the ephemeral group; resistances based on other processes and on a multitude of genes would mostly be permanent. For a breeder, it is clearly essential to know with which kind of resistance he is working.

Elm breeders in Europe, but not those in the United States, have witnessed a serious breakdown of resistance lately. Starting in 1967, a new epidemic of Dutch elm disease has developed in Great Britain. This was something new. Although the disease had caused extensive damage between 1927 (when it was first found) and 1940, it had remained quasi-dormant since then, doing little harm *(Peace 1960)*. The new outbreak appeared to be caused by a new, much more aggressive strain of the fungus *(Gibbs and others 1972)* which was probably introduced on unbarked elm timber imported from Canada *(Brasier and Gibbs 1973)*. The new strain differs from the old type not only in aggressiveness, but also in cultural characters: on an artificial medium, it grows considerably faster, producing more aerial mycelium. This strain has now been found not only in Britain, but also in Holland, France, Germany, Italy, and Iran, while it appears to be the commonly occurring strain in North America *(Brasier and Gibbs 1975)*.

This means that the effect on breeding programs varied. For the programs in North America, nothing changed. In our Dutch program, however, we realized that we had been testing for disease resistance to a relatively weak strain, and thus had considered many elm clones to be resistant, which were in fact susceptible to the new strain. One of them, the 'Commelin' elm, had even been released and planted on a large scale: over 600,000 trees between 1960 and 1974. A complete reorientation of the program was needed, and many selections that looked promising earlier had to be discarded.

From surveying the reactions of many clones to the aggressive strain, some conclusions can be drawn. As a broad generalization, clones resistant to the weak strain exhibited a higher degree of resistance to the aggressive strain than clones that were susceptible to the weak strain. The arrival of the new strain lowered the entire level of resistance, while the ranking of clones, in broad outlines, remained the same. This was reassuring because it showed that the assembling of resistance, carried out in the program so far, had not been in vain, although the level of resistance obtained appeared to be too low. These results also were reassuring because they put the type of resistance we are working with in the category of the horizontal resistance, despite the increase in aggressiveness of the fungus. This permits us to predict that the fungus is now near the ceiling of its potential aggressiveness. In the case of horizontal resistance, the theory *(Van der Plank 1968)* does allow for some increase of aggressiveness in the parasite (though in our case the increase is unusually great). However, there is a definite limit to this increase. In vertical resistance, on the other hand, there would not be such a limit: in that pattern, each new gene for resistance can be expected to be eventually overcome by a change in the fungus.

Another possibility is, however, that the theory does not really apply to our case. Brasier and Gibbs *(1975)* suggest

that in the 1930s both the aggressive and the nonaggressive strain occurred in Europe, but that the aggressive one disappeared, only to be reintroduced from Canada recently. Now this disappearance of the aggressive strain from Europe is extremely difficult to explain in Van der Plank's theory, but reminds one of the case of *Endothia parasitica* in Europe. The latter fungus, when it was first discovered in Italy in 1938, started a severe epidemic in the forests of *Castanea sativa* in southern Europe. This epidemic slowed down after some years, however, and trees recovered. Many stands appear healthy now that were diseased earlier. The fungus is still present, but in a form that has a low aggressiveness. Like in *Ceratocystis ulmi*, strains with different levels of aggressiveness can be recognized morphologically *(Bonifacio and Turchetti 1973)*. In *E. parasitica*, there is evidence that the lower aggressiveness is associated with some contagious condition in the fungus, possibly caused by a virus *(Kessler and Elvidge 1975)*.

After inoculation of *Ceratocystis ulmi* in our clones, some variation appeared in the development of symptoms in the course of the summer *(Gibbs and others 1975)*. While clone 543 had very mild disease symptoms 8 weeks after inoculation, it rapidly developed severe symptoms in the following 6 weeks. Clone 567, on the other hand, developed severe symptoms soon after inoculation, but these did not progress any further. The two clones eventually had symptoms of about equal severity. Apparently they have slightly different types of resistance. Most other clones are intermediate in their behavior. There is a clear tendency, however, for the nonprogressing type of reaction to appear more often in Asiatic species and in some of their offspring than in other species. Also, the highest level of resistance found was in some individuals of the Asiatic species *U. japonica* and *U. pumila*. The European selections (*U.* x *hollandica* 'Vegeta', *U. carpinifolia* 1, and 28) and their offspring were, on the other hand, relatively disappointing. I conclude that the Dutch program should lean more on the Asiatic species, from which we have only a very limited sampling available. New imports, based on wider sampling, are highly desirable. Lester and Smalley *(1972)* came to a similar conclusion for the Wisconsin program.

THE AMERICAN ELM

In the expanding literature on elm breeding in recent years, *Ulmus americana* remains in the background. This is due to several of its properties, which make it a difficult species to work with. For the breeder, *U. americana* is the really slippery elm!

First, its tetraploid nature makes it difficult to work with. A tetraploid species is more buffered against change than a diploid one. The potato breeders, who came up against the same difficulty, have been very successful in bringing their material back to a lower ploidy-level, at which rapid progress was possible. Lester *(1969)* discussed this problem and tried the same techniques for the American elm, but so far without success.

Second, the species remains extremely difficult to cross. While Santamour *(1972a)* has recently shown that many more species crosses in elm are possible than we could expect, *U. americana* still keeps separate so that it cannot profit from the progress made in the rest of the genus. A breakthrough at this point would be highly desirable. Up to now, there is only one report on an authenticated, triploid, spontaneous hybrid with American elm *(Santamour 1970)*. This tree can to some extent serve as a genetic bridge between this particular American elm hybrid and the diploid species *(Santamour 1972b)*; but, being a chance individual, the bridge seems too narrow to be of general use. It should be possible to find a way to produce hybrids at will, perhaps by using irradiated pollen, tetraploidized forms of diploid species and hybrids, embryo culture, or other methods.

Third, the few seedlings remaining from mass-screening for resistance in American elm at different stations have provided a very unpleasant surprise. These individuals have survived many artificial and often also natural inoculations and could thus be regarded as being resistant to a considerable degree. Quite unexpectedly, however, ramets of most of these trees in the form of cuttings or grafts proved susceptible *(Sinclair and others 1974; Lester and Smalley 1972)*. As yet, this effect is unexplained. There was just a minor effect in favor of the selected clones: if inoculations were carried out after the seasonal peak of susceptibility, selected clones showed less symptoms than unselected standards. Both publications further report that seedlings from crosses between those selected trees were hardly less susceptible than unselected seedlings. Resistance is not entirely absent in American elm: Townsend and Schreiber *(1975)* report on a resistant clone.

Fourth, the recent extension of the known range of phloem necrosis to the Northeast *(Sinclair and Filer 1974)* has been another disappointment for those who had hoped to see a resistant and widely usable selection of *U. americana* in the near future. In large parts of the species' area, a new American elm would perhaps need resistance to both Dutch elm disease and phloem necrosis, unless a reasonable control method for the latter disease can be found.

In view of the many difficulties posed by the American elm, one might suggest dropping that species and developing other elms instead with a shape similar to that of the "typical" American elm. Such a goal seems quite attainable by breeding. The commonly occurring spontaneous hybrids between red and Siberian elm sometimes come close to it; they only lack in resistance to the disease. This could be improved by breeding with other diploid elms of a more or less similar shape as *U. laciniata*, *U. laciniata nikkoensis*, *U. japonica*, *U. wallichiana*, *U.* x *hollandica* 'Vegeta', *U. bergmanniana* and others *(Heybroek 1968, 1969)*. This approach looks promising.

However, one would not like to drop the American elm entirely. It seems that some major research efforts are needed to get the development of good and resistant cultivars of American elm effectively on the way. The importance of breaking the incompatibility barrier has been mentioned earlier *(Heybroek 1968, 1969)*. It would further be desirable to know whether the anatomical markers for disease resistance *(Sinclair and others 1972; McNabb and others 1970)* in the resistant selected seedlings are different from those in their susceptible vegetative reproductions, and also to what extent these markers can be used in a large-scale screening program on full-grown trees. In addition, a survey of the species' variability (morphological, physiological) over its entire area would seem a most valuable basis for a rational breeding effort, for instance it might locate centres of diversity.

CONCLUSION

There is not just one single prescribed breeding policy for elms. In reviewing desirabilities and attainabilities, it appears that different courses can be followed to produce better elms, each course with its specific advantages and limitations. It is the breeders' responsibility to determine which options are best suited for his conditions.

If the available options seem too meagre, as is the case in American elm, more or less basic research is needed to open up new options. The import of new gene material can likewise increase the possibilities for developing various safe and valuable clonal, or perhaps even seedling, cultivars.

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PERSPECTIVES ON IMPROVEMENT STRATEGIES FOR METROPOLITAN TREES

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ABSTRACT. The goals of tree improvement may vary considerably, depending on the genus or species under study. Maximum improvement can be achieved only by an adequate knowledge of the variability present in the gene pool, whether the pool is restricted to a single species or all species of a fairly large genus. Bizarre or atypical trees, although often regarded as ornamental, cannot be considered as significant goals of a scientific breeding and selection program. On the other hand, trees that produce no fruit or seed may be highly desirable in a metropolitan environment.

IT SHOULD BE painfully obvious to those attending this Symposium and to the readers of these Proceedings that we have barely scratched the surface of possibilities for metropolitan tree improvement. Papers have been given on selection strategies in elms *(Ulmus)* and maples *(Acer)*. This presentation should, then, deal with the hundred or so other genera grown and used as landscape trees in temperate zone of the United States.

It should be joyfully obvious that there are real opportunities for significant improvements in genera virtually untouched by research. The choice of plant materials and objectives will vary among scientists, depending on their backgrounds, present research situation, and any restrictions imposed upon them.

I will touch upon some of the problems and prospects of improvement research in the other genera, using, when appropriate, examples of work under way or contemplated for the 50 genera being studied by our project at the U.S. National Arboretum.

No attempt will be made to point out the importance of pest resistance or tolerance of urban environmental stress factors. Cold hardiness potentials will be dictated by the seed origins available. Proper evaluation and testing procedures are necessary in all genera. These are lessons that have been presented before.

MONOTYPES

About 20 of the 50 genera being studied at the National Arboretum are biological or cultural monotypes. The classical biological monotype in trees is *Ginkgo biloba*, of which only a single species exists. Others may include *Eucommia ulmoides*, *Idesia polycarpa*, *Oxydendrum arboreum*, and *Kalopanax pictus*. Taxonomic "splitters" may have described varieties or

other species in *Ailanthus* or *Cercidiphyllum*, but the best known species are essentially monotypes. Our imperfect knowledge of the intraspecific variability in these species' gene pools makes a definitive statement of improvement prospects impossible for some genera.

As cultural monotypes I would include genera in which a single species accounts for 95 percent of the types currently grown and used in the nursery trade. In some genera, the non-native species are little known, and our single native species of *Liquidambar* and *Liriodendron* are really cultural monotypes. In *Gleditsia*, some 10 to 12 species are cultivated in arboreta throughout the world, but in the United States *G. triacanthos* is the only species grown commercially in any numbers. Cold-hardiness may be a limiting factor in reducing to one the available species in tropical genera like *Paulownia* and *Albizia*. Other genera, such as *Sophora* and possibly *Robinia*, have only one hardy tree-type species. Although a wider range of plants can be grown in Florida, the Gulf Coast, or California, the scientist should probably aim for a greater range of adaptability for his superior products.

True biological monotypes generally present few serious pest problems. The fact that they have existed in nature for geological periods with a restricted gene pool is testimony to this status. Again, the tree that first comes to mind in this regard is *Ginkgo*; but there are others, like *Maclura* and *Eucommia*. The wide adaptability of *Ginkgo* may mislead us into thinking that monotypes also present few, if any, cultural problems. Of two native American monotypes, *Franklinia alatamaha* has disappeared in the wild, and *Elliottia racemosa* is now consciously being saved from extinction in its native habitat. Both of these species are difficult to maintain in optimum condition under cultivation.

Cultural monotypes may have no advantage in pest resistance. The American chestnut *(Castanea dentata)* could be considered as a sort of cultural monotype. The story of the chestnut blight is well known. Honeylocust *(Gleditsia triacanthos)* was thought to have few serious biological problems until the introduction of the mimosa webworm. Who can say, with certainty, that *Liriodendron tulipifera* might not become the victim of an introduced disease or insect pest that once preyed on *L. chinense*.

In working with biological monotypes, it is important for the scientist to sample and define the degree of variability present in the species. Seed collections from native stands throughout the species range would be ideal, but there may be problems with certain Asiatic species. Failing that, seed and plant collections could be made from earlier plant introductions of diverse known origin. Any collection scheme that is possible and workable is appropriate in the early phases of a research project. Even if a species may be represented by only one or a few mature trees in cultivation, some meaningful assessments of the species' potential can be made.

For cultural monotypes, every effort should be expended toward the collection of other species in the genus, even if the literature indicates that certain species have few good horticultural attributes or are not hardy in a particular climatic zone. For instance, we are growing 12 species of *Gleditsia*, from such diverse origins as Argentina and Hong Kong, to determine their susceptibility to mimosa webworm. Only by these tests can we ascertain whether resistance breeding programs have a chance of success. We have also grown *Albizia* species from tropical Africa and the Pacific. For years we have attempted, unsuccessfully, to bring the rare *Platanus kerrii* from Laos into cultivation. Any genetic or cultural data on species related to cultural monotypes will allow the scientist to develop a breadth of understanding that would be impossible when working with only a single species.

SPECIES VERSUS GENERIC IMPROVEMENT

Much is written about species improvement, but frequently the phrase is improperly used or misapplied. The basic unit of tree improvement is not the species, but the genus—or at least those members of the genus with which the principal species is cross-compatible. I should mention that this concept has long been preached by Ernst J. Schreiner, the dean of American forest genetics.

Of course, improvement in biological monotypes must be restricted to a single species. With many cultural monotypes, the superior adaptability of the principal species or the nonavailability of related species may so restrict our thinking that we neglect the possibilities of interspecific hybridization. Frequently, the main impetus for a broader multispecies breeding pool is the occurrence of a major disease epidemic or insect infestation. Then we attempt to make up for past neglect by experiments that could have been carried out a decade ago, and from which the answers to certain questions would be at hand.

Thus, the determination of the crossability patterns of our major species, whether called "reconnaisance breeding" or the "shotgun approach", is both scientifically and practically sound. There are two major products of tree-improvement research: knowledge and better trees. We, as scientists, have a certain amount of control over the knowledge aspect, and any experiment is better than none at all. We have far less control over the ultimate use of the improved trees that we produce. Any increase in our knowledge of trees must be considered worthwhile; and if we can someday drive down an avenue of trees that we developed, so much the better.

In some genera, the breeding pool may include *all* species of the genus. This is especially true in certain small genera like *Liquidambar*, *Lirodendron*, and possibly *Platanus*. In larger genera, for which taxonomists have erected subgeneric, sectional, and series categories, the crossability patterns tend to reflect the classification. The scientist should appreciate, but not be restricted by, taxonomic classes. In *Magnolia*, many intersectional crosses have been accomplished and, recently, even the subgeneric boundary has been breached. We might find that controlled interclass hybrids are also possible in *Quercus*, *Acer*, *Cornus*, and *Fraxinus* if enough attempts are made. It is remarkable that more natural or garden-origin interspecific hybrids have been described in *Tilia* than there are species in the genus. Yet, to my knowledge, no real breeding effort is being expended on the lindens.

So there is still much to be learned about species crossabilities; and the wider the gene pool at our disposal, the greater will be our chances of producing truly superior trees.

CONIFERS

We had originally intended to include a paper on conifer breeding in this Symposium. Several prospective speakers were asked, including an eminent forest geneticist from the Far West. His "paper" is quoted below in its entirety, anonymously, with his permission:

> You do experiments for other purposes, but keep your eyes open. When you see an interesting plant, which will generally occur in an unexpected place, you grab it and test it.

While there is an element of jest in the above statement, it describes rather well the current thinking about the state of the art. Most, if not all, conifer genetics research in this country is conducted in forestry-oriented institutions by forestry-trained scientists. The major goals of their improvement programs are increased growth rate, improved wood quality, and pest resistance. Some attention is also being given to pollution tolerance and drought resistance. Provenance testing, for the selection of the best geographic seed source for various climatic situations, has long been a major part of

conifer improvement research. The goals of forest tree improvement are thus not totally incompatible with those of metropolitan tree improvement.

Of course the conifers of forestry are mostly pines, while those of horticulture have traditionally been *Juniperus, Thuja, Chamaecyparis,* and the like. Except in the South and on the West Coast, pines are seldom a major urban landscape item. However, in the Northeast, the use of our native eastern white pine *(Pinus strobus)* along highways has increased to the point where the species might be considered overplanted. Certainly, the known sensitivity of this species to air pollutants should prompt a change or the selection and propagation of tolerant types. If progeny tests indicate good heritability of pollution tolerance, seed orchards could be developed to produce an improved seed-propagated cultivar.

As urban forests and greenbelts become more common, we can use the best products of forestry-oriented improvement research on conifers. Whatever the shape, color or growth rate of those trees destined for metropolitan usage, adequate long-term tests of adaptability will be necessary.

FREAKS AND FADS

Also implied in the above-quoted "paper" on conifers was the idea that the interesting plant should be different. The more different the better, according to some persons. This concept did not originate with foresters. Anyone looking at the abundance of dwarf, contorted, creeping, crawling, weeping, yellow-needled, variegated, and otherwise atypical conifer cultivars in nurseries or arboreta would have to conclude that these were plants to be desired. A forest geneticist who found a freak in his provenance or progeny test was sure that such a plant would have horticultural merit.

My own personal opinion is that freak plants should not be considered as goals of breeding. There is no desperate need for more bizarre plants. If they do occur, as byproducts of a research project, the scientist should seek the guidance and counsel of experienced nurserymen and landscape architects to determine if the exploitation of this plant would do any more then add another name to the ever-growing list of seldom-cultivated cultivars.

The possibilities of miscalculation about the merits of freak plants are particularly apparent in conifer breeding. With broad-leaved deciduous trees, the runts are promptly discarded and forgotten. A landscape niche that might be filled by a dwarf elm could better use a normal plant of a different genus, which would, more often than not, present a more pleasing aspect through the years.

The use of weeping trees grafted high on standards is, like pollarded catalpas, a fad that waxes and wanes in popularity. Trees with variegated foliage may be beautiful or pitiful, depending on where and how they are grown. Over most of the 48 contiguous states, the long, hot summers render many variegated trees unsightly in comparison to the same cultivars grown under a cool and moist environment. The development of red-leaved trees may offer more room for improvement and demand more skill on the part of the scientist.

In summary, I would suggest that the geneticist resist once, and maybe twice, the urge to make a cultivar of that strange bud sport or weird seedling. If, after due consideration, he cannot help himself, there may be little harm done.

FRUITLESSNESS

Most trees produce fruit that, at certain times and in certain places, could be considered objectionable. The fruit of some trees is far worse and more universally unloved then others. Heading the list is *Ginkgo biloba.* But ginkgo is dioecious, and the selection and propagation of male trees easily overcomes the potential problems. Other dioecious trees include

certain ash *(Fraxinus)* species, *Nyssa*, *Ailanthus*, *Maclura*, *Morus*, and, functionally, red maple *(Acer rubrum)*. Problems caused by tree fruits are easily solved in dioecious genera and species and, barring any rare sex-linked desirable characters, the male trees can be just as good as the females.

In some trees, such as *Aesculus*, *Gymnocladus*, *Liquidambar*, *Quercus*, *Sophora*, and even *Tilia*, the fruit itself may constitute a nuisance or hazard in areas of intense pedestrian traffic. The main objection to fruiting in other trees, like the spring-fruiting elms and maples, *Albizia*, *Robinia*, and *Paulownia*, is the ubiquitous presence of unwanted seedlings in lawns, garden plots, planters, walkways, and other conceivable and inconceivable places.

In this connection, we should remember the very real differences between self-incompatibility, sterility, and fruitlessness. Most conifers and certain deciduous genera like *Liriodendron*, *Liquidambar*, and *Platanus* are highly self-incompatible, but they are also strongly parthenocarpic. Thus, although few if any viable seeds are produced from self-pollination, the abundance of fruit is not significantly diminished. Fruiting in the 'Bradford' pear is not a problem where that is the only cultivar being grown; but the near presence of other cultivars or seedlings of *Pyrus calleryana*, which may be compatible with 'Bradford', may alter the fruiting pattern.

Sterility refers to the nonproduction of viable gametes, usually as a result of meiotic irregularities. Such irregularities may often occur in interspecific hybrids. However, natural or artificial tree hybrids between species at the same level of ploidy may be fertile; and even if viable seeds are not produced, they may be parthenocarpic and produce fruit. One outstanding example of interspecific hybrid sterility at the diploid level is the original clone of *Magnolia* x *thompsoniana (M. virginiana* x *tripetala)*, which has not been known to produce a mature fruit since its origin in 1808. Hybrids in most trees, however, are not sterile, and even if partially sterile, are not fruitless.

Meiotic irregularities arising from triploidy may also result in sterility and fruitlessness. The naturally occuring triploid aspens *(Populus tremuloides)* and the many triploid cultivars of apple *(Malus)* are, however, quite fruitful. When triploidy has occurred through interspecific hybridization between a tetraploid and a diploid species, sterility may or may not result. The triploid progeny from the cross of the tetraploid *Magnolia liliflora* with the diploid *M. stellata* (some 50 plants) have not produced a single mature fruit in 10 years of flowering. On the other hand, triploid hybrid birches *(Betula)* may produce abundant fruit and viable seed. The use of this approach to fruitlessness is restricted to genera having a polyploid series of compatible species. Sterile triploids may be possible in *Fraxinus*, *Carya*, and *Tilia*. In *Aesculus*, we have produced triploid hybrids from crosses of diploid species with the hybrid tetraploid (amphidiploid) *A.* x *carnea*.

Another method of achieving the triploid, sterile, and fruitless condition is by crossing colchicine-induced tertaploids with normal diploids of the same species. Judging by breeding experience in other plants, we could expect some successes and some failures. It might be expected that a triploid *Liquidambar styraciflua* would be sterile, but not fruitless. However, the possibilities of this approach seem so promising that we are attempting such work with a number of flowering trees, including *Albizia*, *Catalpa*, *Paulownia*, and *Sophora*.

Fruitlessness may also be caused by "doubleness" of flowers or be "created" by the selection and propagation of branches of monoecious trees that produce only male flowers. Regardless of its cause, or the preferences or intentions of the geneticist, the lack of fruit and seed can be highly desirable characteristics.

SELECTION SEQUENCE

Those characteristics that are the *limiting* factors in the utilization of a tree must be stressed in the initial phases of selection. If there are several important factors, some priority ranking must be assigned to those factors, and the screening process can be designed to shorten the duration of the testing period.

In breeding for tree-type magnolias at the National Arboretum, growth rate and habit are, naturally, of prime importance. However, magnolias are flowering trees, and the presence of attractive flowers and their abundance will be the key elements in the tree's popularity. Fortunately, in the 7 to 15 years required for a magnolia seedling to flower, some very good assessments of growth performance can be made. After flowering for several seasons, some trees with outstanding growth characteristics may have to be discarded. Since magnolias have few serious pests, any further screening to encourage wider use of the potential cultivar should involve tolerance of air pollutants or salty and compacted soil.

Where a disease is the limiting factor, and artificial inoculation procedures for young seedlings have been developed, the geneticist can indulge in severe mass-screening procedures. Resistance to secondary pests and tolerance of environmental stresses may then be determined on a small, selected population.

Verticillium wilt in green ash *(Fraxinus pennsylvanica)* may not be considered as a true limiting factor, since the planting of ash has not been deterred by our lack of knowledge about resistance. Still, ash is known to be highly susceptible to Verticillium. Since there are already male cultivars having desirable growth characteristics and good full color, the next logical step in improvement is the production of disease-resistant cultivars, or rootstocks. Among insect pests, certain borers may be real problems, and some further testing of the disease-resistant population could be made. And what about the flower-gall mite, which can make a male white ash *(F. americana)* less than a thing of beauty?

Screening for insect resistance is far less reliable than screening for disease resistance, because during periods of peak insect populations, even some non-host species may be attacked. Any tree-improvement project worthy of the name must determine, at least, the *relative* resistance of their selections. Some attention must be paid to borers in birch *(Betula)* and dogwood *(Cornus)*, mimosa webworm on honeylocust *(Gleditsia)* and mimosa *(Albizia)*, leaf miners in birch and black locust *(Robinia)*, and even Japanese beetle on practically everything.

A number of insect and disease pests are known to cause problems in the lindens *(Tilia)*, but seldom warrant control measures. What is known about certain linden species, however, is that they are extremely intolerant of poor soil aeration and salt in the soil. Improvement procedures for the development of superior cultivars (or rootstocks) in *Tilia* should begin with mass screening against these environmental stresses.

The development of improvement strategies for each tree species or genus will depend on the availability of plant material, and the facilities, equipment, experience, and opinions of the scientist. No approach is inherently wrong or right, but *some* approach is necessary.

SOME APPROACHES TO COLLECTING ORNAMENTAL TREES AND SHRUBS

by JOHN L. CREECH, *Director, U.S. National Arboretum, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C.*

ABSTRACT. The author discusses some of the potential benefits from collecting seed of trees and shrubs from their native habitats, and the role of arboreta in providing seed material to plant breeders as well as maintaining genetic resources. Some observations are made on methods of field work.

WE LIVE IN A TIME when great concern is being expressed over the loss of wild plants, ranging from the progenitors of crop plants to endangered species in habitats that are being eliminated through the encroachment of civilization on natural areas. In most localities, noneconomic woody plants are the first to go—though they often have some interim use as firewood, fence material, or some other practical value when land is cleared or grazed.

This is also an age when there is not only a world-wide interest in "greening up" cities, but also awareness of the impact of pollution, high-intensity street-lighting systems, restrictions on certain pesticides in urban areas, and several other environmental factors on our street trees. Most of these factors are being discussed during this Symposium.

The exploration for and introduction of species and cultivars from both domestic and foreign sources are basic to the selected strategies being proposed to meet the needs of breeders. The question raised by the need for a diversity of genetic material in view of the continual demise of woody-plant resources is whether we may soon be short of available plant materials.

COLLECTING GERM PLASM

Available resources can be wild species collected from localities throughout their natural distribution, or as an alternative, specimens growing in botanical gardens in those countries where the species are native. Cultivars can be introduced from foreign botanical gardens, nurseries, experiment stations, and private gardens. In many instances quarantine regulations make the movement of vegetatively propagated selections quite difficult. In general, a broad array of documented seed from natural areas is the best source of breeding material, provided the breeder can afford to be patient.

Since colonial times, we have introduced trees and shrubs into cultivation, either our native species or those from

foreign countries. The history of our efforts to introduce useful ornamental species has been well documented *(Manks 1967)*.

The search for new plants has been guided by our needs to improve the urban and rural environment. The many introductions of the Siberian elm *(Ulmus pumila)* from China and Siberia were intended for windbreaks and shade trees in the cold dry regions of the north-central United States. The goal was to find trees from the inner regions of Asia that would be suitable to a similar climate in the United States. This search was not related to the subsequent use of the same species in research to develop resistance to Dutch elm disease. Yet the information accumulated as a result of the early introduction programs with *U. pumila* and other Asiatic elms has been most valuable in the current research effort.

The U. S. Department of Agriculture collected *Castanea mollissima* and *C. crenata* from 1927 to 1931 in China and Japan as sources of resistance to chestnut blight. The disease had spread from Asia to the United States, where it devastated our native stands of chestnut *(C. dentata)*. The goal of collecting was to gather large quantities of seed from the regions where the fungus and the most resistant species occurred together.

Finally, there are instances in which trees were introduced for one purpose but made their fame in a different manner. *Pyrus calleryana* was introduced in the early 1900s in hopes that its resistance to fire blight *(Erwinia amylovora)* could be transferred to the common pear. It failed in this way, but it became useful as an understock and then later as an ornamental street tree. *Pyrus calleryana* might not have achieved this ornamental status had there not been the economic emphasis that required an intensive seed-collecting effort.

Most of the introduced plants cultivated in the United States are, to a great degree, cultivated in the lands where they are native. These have been secured through the activities of botanists, professional plant collectors, and lay people of many persuasions, ranging from priests, doctors, government officials, and nurserymen to amateur gardeners.

In our contemporary plant-collecting activities, the cooperative program initiated in 1956 between Longwood Gardens, at Kennett Square, Pennsylvania, and the Agricultural Research Service has been the most successful and sustained effort. It has supported 13 explorations for ornamental trees, shrubs, and herbaceous plants for both garden and conservatory. This program, we hope will continue for some time, because there are many fertile areas still to be explored.

The PL-480 grant program sponsored by the Department of Agriculture is one post-World War II source of trees and shrubs that has not been so prominent. These in-country funding programs are near termination in regions of interest to us. However, one PL-480 project that has been successful is the collecting of native trees, shrubs, and other ornamental plants of west-central Yugoslavia. The collecting work, done by the Biological Institute at Dubrovnic, has resulted in about 285 lots of seed sent to the United States. The value of this effort is that there has been a sustained collecting activity over several years. This has resulted in a much broader array of variants of any given species than could be gathered by a single collector in one season. Unfortunately, the distribution of PL-480 funds has not necessarily coincided with the countries where there is a broad array of temperate woody species.

In addition to these cooperative programs, the National Arboretum sponsors a program of collecting native ornamentals of Appalachia in cooperation with West Virginia University. This program, now in its third 2-year grant period, emphasizes the collection, distribution, and conservation of native hollies, azaleas, hemlocks, and other species that will be of promise in the nursery trade. There is much in common between this kind of

domestic grant program and the PL-480 projects described above. It utilizes local expertise on a sustained basis and brings valuable germ plasm into cultivation without endangering wild species.

The exchange lists from botanical gardens and arboreta are another means of obtaining genetic resources. These lists have had a poor image in recent years because some of the material tested has been found to be of questionable parental identity. More recently, arboreta have begun to provide seed of native species collected in the wild and documented with herbarium specimens to support identification. If this trend continues, seed lists may become of greater importance to plant breeders. This is especially true as more nations restrict the collecting of wild plants by foreigners except in close collaboration with local institutions.

My own experience in field-collecting over the past 20 years has been marked by a shift from rather free access to a country to a scheduled march-route sanctioned by the host country and its plant organization. Though this might have discouraged the early plant collectors, it is decidedly advantageous in terms of transportation and shipment of collections. Furthermore, it allows for follow-up collecting by the local people who accompany the foreign collector.

MAKING GERM PLASM AVAILABLE

The increase and evaluation of woody species are still developing and in need of additional improvement. We have not solved the problem of adequate distribution and evaluation of tree and shrub introductions so as to meet the needs of breeders and, at the same time, conduct objective evaluations for purposes of adaptation.

The common practice in handling introduced woody-plant seed is to germinate the entire lot and then distribute seedlings widely. The other alternative is to raise the seedlings at the home institution, line them out in the nursery, and eventually select from them or use them in breeding. Obviously, both procedures have their merits and shortcomings. The National Arboretum and the Glenn Dale Plant Introduction Station attempt a combined operation because they have both breeding programs and a broad distribution program. When seeds are received from a foreign source, they are sown immediately. The resulting seedlings are destined for three purposes: (1) to provide trees and shrubs representative of the wild species for our permanent collections; (2) to provide the research staff with new materials for their breeding and evaluation programs; and (3) through the remaining seedlings and an offer in our domestic distribution list, to establish the new materials at other botanic gardens and arboreta.

This procedure permits us to use introductions to best advantage. We presume that there will be close cooperation between breeders working on the same genus. The plant breeder must rely on arboreta as sources of parental material. There is no question but that arboreta are and will be the main repositories for the germ plasm of woody ornamental plants. Therefore, these institutions have a responsibility to see that the specimens assembled in their collections include a sufficient array of documented wild materials to benefit breeders of the future. It is very discouraging for the plant collector to introduce a species from its native habitat only to find that the representative plant in a major collection is one obtained from a foreign source without proper documentation of origin. If the long-range needs of breeders and other users of these genetic resources are to be considered, arboreta must plant specimens with proper documentation.

The Germ Plasm Resources Laboratory at Beltsville, Maryland, has the basic responsibility for plant introduction. In addition to the National Arboretum, four regional introduction stations—at Ge-

neva, N.Y., Ames, Iowa, Experiment, Ga., and Pullman, Wash.—and the ARS research stations at Glenn Dale, Md., Savannah, Ga., and Miami, Fla., collect and distribute plant materials. The four regional stations also have undertaken a sustained program of more than 40 domestic explorations. Ten of these have been for collecting ornamental plants *(Burgess 1971)*. These collections are sent to one or more state experiment stations, which agree to maintain the germ plasm for use by breeders and other scientists.

SOME TACTICS OF PLANT COLLECTING

I have suggested that seed lots collected in native habitats offer breeders an opportunity to improve on existing shade trees. Sufficient variation exists among trees and shrubs to encourage greater use of seed collections. This variation has been used to a limited extent, selecting within a seed sample and through comparative evaluation among seed lots from different geographic sources. In Japan, geographic races of *Cryptomeria japonica* from the moist, snowy regions along the Japan sea perform differently in winter survival than do those collected along the Pacific Ocean side of Honshu where the winters are dry and sunny. Seed progenies of *Pinus densiflora* collected from south to north in Japan show marked differences in winter injury when grown together on the northern island of Hokkaido. *Zelkova serrata* populations from several sources in Korea have behaved differently when grown in nursery rows in New Jersey, but with a uniform growth character within each sample.

The availability of geographic and ecological strains of trees and shrubs offers great possibilities, in lieu of vegetatively propagated selections. The genetic variation may be of significance in relation to resistance to insects and diseases, horticultural traits, and adaptation in comparison to vegetatively propagated cultivars.

Several years ago (1961), I collected seeds of *Rhododendron japonicum* from the southernmost colonies in Kyushu, Japan, to the northernmost stands at Mt. Hakkoda, Honshu. The southern colonies contained plants with either yellow or orange flowers. As one travels northward, fewer yellow-flowered plants can be found. At the northernmost stand, the flowers are uniformly orange. It can be presumed that there is a relationship between flower color and hardiness. In China, there is a closely related species, *R. molle*. It is entirely yellow-flowered and is considered to be less hardy than *R. japonicum*. Dr. W. L. Ackerman of the National Arboretum is studying these Japanese seed collections to develop true-breeding lines as a means of providing nurserymen with color forms reproducible by seed. The same use has been made of seedling progenies of the Japanese maple *(Acer palmatum)*, of which red-leaved forms have been successfully raised from seed by nurserymen.

There are undoubtedly additional examples of species in which seedlings are or should be grown in preference to clonally propagated selections. This technique is worth considerably more attention as we face additional economic limitations in plant production. Furthermore, many species are difficult to propagate vegetatively. Selected seed lines are far more appropriate than the unselected seedling material being planted in some areas as an alternative to clonal selections.

The quarantine aspect of plant introduction is an essential safeguard against inadvertently introducing new insects, diseases, and weeds. In general, most quarantine regulations are based on the risk factor. For example, seeds rather than vegetative material should be introduced when possible. For clonal propagations, unrooted material should take preference over rooted plants, and woody

plants should not be more than 2 years old.

The greatest concerns are viruses, which are not readily detected by visual observation. Some viruses are symptomless, and detection requires a complex indexing technique. As a result, most governments have very stringent regulations about importating vegetative stocks of certain genera. In the United States, it is necessary to obtain permission from the Plant Protection and Quarantine Programs Unit, Animal and Plant Health Inspection Service, Federal Building, Hyattsville, Md. 20782, before vegetative stocks or seed of woody plants can be imported.

BASIC AIDS TO FIELD COLLECTING

The methods of field collecting vary widely according to the objectives and nature of plant materials. While collecting of economic crops is often associated with areas of primitive agriculture, the search for germ plasm of woody ornamental trees and shrubs is more often carried on in natural sites remote from civilization. As a consequence, breeders have been dealing with a rather narrow base of germ plasm, and selections of shade trees have been made from single-seed collections made in the wild, but more often, from specimens in botanical gardens. This problem stems from the limitations placed on field collectors for making repeat visits to a foreign country. Sustained collecting is essential to achieving a broad base of germ plasm.

When species with good prospects have been determined, familiarity with the total range of distribution of the species is important. The various manuals of cultivated plants provide a key to describe species and their country of origin. Rehder's *Manual of Cultivated Trees and Shrubs* is essential. Local and regional floras *(Ohwi 1965)* are important resources in determining species to be collected. In addition, plant distribution maps *(Hara and Kanai 1958)* are extremely valuable in relating travel plans to distribution range of species. Though some of these maps are published, many others are available through personal contacts with local botanists. Finally, the agro-climatic analogs prepared by Nuttonson *(1951)* have been most useful in predicting the degree of adaption one might expect from collections.

There are many additional sources of information that are basic to field collecting. Perhaps most important is a working relationship with competent local botanists, horticulturists, and foresters. It is best to establish a single main contact in a foreign country. Then, allow him to make the local contacts according to a schedule established to meet the objectives. Obviously such logistical details as country clearance, collecting permits, transportation, shipment of supplies, and return shipment of collections, including quarantine permits, have to be completed well in advance.

In an initial visit to a country (like Japan) that is rich in woody plants, both wild and cultivated, the collector is first inclined to gather everything. But on subsequent journeys, concentration on collecting a few important species throughout their entire range of distribution is more productive. In such collecting, one must plan the trip according to the advance of the seasons; i.e., south to north, and lower elevations to higher ones in the case of flowering. In certain climates, such as the warm southern islands of Japan, seed collecting can be undertaken during the entire winter. In other areas, seed collecting is limited strictly by the approach of winter. There is no single optimum time to be in the field. That is why the early collectors, forced by surface transportation to spend periods of 2 to 3 years in the field, had some advantage over modern collectors. The latter may limit their journeys to a few months according to flowering or seeding seasons.

The collector, once having elected to

emphasize certain genera or species, must plan his schedule according to the advance of the season. For example, in collecting *Rhododendron kaempferi* in Japan, I followed the flowering season from early May in Kyushu to early July at the northernmost limit in Hokkaido. Similarly, I was able to follow the pattern of distribution of *Camellia japonica* from Okinawa to the northern tip of Honshu, where the last colony is to be found. In terms of elevation, it was possible for me to collect *Rhododendron pseudochrysanthum* at elevations from about 9,000 feet to 14,000 feet on Mt. Morrison, Taiwan. In this instance, I made an effort to gather seed at about 500-foot changes in elevation. As mentioned earlier, we were able to obtain seed of *Cryptomeria japonica* from four distinct climatic regions in anticipation of differences in performance. These are a few examples of opportunities that are open to collectors who are intent on providing a good sampling of a species.

Lacking the opportunity for actual collecting, breeders can always request the help of foreign botanic gardens and arboreta. They may be willing to collect native species at a nominal fee. In either case, the success of tree improvement through selection will depend on our ability to acquire a diversity of germ plasm. Otherwise, only a limited degree of progress can be expected.

CONCLUSIONS

Many opportunities exist for obtaining resources for the improvement of trees and shrubs. Collections of seed gathered from native habitats can provide breeders with sources of disease and insect resistance, improved horticultural traits, and better adaptation. Although direct collecting in the wild is the best approach, breeders should not overlook seedlists of arboreta and botanic gardens that emphasize species documented as to origin. Ultimately, seed strains of shade and street trees with acceptable quality may become a standard source of plant material for urban plantings. In the meanwhile, we will need to improve our methods of distribution and evaluation of germ plasm of trees and shrubs to make this material available widely. The arboreta and botanic gardens that maintain the genetic resources developed through such research programs will become a major resource for future plant breeders.

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TESTING AND EVALUATING NEW TREES FOR METROPOLITAN LANDSCAPES

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ABSTRACT. In the landscape-tree industry, genetic variation among species, clones, and other genetic units is most commonly exploited for improvements in appearance traits. The relatively little known of genetic differences in performance traits comes from the personal experiences of arborists and horticulturists. Further genetic improvements in the ability of trees to survive in urban environments require the use of systematic and statistically sound procedures of testing and evaluation. Some fundamental principles of testing and evaluation are reviewed. If selections are to be used in urban localities, it is important that they be tested in those situations, unless clone-environment interaction is likely to be small for the traits, trees, and sites in question. A plan is outlined for coordination of the respective activities of research institution, nurseryman, and arborist in establishing test plantations.

ARBORISTS, CITY FORESTERS, landscape architects, and nurserymen all utilize genetic variation among trees. Differences among genera, species, and cultivars impart variety to the landscape and constitute the basis for recommending one tree over another. Successfully exploiting this variation to select better trees for metropolitan landscapes requires, of course, that genetic superiority first be recognized. How to do this correctly and efficiently is a question that demands exploration as we attempt to adapt scientific methods to the improvement of trees for urban environments. Some procedures can be drawn from experiences in forest-tree improvement; but many problems in urban-tree improvement require answers that cannot be borrowed from other disciplines.

Recognizing genetic superiority requires two steps: testing (deliberately exposing trees to an appropriate environment) and evaluation (measuring genetic differences in quality of appearance or performance). We will deal here with testing and evaluation in their more formal modes—where these activities are

distinct and deliberately planned phases of the tree-improvement program.

But we do not mean to imply that testing and evaluation are necessarily new or complicated procedures. Anyone who plants a tree is testing it in that environment; and he will eventually evaluate the results according to the tree's appearance or survival. The usefulness of this technique is revealed by the availability of numerous lists of species appropriate for different uses and regions—all compiled without resort to formal procedures of testing and evaluation.

In fact, the sophistication of procedures needed in testing and evaluation may vary, depending upon (1) the traits being measured and (2) the degree of genetic variation among the trees being tested. Selection among species, for example, is relatively easy because the large genetic differences in traits usually eclipse the effects of environment on their expression. Knowledge gained through trial-and-error on the suitability of different species is usually very sound. Similarly, genetic variation in traits that are stable over a wide range of environments is also easy to measure without complicated experiments. Traits that fall in this category are usually related to *appearance*: flower color and size, branching habit, leaf shape, etc. Testing in such cases may be coincident with the necessary process of raising the plant material, and evaluation may be reduced to the simple recognition of unusual trees.

The situation is different when genetic variation is small (intra- rather than interspecific) or traits are heavily influenced by environment (often *performance* traits like growth rate and disease susceptibility). When this is true, testing and evaluation may require statistically designed and analyzed experiments performed in controlled or selected environments. Until recently such procedures have not been as necessary as they are now, or at least they have been avoided. As we become more concerned with intraspecific variation in performance traits of urban trees, it is important that we begin with sound principles and procedures of testing and evaluation in mind.

In the following sections we review some fundamentals of testing and evaluation and some points occasionally overlooked, and we add a few thoughts of our own. It is not meant to be a comprehensive review. In the last section we offer some practical ideas on the implementation of testing programs in the field.

TESTING

Experimental Design

The function of experimental design in tree-improvement research is to permit the separation of genetic from environmental effects on the phenotype (performance or appearance) of the tree. While many kinds of experimental designs have been devised *(Cochran and Cox 1957)*, only two are of wide applicability in tree improvement: completely randomized and randomized block. The essence of both is replication and random location of each clone in the experimental area. (We use clones for illustration, but the designs apply equally well to other genetic units such as families, provenances, varieties or cultivars, and species.) One replicate of a clone is defined as a plot of one or more individual trees.

The completely randomized design is the simpler of the two. It consists of two or more plots of each clone randomly located within the entire test area.

The randomized-block design is more commonly used, however; and it has certain advantages. It differs from the other in that replicates are grouped into two or more spatially distinct blocks. Thus, one plot of each clone is randomly located within each block, not within the entire test area, and the number of replicates equals the number of blocks. The randomized-block design is particularly useful when large environmental differences exist over the test site. Used correctly, this design enables one to "block" much

of the environmental variation, thus permitting greater accuracy in detecting genetic differences.

Optimum numbers of replicates and of trees per plot cannot be determined *a priori* for any particular test site, and they depend also on the particular traits being measured. Purely statistical considerations indicate as many replicates as possible. However, in practice the number of replicates is usually determined by the amounts of space, plant material, personnel, and money available. To a lesser extent the same is true of plot size, but forest geneticists usually opt for sizes of 4 to 10 trees *(Wright and Freeland 1960)*. Similar plot sizes would be best to use in urban-tree improvement when experiments will consist of rectangular plantations with contiguous plots.

So far we have discussed only the design of single experiments or plantations. Another kind of replication to be considered is repetition of entire experiments in many different environments (for example, different cities). The principal purpose of this is to obtain a measure of clone-environment interaction. (Clone-environment interaction exists if the best clone in one environment is not the best, or is best by a smaller margin, in another environment with respect to any one trait.) Although interaction often occurs, it is seldom possible to determine exactly what environmental factor it is associated with. Thus, while experiments on two different sites could be sufficient for detecting interaction, it might not be possible to recommend one clone over another for any but those two sites.

For this reason, and because plant material is usually limited, Wright *(1973)* recommended testing on a large number of sites with few replications at each, rather than on one or a few sites with many replications. If unexplainable interaction occurred, recommendations based on the multiplantation experiment would be more broadly applicable because information would be available from more sites. The main drawback with this suggestion is the loss of statistical accuracy (due to fewer replications) that would occur if a desired condition for testing, such as an insect infestation, could be obtained at only one test site.

Testing is best done at some age past the nursery stage because of the ever present possibility that juvenile and mature performance will not be closely correlated. But even if nursery plantings are not considered part of the test, they should still be arranged in an adequate experimental design, preferably randomized blocks. Nursery-induced effects on performance can persist for many years after field planting, sometimes falsely giving the appearance of genetic effects *(Wright 1973)*. This problem can be avoided if replicates are blocked in the nursery and the blocks are retained without mixing when the trees are field-planted. Nursery effects then simply become a part of easily measured block, or environmental, effects.

Test Material

The kind of genetic units tested must correspond with the method by which selections will be propagated. Tests of provenances from different parts of a species' natural range are common in forest-tree improvement, but they are designed for seedling propagation of superior provenances. If vegetative propagation will be used, as is common in the landscape-tree industry, the breeder must test clones or clones on seedling rootstocks. A well-designed test of different provenances has little direct utility in selecting superior clones unless each tree representing a provenance is cloned and replicated in the test in addition to the provenances themselves. Unfortunately this can greatly increase the size of the experiment. All other things being equal, a test of 10 clones in each of 20 provenances is 10 times as large as a test of the 20 provenances alone.

Then why not simply begin with a clonal test of some "selected" trees and disregard provenances altogether, as is

sometimes done? Genetic differences often increase as relatedness among individuals decreases. Thus, differences among provenances from various parts of a species' range often exceed differences among families from the same provenance. Families, in turn, usually differ more than individuals that have the same parents. Without prior knowledge of the variation pattern within a species, it is best to begin with as broad a base of genetic variation as possible.

While combined provenance-family-clonal tests can be cumbersome, they have been used in some improvement programs. An alternative, if time is not limiting, is to test provenances and families first and then do a clonal test of individuals from the best families.

New breeding efforts with some of the more commonly planted species will face a fair wealth of clones marketed by commercial nurseries and in common use by the public. While these clones have almost all been selected for appearance rather than performance *(Santamour 1971)*, they must be given more weight then would otherwise be warranted by their proved superiority to survive under conditions of urban stress. These clones have overcome the considerable hurdle of being successfully introduced into trade, and they are readily available. Thus, new breeding programs should incorporate "old" selections into their testing phases, not only to evaluate them further but also to serve as standards of comparison.

Testing Conditions

Broadly speaking, testing may be done either in the field under environments similar to those that occur in actual practice (for example, city streets) or in artificial environments in the greenhouse or laboratory. When choosing between the two methods, it is well to remember that no testing situation is completely satisfactory—unless it be establishing tests in every location where selections will eventually be used. The only way to determine with certainty whether a tree will perform well on a particular city street is to actually plant it there!

It is obvious, though, that field conditions more closely represent the environments in which the products of the breeding program will be grown. Artificial environments can seldom be made to equal the complexity of natural conditions. Thus, field-testing will probably be the more generally useful of the two methods in urban-tree improvement. On the other hand, problems with field-testing, such as the difficulty of obtaining stress factors at desired levels and times, favor the use of artificial environments for some testing situations. This is especially true with studies of resistance to insects and pathogens—artificial tests are sometimes the only ones practicable.

The decision of whether or not field-test should take into account the trait or traits in question. If information on many traits is desired, or if it is impossible to anticipate all the traits that may be important, the clones should be field-tested. The reason for this is that environmental stress conditions cannot be made complicated enough in artificial environments to give reliable information on more than one or two traits. Field testing is also recommended if the traits under consideration may be complex ones—that is, affected by more than one genetic mechanism or environmental factor. Such traits show clone-environment interaction; when measured in two different environments they are best regarded as two traits rather than one *(Falconer 1960)*. It is possible that most traits like growth rate and resistance to specific insects and diseases fall in this category. If the interaction is large and not interpretable, as discussed above, field-testing in many locations may be necessary.

EVALUATION

Evaluation proceeds in three steps: measurement, statistical analysis to determine if genetic differences are present, and equating the measurement scale to

degrees of quality. While what is good for one purpose may be poor for another (for example, high number of fruits per tree), the determination of quality for any given trait is usually automatic and needs no further consideration here. Furthermore, a statistical analysis is usually essential for valid, irreproachable interpretation of data; but even an elementary discussion of statistical analysis is beyond the scope of this paper. Let it suffice to say that a properly replicated and randomized experiment is amenable to statistical analysis. We would, however, like to discuss briefly the measurement of traits. Proper measurement techniques are not always obvious and can greatly influence the accuracy and intelligibility of results.

The choice of traits to be measured depends, in general, on the species being studied and the use to which it will be put. However, some aspects of the choice pertain to the evaluation process itself. In particular, every effort should be made to choose traits that are as simple and basic as possible. As stated above, complex traits have a greater probability of being associated with clone-environment interaction, an undesirable situation when it comes to putting results into practice. Furthermore, complex traits sometimes have little meaning to someone who did not make the measurements. To take an extreme example from the literature, a trait like overall quality—even if defined by a list of criteria—is meaningless to arborists who prefer to emphasize different factors when judging a tree's performance or appearance.

Sometimes it is possible to measure a trait in several different ways. For example, insect damage may be measured as the number of trees per clone with attacks, number of trees per clone killed by attack, number of attacks per tree, and other manifestations of insect predation appropriate to the insect in question. (These, by the way, are perhaps less complex traits than some combined index of insect damage.) In such cases it is helpful to use all appropriate measures if time permits. Even if they are highly correlated, one will invariably give a higher significance for genetic differences in the statistical analysis. That this method or trait is actually the best may not be apparent until the statistical analysis is performed.

All data must, of course, be in numerical form for analysis. This is easy with quantitative traits like height, but even qualitative traits may usually be expressed numerically. When possible this should be done objectively, but subjective ratings can be used if the trait and scale of measurement are carefully defined. For example, foliage color can be measured objectively, but tediously, by wavelength or correspondence with color-chart values. We have measured winter foliage color of Scotch pine by visually rating trees on the basis of a numerical scale corresponding to colors from green to yellow. Results were intelligible and surprisingly consistent for sets of measurements made at different times and by different observers.

With any measurement system it is important that distances between successive points on the scale be equal. It is particulary necessary to be careful of this when using subjective ratings, but quantitative measurements can also be incorrectly used. For example, one might devise a scale of air-pollution damage ranging from 0 (= dead) to 20 (= no damage). However, the difference between 0 and 1 (the difference between dead and living) might not be biologically equivalent to the difference between 19 and 20 (the difference between very little and no damage). A better method would be to score mortality separately and rate damage on a scale of 1 (= very severe) to 20 (= no damage).

Comparisons among clones are always relative—other conditions will almost invariably result in different absolute values of performance or appearance. Thus, the scale of measurement units should correspond with the range of values that

exist in the experiment at hand. Statisticians prefer a scale of about 30 steps between the smallest and largest measurements in a set, but shorter scales may be used if necessary *(Sokal and Rohlf 1969)*. An important point—often overlooked—is that measurements can be excessively precise. While there is no simple formula for the relationship, a useful rule of thumb is that precision in measurement decreases in importance as the variation among trees within a plot increases.

APPROACHES TO FIELD-TESTING

Testing in artificial environments obviously presents no particular problems unique to urban-tree improvement. However, the opposite is true of field-testing because of the unusual nature of field conditions like highways and city streets. Often space is limited, and usually access is controlled by some agency or office of the government. Certainly few research institutions own land entirely suitable for testing in urban environments.

Much of the problem lies, as Santamour *(1968)* has pointed out, in the stratified nature of the landscape-tree industry. In successive stages, the tree passes through the hands of the producer (nursery), planter (arborist), and consumer (public); and the planner (landscape architect) and research institution can sometimes add additional levels. None is in complete control of the whole tree-growing operation. Because the testing process spans all these levels, it will be necessary to develop good coordination in order to implement sorely needed testing programs.

Few attempts have been made at large-scale field-testing in urban-tree improvement. The best known and probably largest program is that of the Ohio Agricultural Research and Development Center, which is testing 128 species and cultivars of shade trees in one location *(Chapin and Kozel 1975*. Lighty *(1975)* has proposed an ambitious plan whereby each cooperating member of the American Association of Botanical Gardens and Arboreta would agree to plant and evaluate cultivars of certain species according to agreed-upon procedures and cultural conditions. A final report would summarize the results of all test sites.

Both schemes, however, circumvent the question of how to field-test in urban environments, the conditions in which superior selections will be expected to survive. What are some of the specific problems of testing in urban environments, and how might they be overcome?

Space and Experimental Design

Open spaces suitable for the establishment of large test plantations are difficult to obtain in urban localities. One alternative, used by Dr. Townsend in testing his red maples, is to plant along highway rights-of-way. These areas often compose a major share of the idle land in large cities, and because of their size they present few problems in experimental design. They are particularly suitable for testing if a major use of selections will be highway beautification.

Container-planting is another use that lends itself well to testing. The greatest stress factors for trees growing in containers are probably edaphic ones: lack of moisture and nutrients, extreme soil temperatures, etc. If above-ground stresses assume lesser importance, trees for container planting could be adequately tested anywhere, as long as they are grown in containers. Such testing presents no exceptional problems associated with space or experimental design other than the actual construction of the containers.

Testing in containers would also indicate, to some extent, ability to survive in narrow "tree lawns" (spaces between street curb and sidewalk) or small plots of ground in parking lots. But if the major uses of new selections will be for these purposes, tree lawns and parking lots are the best test areas. Such tests would, of course, be limited in size by the number

of available planting sites in cities. A recent survey of tree planting activities by municipalities in the northeastern United States indicated that most plant only a few hundred trees per year *(Gerhold et al. 1975)*; and presumably only a portion of these sites would be appropriate for testing clones of a single species. Thus it may be necessary to screen the clones in other test situations and eventually test only a selected few on tree lawns and other strictly urban sites.

The sizes and locations of planting sites will determine to a large extent the experimental design to be used in an urban test. One ideal situation would be two or more strips or double strips (both sides of street) of tree lawn, each large enough to accommodate a full set of clones. One plot of each clone could be randomly planted within each strip. The strip would then constitute one block of a randomized block design. If several strips are available but are too small for a full set of clones each, a system of incomplete blocks could be devised if the composition of each is carefully planned *(Cochran and Cox 1957)*.

Probably a more common situation for a test would be a disorganized system of sites distributed throughout a city and varying in size from single-tree locations to entire city blocks or more. If that is the case, one could still resort to a completely randomized design and make no attempt to group replications into blocks. Besides the difficulty of measuring such scattered plots, the main disadvantage with such an experiment would be the variation in performance caused simply by large, unblocked, environmental differences over the test area. This error variation could easily be large enough to make detection of small genetic differences impossible.

Along the same line, if it is possible to use the randomized-block design, environmental differences among plots within a block should be made as small as possible. In most kinds of testing it is possible to control this by manipulating the shape and orientation of blocks with respect to environmental gradients. This would not be possible when testing along city streets because the shape (linear) and direction are predetermined by the sites themselves. Furthermore, average distances (and probably environmental differences) among plots are greater in linear blocks than in areal blocks of the same size. Thus every effort should be made to reduce the length of blocks by either limiting the number of clones to be tested or by reducing plot size to one or two trees. This, and the fact that mortality in street plantings is usually less in forest plantings, will favor the use of smaller plots than is common in forest-tree-improvement research.

Genetic Diversity

The aesthetic undesirability of having a diversity of trees along one street is sometimes suggested as a drawback to testing in cities. This is true if the material being tested contains a number of species or clones of one species that differ widely in appearance. However, in testing performance of clones within a species, this consideration is probably inconsequential unless trees of very unusual form are included. The greatest genetic gains in performance will come from selecting among thousands of wild plants rather than among the few cultivars of a species. Any group of wild plants chosen randomly with regard to appearance will look much more homogeneous than the same number of clones previously selected for unusual branch angle, foliage color, or leaf shape.

Means of Outplanting

Few public research institutions have facilities and manpower to grow and plant trees of the size necessary for street plantings. One means of circumventing this problem would be to establish cooperative programs among the institutions, commercial nurseries, and municipal arborists. The institution would furnish the seed or seedlings of material to be

tested; the nurseries would propagate the clones and grow them to salable size; and the purchasing agencies would plant the trees according to certain constraints of arrangement and conditions of care specified by the breeder.

The arborist would, of course, have to agree to cooperate; but his time commitment need only be minimal. He would only have to specify the locations to be planted and the number of trees needed for each. From this information the breeder would devise the experimental design and determine which clones would go in which locations. (With minimum precautions, randomization would be automatic.) Before the sale, the breeder and nurseryman would temporarily label the trees according to intended location (for the arborist) and identify them (to enable the breeder to later map plot composition).

A means of entirely avoiding the problems of outplanting when testing clones now in use is to simply evaluate the performance of trees already growing on city streets. Such evaluations are in progress at the Ohio Agricultural Research and Development Center *(Chapin and Kozel 1975)* and The Pennsylvania State University. This is not fundamentally different from testing and evaluation as we have discussed them so far—it is just that the test is not planned when the plantings are made.

For this reason, however, sample plots must be selected carefully. There should be at least two for each clone; and they should be random with regard to age, time of planting, cultural practices, and planting location. It would not be valid, for example, to compare two clones in traits affected by age if all trees of one clone are 15 years old and all trees of the other are 25 years old. Similarly, comparisons in traits affected by site would not be valid if all trees of one clone are located in one city and all trees of the other in another city. The statistical effect of lack of control over these nongenetic variables is to increase error variation and make comparisons less accurate.

SUMMARY

Testing and evaluation of urban trees will be more difficult than they are in breeding programs with other kinds of plants. But the hurdles are not impossible to overcome. If breeders use proper techniques and obtain the cooperation of nurserymen and arborists, rigorous testing and evaluation programs can be developed. Only then will methodically acquired knowledge begin to replace the trial-and-error techniques on which arborists must now rely, and we will be able to approach with greater assurance the ultimate test of improved trees—getting them into use.

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HOW TO NAME, REGISTER, AND PATENT SELECTED CULTIVARS OF AMENITY PLANTS

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ABSTRACT. A consideration of the historical development of the concept and term "cultivar" precedes a discussion of some aspects of the choice and validation of new cultivar names, methods for the documentation of these names, and a brief survey of plant patents and trademarks. The registration of all cultivar names, through national or international registration authorities, is strongly recommended.

HISTORICAL ASPECTS AND CONCEPTS

BOTANISTS AND TAXONOMISTS who devote research time to the nomenclature of cultivated, ornamental, and economic plants have often been held in disrepute by the fraternity of commercial and professional plantsmen and plant breeders, because of the seemingly never-ending parade of changes in rank and name, botanical and horticultural, proposed and published in the trade and professional literature.

An excellent case in point was the rejection of the name *Viburnum fragrans* Bunge in 1966 by W. E. Stearn of the British Museum of Natural History. In a paper in TAXON, the official international Association of Plant Taxonomists and the International Bureau of Plant Taxonomy and Nomenclature, he rejected this name for reasons of priority and was obligated to erect a new specific epithet—*Viburnum farreri* Stean, which is now considered the correct name. Name changes such as this, and the many others that have occurred, however odious they may seem, are established in good faith and are the result of strict adherence to the internationally devised and accepted concepts, precepts, procedures, and rules (such as the Rule of Priority) specified in the INTERNATIONAL CODE OF BOTANICAL NOMENCLATURE *(Stafleu and others 1972).*

This perpetuating document was created to insure nomenclatural stability the world over; and it is revised every 5 years to reflect developing trends and concepts, to provide new interpretations, and to clarify apparent ambiguities. When the taxonomist, following this code, changes specific or generic names, or demotes a species name to the botanical rank of *varietas* or *forma* or sinks it into the synonomy of another species, it may take years for these new names or rank assignments to overcome resistance and replace

the earlier incorrect name in the literature and commerce.

There have been numerous editions of the BOTANICAL CODE, the latest published in 1972 following the 1969 International Botanical Congress held in Seattle. I do not propose to discuss the rules of botanical nomenclature or their ramifications in any great depth here. However, it is important to appreciate them, as they are the basis for, and provide the format for, the INTERNATIONAL CODE OF NOMENCLATURE OF CULTIVATED PLANTS *(Gilmour and others 1969)*. This code, which can be referred to as the *Horticultural* or *Cultivated Code,* was certainly an outgrowth of the *Botanical Code*.

Since the publication of Philip Miller's THE GARDENERS DICTIONARY *(6th edition, 1752)*, which is the starting reference for the nomenclature of cultivated plants, botanists and horticulturists have confronted difficulties and a certain degree of frustration in developing mutually acceptable and feasible procedures for the naming of cultivated plants. The history of the literature and attendant verbal clashes often has produced an unfortunate attitude that "Never the twain shall meet". This is an erroneous sentiment, for as we all know, the common meeting ground for both is the same raw material. Although their purposes and emphases may be divergent, they certainly are not mutually exclusive.

Horticulturists and plant breeders are involved with development, selection, distribution, and cultivation of superior environmental, amenity, and economic plants. On the other hand, taxonomists, who by definition are also nomenclaturists, are interested particularly in developing bodies of scientific classification knowledge (including phylogeny) for the whole plant kingdom, but generally as applied to naturally occurring plants with geographic and/or ecological patterns of distribution.

The taxonomist who devotes energy and research to cultivated plants, in addition to being fairly rare, is often suspect to both his botanical and horticultural colleagues. By the former because the research materials are not exclusively "wild" or naturally occurring, and by the latter because of the seeming inappropriateness of the principles of botanical taxonomy and nomenclature to cultivated plants that have arisen as the result of various processes in cultivation, or that were selected in the "wild" and subsequently introduced into cultivation.

Numerous attempts, mostly unsuccessful, were made before 1953, to reconcile, compromise, and apply the concept and accepted procedures for naming "wild" plants to cultivated plants (in the sense of cultivated or horticultural varieties that are synonoymous with horticultural or cultivated forms). The early history of these struggles, and the naming of cultivated plants, using the *Botanical Code,* and the subsequent production of a *Cultivated Code,* is well recorded by W. F. Stearn of the British Museum in the introduction to the first edition of the INTERNATIONAL CODE OF NOMENCLATURE OF CULTIVATED PLANTS, published in 1953 by the Royal Horticultural Society.

It was with this *Cultivated Code,* a separate publication independent of the *Botanical Code,* that the new nomenclatural category or rank called "*Cultivar*", was introduced into the hierarchy of plant classification and internationally recognized as the lowest nomenclatural element in the scale. Here at last was a distinct term, exclusively reserved for plants in cultivation that arose in cultivation, or were selected from cultivated or naturally occurring populations and subsequently introduced into cultivation. It is important not to lose sight of the fact that this *Cultivated Code,* with its precise set of guidelines or rules for creating and applying cultivar names to unique selections or clones, was conceived by botanical taxonomists and nomenclaturalists in 1950 at the Stockholm International Botanical Congress.

Never again can a cultivated or horticultural variety, now known as a "*cultivar*", be confused or interpreted as synonymous with the botanical categories or ranks of *varietas* or *forma* (plural: *varietates* and *formae* respectively). As distinguished from the horticultural rank of cultivar, the botanical ranks, including that of *subspecies*, possess known, more or less predictable natural geographic distributions (though diffuse, particularly in the case of *formae*), or recognized ecological preferences combined with one, or preferably more, discernible morphological features.

In review, the compound coined term, *cultivar* from "CULTIvated" and "VARiety", is now fully accepted by botanists as having priority over the earlier terms of "cultivated" or "horticultural" variety, and is not biologically or nomenclaturally synonymous with or homologous to the botanical term *varietas*. Credence to the term cultivar is emphasized and legislated for as article 28, page 35, in the *International Code of Botanical Nomenclature* (1972):

> Variants of infraspecific rank, which arise in cultivation through hybridization, mutation, selection, or other processes, and which are of sufficient interest to cultivators to be distinguished by a name, receive cultivar epithets preferably in common language (i.e. fancy epithets) markedly different from the Latin epithets of species and varieties. Examples: *Anemone* X *hybrida* 'Honorine Jaubert,' *Fravinus excelsior* "Westhofs Glorie,' *Juglans regia* 'King', *Primula malacoides* 'Pink Sensation' and *Viburnum* X *bodnantense* 'Dawn' are variants which have arisen in cultivation and are recognized as cultivars. Variants found growing in the wild, which are brought into cultivation, may also be given cultivar epithets. Examples: *Phlox nivalis* 'Gladwyne' and *P. nivalis* 'Azure' are variants taken into cultivation from the wild for their horticultural interest.

This definition is further amplified and defined as article 10, page 12, in the *International Code of Nomenclature of Cultivated Plants* (1969):

> The international term *cultivar* denotes an assemblage of cultivated plants which is clearly distinguished by any characters (morphological, physiological, cytological, chemical, or others), and which, when reproduced (sexually or asexually), retains its distinguishing characters. The cultivar is the lowest category under which names are recognized in this Code. This term is derived from *cultivated variety*, or their etymological equivalents in other languages.

Because an excellent discussion of "The Concept of the Cultivar" by James S. Pringle has been published, there is no need to further define the concept.

However, the term and concept of the cultivar met with considerable resistance throughout the 1950s and 1960s, and to some extent into the current decade. This resistance comes from some "classical" botanists who do not recognize that plant differences can arise in cultivation as the result of various processes, and from some horticulturists and plantsmen who do not wish to change their ways. It is heartening therefore to realize that the published works of the majority of horticultural authors over the past 4 or 5 years utilize the cultivar concept and assiduously avoid the use of the terms, abbreviations, or typographic techniques such as "cultivated variety", "horticultural variety", "variety", "var.", "f.", double quotation marks, or even polynomals without any rank designation.

An example of correct usage is the excellent volume, DWARF SHRUBS (1974) by Donald Wyman, one of the most eminent horticultural spokesmen in the United States. In this book cultivar names are used consistently and are enclosed by single quotations marks (e.g., *Ilex crenata* 'Mariesii'). Single quotes are one of the two alternative typographical methods provided for in the *Cultivated Code* to designate cultivar names. The other equally suitable and correct method is to precede the cultivar epithet with the abbreviation "cv." (e.g., *Ilex crenata* cv. Mariesii) without single quotation marks. In either case, the first letter of the cultivar name is always capitalized. Typographical underlining which indicates italics is never used for cultivar names, but is reserved for Latin names at any botanical rank.

CHOICE AND VALIDATION OF NEW CULTIVAR NAMES

Recently the American Association of Nurserymen published a neat and compact guide (undated, but published in 1974) entitled NAMING AND REGISTERING NEW CULTIVARS. I strongly recommend that any person—commercial, academic, or governmental—who is in the business of producing, selecting, naming, and ultimately distributing superior clones of amenity and environmental plants, obtain a copy of this booklet, as well as the 1969 *Cultivated Code* on which the booklet is based. The guidelines specified in both publications are clearly stated, particularly entries 1 through 21 in the American Association of Nurserymen booklet which, although based upon articles and recommendations in the *Cultivated Code*, is somewhat easier to follow, because it rephrases some of the more technical language and examples.

Several major categories need to be stressed, however, so that there will be no doubt as to the correct procedures and requirements for selecting, documenting, and validating cultivar names for new superior selections or clones.

1. Any person may apply a cultivar name to a selected plant as long as the plant has not previously been legitimately named. A new cultivar name cannot be erected and applied to a plant for commercial or commemorative purposes if that plant has a perfectly legitimate and valid name in accordance with the rules of the *Cultivated Code*.

2. A legitimate cultivar name may be in any modern language, and should preferably be a fancy name. It may not be in Latin or have a Latinized ending. The cutoff date for this rule is 1 January 1959. A Latinized cultivar name published after that date, even if accompanied with an appropriate description, is automatically invalid and cannot be used. Latinized cultivar names published before 1 January 1959, with or without a description of any type, are automatically regarded as legitimate and valid.

3. To be considered valid after 1 January 1959, a cultivar name in the new, fancy, and modern language must be suitably published and accompanied by an adequate description or a reference to a previously described entity, either at cultivar or botanical rank, that has an illegitimate and invalid epithet. Also, to be valid and legitimate, a cultivar name published after 1 January 1959 must not consist of more than three words—and individual letters, an abbreviation, or a numeral count as one word. "Suitable publication" is defined in the *Cultivated Code* by articles 37 and 38, page 20. Official registration of a new cultivar name by a national or international registration authority appointed by the Internation Commission for the Nomenclature of Cultivated Plants of the International Union of Biological Sciences automatically implies publication of the name and is a preferred method by which to validate a name.

Publication vehicles such as ARNOLDIA from the Arnold Arboretum, BAILEYA from the Bailey Hortorium, the JOURNAL OF THE ROYAL HORTICULTURAL SOCIETY and its companion yearbooks, BULLETIN OF THE AMERICAN ASSOCIATION OF BOTANIC GARDENS AND ARBORETA, HORTSCIENCE, plant society literature, and other technical or horticultural journals that have reasonably wide circulation, are most desirable.

However, since registration of a cultivar name is not mandatory or obligatory, the originator, who may also be the namer, may elect to publish a new cultivar name with the validating description in any journal, book, checklist, or nursery catalog of his choice. Nursery catalog entries for new cultivar names are very common and are perfectly legitimate publication resources, as long as the catalogs are dated (commencing 1 January 1959), the formulation of the name adheres to the rules of the *Cultivated Code*, and the

validating description is adequate. Too often, however, because of space and financial limitations, the descriptions accompanying new cultivar names that appear in nursery catalogs are grossly inadequate.

In addition to the morphological characters and ecological features, if any, that serve to distinguish a newly named clone or selection from its closest clonal allies and all other named cultivars, or parents within the genus, an adequate description should include all data known about its history, parentage if of hybrid origin, and the names of the individuals responsible for selection, introduction, naming and distribution. The inclusion of such details, together with diagnostic morphological characters in the descriptions of new cultivars, will go far in preventing nomenclatural and identification problems from developing, and will greatly assist the taxonomist and registration authority in untangling existing problems, particularly those of synonomy and those resulting from the proliferation and multiplicity of cultivar names.

4. A cultivar name for a recent selection or clone must not duplicate a name already in use for a different plant within the genus. The *Cultivated Code* does allow, in article 48, page 22, the re-use of earlier, validly published, fancy names if proof exists that, after at least a 10-year lapse, the plants to which the names were originally applied are no longer anywhere in cultivation. This is a controversial article; and most registration authorities, who have the ultimate authority to reject or to accept any particular cultivar name, prefer to avoid *any* name duplication, particularly within woody genera.

5. The Rule of Priority or Homonyms holds in the application of cultivar names, as it does for botanical ranks and categories. This means that two different plants or clones in a genus cannot have the same cultivar name, and the earliest legitimate and validly published application will automatically have priority. The plant or clone having the latest application of the name should be given a new and different name. Similarly, different names cannot be applied to two or more plants that are proved to be identical and of the same clone. The earliest legitimately published epithet is, accordingly, granted validity and priority.

6. Numbers or abbreviations used to designate pedigrees, and hybrid formulae, should not be used as cultivar names, nor as a partial element of cultivar names. Botanical or common names of genera or species that are ambiguous, or could lead to confusion, should not be used as cultivar epithets. Common names have no nomenclatural or taxonomic status or stability; and if used at cultivar rank after 1 January 1959, they are to be automatically rejected and considered invalid. It is strongly stressed that cultivar names that have never been published formally, but appear only as *nomen nuda* on plant labels, arboreta or botanic garden accession cards, invoices, shipping forms, and the like, are considered to be invalid until such time as they are legitimately published with a description, and preferably registered.

7. In union with an irrevocable ruling in the *Botanical Code*, the *Cultivated Code* recommends emphatically that the published description of a new cultivar be accompanied by an illustration of the plant, and that a preserved, pressed and dried, authentic (clonotype) specimen, together with a colored illustration, be deposited in a herbarium. This fact should be cited with the description. Although this practice is only a recommendation, strict adherence to it, and making it a firm rule or article in the next edition of the *Cultivated Code*, will insure further that any particular cultivar name applied to a specific and distinct plant or clone, which may for decades or even centuries be propagated by asexual methods, can never be re-used and never confused with any other plant or clone within the genus. Herbarium specimens, registration, and detailed historical and morphological descriptions are all ele-

ments of documentation essential to correct application of cultivar names. This subject will be expanded later.

8. Several other fine points primarily regarding orthography and construction of cultivar names are established in the *Cultivated Code* and the American Association of Nurserymen booklet, and they are essentially self-explanatory. To summarize: it is recommended that the following categories of names should not be used as cultivar epithets: the articles "a" or "the"; nearly identical names that could cause confusion; names that are too long; common descriptive terms, forms, or titles; names of countries or states used alone; numerals intended as trial or temporary designations; names of politically conspicuous individuals; names that exaggerate the plant's merits; and abbreviations.

9. The format for naming new interspecific or intraspecific hybrid clones arising in cultivation is identical to that of all other classes of cultivars. It is appropriate and recommended practice; however, new hybrid cultivar names should be preceded, in publication, with the hybrid formulae designating the parents, or with the hybrid group name that encompasses several similar and obviously closely allied, but distinguishable individuals (article 26, page 16, of the *Cultivated Code*).

REGISTRATION AND DOCUMENTATION OF CULTIVAR NAMES

Registration of all cultivar names within a particular genus, or series of genera, is the responsibility of the internationally appointed registration authorities and their designated registrars. Duties implicit in this function are to record all cultivar names proposed for cultivated entities, to establish which names are valid and legitimate and which are clearly synonymous, and to include all names in a published register. To accomplish these duties adequately, the registration authority must interpret the *Cultivated Code* and assure that all cultivar names (particularly newly erected ones) adhere to the rules of this code. The main objective of registration is to stabilize and standardize the nomenclature of cultivated plants. This goal is accomplished by recording, documenting, and publicizing the origins, discoverers, namers, introducers, and distinguishing features of the newly named clones.

The modest information available for older cultivar names is scattered throughout multitudinous nursery catalogs and horticultural and botanical literature. Such information is often of dubious authenticity, with the result that the names of individuals directly responsible for originating, discovering, and naming clonal selections are lost to posterity. Often the history of origin and introduction is so obscure that numerous nomenclatural and synonymy problems can never be resolved.

Registration provides permanent recognition to persons involved with the discovery, introduction, and naming of new cultivars by full documentation and suitable publication of their names. It also preserves valid cultivar names and guarantees, in good faith, that the names of the originators, selectors, and introducers always will be associated with the valid and legitimately published names. Registration prevents any possibility of confusion that could arise from the duplication of cultivar names for different plants, or the application of two or more different cultivar names to a single clone. It also helps to distinguish cultivar names from common and botanical names and ranks.

International registration of cultivar names does not imply any judgment on the part of the registrar of the ornamental or horticultural merits or attributes of any clone, although it is hoped that the applicant for a plant registration would provide adequate documentation to be published by the registrar. The *Cultivated Code* clearly instructs the registration authorities to avoid any judgment,

prejudicial or complimentary, regarding the plant whose name is being registered. The only judgments that are to be made must relate directly to the validity and applicability of the cultivar name being registered.

Plant registration is not legally binding in the same sense as national, regional or state plant patents or trademarks. However, international registration of cultivar names is widely supported, in theory and in practice, by botanists, horticulturists, and plantsmen the world over.

The mandates given to the appointed registration authorities by the *Cultivated Code* are quite specific (articles 53, 54, 55, and 56 and appendix I, pages 23-25), but the implementation of the responsibilities and procedures may vary among these authorities—which may be plant societies, such as the Holly Society of America, Inc., or botanic gardens, arboreta, or research institutions, such as the Arnold Arboretum and the National Arboretum.

The most important aspect of registration is the published documentation in formal checklists, registration lists, or cultivar enumerations for specific genera such as those produced by the Arnold Arboretum in ARNOLDIA, or by the National Arboretum in its "Contribution" series. These published lists are the basis of cultivar nomenclature; and it must be emphasized that international registration is only a published and documented record of a name or epithet, and does *not* apply to the actual plant or clone being named, but offers protection only to the *name* being proposed. The American Association of Nurserymen booklet (item 22, page 6) is somewhat misleading in indicating "Registration of New Plants". It would be correct, however, to imply that ". . . while the registration of a new cultivar [name] has no effect on obtaining a plant patent or breeder's rights [for a particular plant or clone], it is helpful in enforcing the rights granted by a patent or breeder's rights [for a particular plant or clone]". (Words in brackets are additions I conside desirable.

Within the scope of registering cultiva names is the extreme importance o herbarium specimens for documenting th plant being named and to help in au thenticating cultivar names, particularl of woody plants. This cannot be over emphasized when cultivated plants an their wild allies or ancestors are bein scientifically investigated, or when th progress and results of hybridization pro grams that utilize biochemical and cyto logical analyses, and are designed t produce superior and improved cultivars are being documented.

Registration forms with detailed in structions are available from the appro priate registration authority. The generi or family specialities and addresses o these authorities are listed in the Ameri can Association of Nurserymen bookle NAMING AND REGISTERING NEV CULTIVARS and in the 1974 edition o the DIRECTORY OF AMERICAN HORTICULTURE, published by th American Horticultural Society. Althoug the actual format of the registration ap plications may vary, in general most au thorities request the information specifie in appendix I of the *Cultivated Code*. Th National Arboretum, authority for sev eral woody genera, and the Arnold Ar boretum, authority for all woody gener not otherwise assigned, also request hard iness ratings, color readings, photograph and herbarium specimens, and occasion ally living plants in lieu of herbariur specimens. A modest fee may also be re quested by some authorities to facilitat handling and processing.

PATENTS AND TRADEMARKS

The United States Federal Plan Patent Act of 1930, amended in 195(specifies that any person who invents c discovers and propagates a new variet (should read "cultivar") by asexual pr cedures may obtain a patent through th Plant Patent Office. When an applicatio

for a plant patent is submitted, it must be in very legalistic and often cumbersome language, and must present unequivocable proof that the new cultivar is indeed a unique invention or discovery, morphologically distinct from all other cultivars of that particular group. Furthermore, the applicant must guarantee to provide an adequate supply of asexual propagations to the public.

When the specifications of a plant patent have been met, the applicant is offered the protection that under law only he or his licensee may legally propagate the unique plant for a regulated time period. Note that a plant patent protects the actual plant entity or clone, whereas registration offers international acceptance and protection of the cultivar name and nomenclatural stability for a clone. A plant patent does not affect the name of a cultivar or clone, although a name may be included, if desired, in the patent specifications. A plant that has been awarded a patent may at any time be given a cultivar name, which accordingly may then be registered.

Often legal agreements are essential to protect ownership rights, and advice from a patent lawyer is recommended. This is particularly critical if a plant thought to be unique and new is merely "discovered" in the wild or in cultivation, and is not the direct result of the prospective applicant's hybridization or selection programs. Answers to the more complex questions of plant patents can be obtained from the Plant Patent Office of the United States Department of Commerce, Washington, D. C.

The United States Plant Variety Protection Act of 1970 offers essentially the same type of protection to the applicant and inventor as does the plant patent. The primary and most critical difference is that this act is applicable only to sexually reproducing plants that may be deemed as new and unique, and whose distinctive characteristics are reliably stable from generation to generation by means of seed propagation. Like patents, however, the Plant Variety Protection Act does not provide any regulation, protection or registration of a cultivar name. In contrast, the 1964 Plant Variety and Seeds Act of Great Britain gives protection and rights to plant breeders, but also makes registration legally compulsory for some genera and species, primarily seed-reproduced ornamentals and some vegetables.

Under United States law, cultivar names may not be trademarked, and trademarks cannot supersede or include a valid cultivar name. Some states in this country, and in certain other countries, do allow cultivar names to be trademarked. In these cases the trade-marked name can be incorporated into a registration list of cultivar names only with the express permission of the holder of the trademark, and then must be clearly indicated with an ®.

Many of the elements in the foregoing discussion could be expanded to hours of intensive interpretation and analysis. The basic concepts and procedures must first be assimilated so that nomenclatural stability of cultivars may proceed and be perpetually assured. I close my comments with the suggestion that cultivar names should not be applied in popular literature or catalogs before they are approved by the appropriate international registration authorities.

Some type of pressure, perhaps legal, needs to be applied to attain the goal of registration of all proposed cultivar names. If name registration could be enforced legally before a plant could be listed in a catalog or sold, then only truly distinct cultivars would be introduced, and their names would always be in full accord with the rules of the *Cultivated Code*. Many hybridizers and plantsmen are very conscientious and carefully register their new names. There is a residue, however—particularly of nurserymen—and, I regret to report, of professional academic plant breeders, who could be more flexible in their attitudes. Improvement in the area of voluntary or

enforced registration would be of enormous benefit to the science of taxonomy and the art of nomenclature of cultivated plants.

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THE NATIONAL ARBORETUM INTRODUCTION PROGRAM FOR NEW AND IMPROVED SHRUBS AND TREES

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ABSTRACT. The U.S. National Arboretum introduction program is an integrated program that includes the evaluation of potential new cultivars and stock increase of those plants selected for introduction.

WIDE DISTRIBUTION AND CULTIVATION of a superior new shrub or tree cultivar can be achieved only by a planned introduction program. Achieving the ultimate goal of wide distribution, commercial production, and consumer acceptance depends upon a program that incorporates evaluation throughout the geographic adaptive range, stock increase before introduction, and coordinated release and promotion. The best plant may never attain this goal and subsequently provide the funds for additional projects unless the plant breeder formulates and pursues a planned introduction program.

The research-project yardstick in reality is the production of the best possible plants that get to the largest number of people in the shortest time. The long-time commitment of money, time, and personnel to breeding research of woody ornamental plants can be justified only when the new cultivars are produced in sufficient numbers to be readily available to the public and form a common element in our daily environment.

A new plant may encounter many obstacles before it is widely recognized as a superior cultivar. Not the least of these obstacles is the competition from widely, and often adversely, publicized new cultivars that represent no significant horticultural improvement. Such plants are numerous because practically anyone can select, name, patent, trademark, and introduce a plant.

To be able to surmount competition, a superior cultivar must have distinctive attributes such as outstanding horticultural merits, disease and insect resistance, pollution tolerance, hardiness, propagation capability, landscape adaptability, and the like—attributes that sell the plant first to the nurseryman and finally to the consumer. The plant breeder is challenged with the responsibility not only to critically evaluate potential cultivars and select only the truly superior, but also to assume a large share of the job of selling the new cultivar. The salesmanship of the plant breeder to a large degree delineates the designation of superior cultivar for a new introduction.

The commercial nursery is the final

hurdle and crucial bridge between the plant breeder and the consumer public. The success or failure of a superior cultivar is dependent upon the nurseryman's selling and unrestricted plant dispersal. The nurseryman is a businessman who may or may not have much scientific background, but he is an expert in methods of propagation, production, and marketing necessary to get the plants to the people. So, if a plant is to make it from research into tomorrow's landscapes, the plant breeder must develop it, the nurseryman must produce it, and the public must accept it.

The National Arboretum introduction program for new and improved shrubs and trees evolved as the diverse research projects began to yield introductions. It soon became evident, as the woody-ornamental breeding projects developed and introductions became more numerous, that a specific program was needed to expedite introduction procedures. In 1969 a cooperative program for increasing stock of the new cultivars was initiated to promote introduction. Although this program partially fulfilled the need to increase numbers of plants, it lacked selling impact. A second program—to evaluate potential new cultivars—was initiated in 1971 to assist in the final evaluation of selections under other climatic conditions and hardiness zones before introduction and thus enhance the sell. A brief resumé of these programs previously was presented along with an enumeration of the 40 National Arboretum cultivar introductions *(Egolf 1971, 1972)*. The following discussion of these programs provides models that might assist other research projects in developing introduction programs.

COOPERATORS

Probably no research institution has adequate facilities and funds to independently develop and pursue an introduction program solely for the products of its research projects. The National Arboretum is no exception. However, in our program a compromise that utilizes the expertise of cooperators has been mutually beneficial to both the plant breeder and the cooperator. The effectiveness of such mutual agreement is dependent upon the selection of cooperators.

There is no research institution so geographically located that it can adequately test and precisely define the area of cultural adaptability of a new plant for such characteristics as cold hardiness and growth response. An accurate appraisal of the response of a particular plant can be achieved by the enlistment of cooperators throughout the range of potential climatic adaptability. Also, limited trials in areas of more extreme climatic conditions might be attempted. Wide distribution of cooperators provides data on the maximum area of plant growth from the evaluation program and allows rapid dissemination of plants from the stock-increase program.

A cooperator must be an individual or institution who will cooperate by making keen observations, detailed notes, and periodic reports. The best cooperators are those who have a special interest in the species or genus, or nurserymen who grow and sell similar plants. Likewise, some arboreta, universities, and experiment stations are so located or have staff that make them ideal cooperators. The list of cooperators may change as other genera or plants become available for distribution, or if an individual or organization fails to provide beneficial cooperation. Periodic review of the cooperator list will make sure that those who wish to become cooperators are recruited and that all participants are active.

EVALUATION PROGRAM

Critical evaluation of the initial seedling from a population is the most crucial step in any plant-breeding program. Only those seedlings that hold promise of becoming superior cultivars or potential parental clones warrant inclusion in an

evaluation program. The initial selections are propagated and planted in test rows to further evaluate stability of horticultural characteristics. Simultaneously, controlled inoculation of a disease and cultural and propagation studies are pursued. Data from such studies determine the seedling selections for inclusion in cooperative evaluation.

In the National Arboretum program, only rooted cuttings are distributed to assure perpetuation of the genotype, to eliminate any identification problems, and to avoid differential growth response that might result from stock and scion of grafted plants. Although propagation potential may impose restrictions or limit acceptance of selected plants, there are few woody plants in which cuttings cannot be rooted by some technique. It is the plant breeder's responsibility to assess the propagation potential, determine a recommended technique, and advise the propagating nurseryman.

A questionnaire listing data on parentage, horticultural characteristics, pest resistance, pollution tolerance, hardiness, and size and number of plants available for shipment is forwarded in December to each potential cooperator, who may be a nurseryman, a researcher, a botanic garden or arboretum staff member, or an individual with a wide knowledge of a plant group. The cooperator, after reviewing the questionnaire, makes a request for the desired plants. He is then sent for approval and signature a Standard Form Memorandum of Understanding for Evaluation of Potential Cultivars (Exhibit I) with accompanying information on patenting (Exhibit II), that specifically lists the plant material. This memorandum is a legal agreement between the National Arboretum and the cooperator, which prohibits any propagation of evaluation plants until authorized. After receipt of the completed memorandum, the plants (usually three to five, and bearing a code number) are shipped in late January or early February.

Evaluation cooperators are periodically requested to complete report forms that provide specific data on a limited number of characteristics such as hardiness, disease resistance, flowering, fruiting, and general cultural considerations. Probably the most significant and foremost question of nurserymen is the hardiness range that will define the parameters of cultural adaptability. Experience has shown that the fewer and more direct the questions asked, the more meaningful the response. Compilation of evaluator data not only defines the cultivar response and adaptability, but also can assist the plant breeder's isolation of parental clones.

Comprehensive evaluation before introduction, in addition to critical analysis of cultivars, provides both a broad exposure sell and a quantity of stock plants for future mass propagation. The evaluation period of 3 to 10 years, depending on the nature of the plant, can be the most effective sell for the new cultivar. The observation of a new cultivar during the evaluation period by nurserymen, researchers, and gardeners can do more to promote the introduction than pages of descriptive manuscript and advertisement. The enthusiasm of one horticulturist for the plant is the cheapest propaganda, and it expands into a chain-reaction response as he meets other horticulturists. The nurserymen are the crux of the program and the most influential evaluators, since during the evaluation period they may be sold on the plant and may project its potential for commercial production.

At present, the National Arboretum evaluation program consists of 90 cooperators, which include 36 nurseries, 17 arboreta and botanic gardens, 22 universities, and 15 miscellaneous. In addition to the domestic evaluation program, the new cultivars are sent to foreign countries for evaluation and promotion. Foreign distribution, which includes 14 countries, not only provides greater geographic distribution, but also enables display of plants at national and international horticultural exhibitions. Again, a foreign

EXHIBIT 1

STANDARD FORM MEMORANDUM OF UNDERSTANDING
Between

_____
(Name of Cooperator)
And the
United States Department of Agriculture
Agricultural Research Service
For
Evaluation of Potential New Cultivars of
Ornamental Shrubs and Trees

The Service Agrees:

1. To supply the Cooperator with plant material for evaluation, as follows:

The Grower Agrees:

1. To furnish the land and labor and meet all expenses involved in planting and adequately caring for the plant material.
2. To permit representatives of the Service to make observations of these materials in the field and to obtain samples when desired.
3. Not to propagate additional plants for his own use, nor to sell, give away or otherwise distribute any part of these selections until authorized by the Service to do so.
4. To use the official name or number of the selection, or selections, assigned by the Service in all reference to such selection or selections.

It is Mutually Agreed:

1. No restrictions shall apply to propogation and disposal of plant material after the selection has been named and officially released by the Service.
2. That all information derived from these studies shall be jointly shared by the Cooperator and the Service.
3. This agreement supersedes existing agreements and shall apply to Service plant material already distributed to the Cooperator for testing.
4. The patent provision applicable to this agreement shall be in accordance with the statement on the reverse of this form.

The responsibilities assumed by the Service are contingent upon funds being available from which the expenditures may be met.

No member of or delegate to Congress or resident commissioner shall be admitted to any share or part of this agreement or to any benefit that may arise therefrom, unless it be made with a corporation for its general benefit.

This agreement shall become effective _____, and shall continue indefinitely but may be terminated by mutual agreement at any time.

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE

_____
Name of Cooperator

By _____ _____
Name Title

_____
Address

_____

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EXHIBIT II

INDIVIDUAL OR COMMERCIAL CONCERN
(7 AR 185)

Any invention resulting from this cooperative work and made jointly by an employee or employees of the United States Department of Agriculture and a cooperator or an employee or employees of a cooperator shall be fully disclosed, either by publication or by patenting in the United States. The domestic patent rights in any such United States patent shall either be dedicated to the free use of the people in the territory of the United States or be assigned to the Government of the United States of America, as represented by the Secretary of Agriculture. Where the domestic patent rights are assigned to the Government, the United States Department of Agriculture shall have an option to acquire the foreign patent rights in the invention on which an application for a United States patent is filed, for any particular foreign country, said option to expire in the event that the Government fails to cause an application to be filed in any such country on behalf of the Government or determines not to seek a patent in such country within six months after the filing of the application for a United States patent on the invention. Where the domestic patent rights are assigned to the Government, but the foreign patent rights are retained by an employee, the employee shall grant to the Government a nonexclusive, irrevocable, royalty-free license in any patent which may issue thereon in any foreign country, including the power to issue sublicenses for use in behalf of the Government and/or in furtherance of the foreign policies of the Government, and said license shall also include the power to sublicense American licensees under Government-owned United States patents to practice the invention without payment of royalty or other restriction in any foreign country wherein a corresponding patent may issue to the employee or his foreign assignee. Any invention made independently by an employee or employees of the United States Department of Agriculture or by a cooperator or an employee or employees of a cooperator shall be disposed of in accordance with the policy of the United States Department of Agriculture or a cooperator, respectively, provided, that in the event the invention is made solely by an employee or employees of the cooperator, the cooperator shall grant or shall obtain from the assignee of any patent issued on said invention an irrevocable, nonexclusive, world-wide, royalty-free license for the Government for all government purposes, and provided further, in the event the invention is made solely by an employee or employees of the cooperator, that unless the cooperator or his assignee has taken effective steps within three years after a patent issues on the invention to bring the invention to the point of practical application or has made the invention available for licensing royalty-free or on terms that are reasonable in the circumstances, or can show cause why he should retain the principal or exclusive rights for a further period of time, the Government shall have the right to require the granting of a license to an applicant on a nonexclusive, royalty-free basis.

award reaps free promotion through publication and press releases. International sell directly influences domestic sell.

Even though the primary objectives of the evaluation program are to get selections tested over a diverse area by a number of experts, it is not the intent that the evaluators make final selections of cultivars. Their expertise can confirm and extend the previous assessment of cultivars made during the 3 to 10 years prior to evaluation. A plant must pass through evaluation and receive favorable acceptance from a sufficient number of testers before there is additional propagation for stock increase.

STOCK-INCREASE PROGRAM

Following evaluation and final selection, the next step in the planned introduction of a superior cultivar is stock increase. Since the emphasis is now on numbers of plants in the quickest possible time, the expertise and skills of the professional propagator are enlisted in a Cooperative Stock Increase Program.

In this program, plants of the new cultivar under code number are distributed by the National Arboretum to cooperating wholesale propagation nurseries—under a Standard Form Memorandum of Understanding for Increasing the Planting Stock of Vegetatively Propagated Plants Furnished the Nursery (Exhibit III). In this memorandum, the restrictions on patents still apply (Exhibit II). The cooperator agrees to increase stock, use the designated cultivar code, and report the number of plants propagated at the end of each growing season prior to release.

The same procedure as for the Evaluation Program is followed in completing the memorandum. From a stock block of younger plants established at the Arboretum in anticipation of stock increase, a quantity of plants must be propagated

STANDARD FORM MEMORANDUM OF UNDERSTANDING
Between

_____
(Name of Cooperator)
And the
United States Department of Agriculture
Agricultural Research Service
For
Increasing the Planting Stock of Vegetatively
Propogated Plants Furnished the Nursery

The Service Agrees:

1. To supply the nursery planting stock for increase, as follows:

The Nursery Agrees:

1 To increase these stocks in accordance with sound practices.

2. To make the increase planting available for observation, and when necessary, for roguing by representatives of the Service.

3. When total planting stock of each clone is increased to _____ plants, to return _____ percentage of the stock of each as liners under 12" to the Service

4 To use the official name or number of the cultivar or cultivars assigned by the Service in all reference to such cultivar or cultivars.

It is Mutually Agreed:

1 _____ percentage of the crop shall be the property of the cooperator after notification of public release by the National Arboretum of the Service, and he may dispose of his share as he sees fit, subject to other provisions of this memorandum.

2 To afford a sound basis for the announcement of available sources in the nursery trade, at the end of each growing season prior to release, the Nursery will report the amount of increase of each cultivar in his possession being increased under terms of this memorandum, and that the Service will in turn report to the Nursery the known total increase reported to be in the possession of all cooperating nurseries

3. The patent provision applicable to this agreement shall be in accordance with the statement on the reverse of this form.

The responsibilities assumed by the Service are contingent upon funds being available from which the expenditures may be met.

No member of or delegate to Congress or resident commissioner shall be admitted to any share or part of this agreement or to any benefit that may arise therefrom, unless it be made with a corporation for its general benefit.

This agreement shall become effective _____, and shall continue indefinitely, but may be modified, amended, or supplemented by mutual agreement and may be terminated by either party upon _____ notice.

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE

_____
Name of Cooperator

By: _____
Name Title

_____
Address

_____

_____

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for stock increase distribution. Usually 25 to 100 plants are shipped to each cooperator in January or February. Also, if he was an evaluator, he is instructed to obtain additional cuttings from specific evaluation plants. If his nursery is not too distant from Washington, D.C., additional cuttings may be supplied at another season. It is essential that sufficient stock be provided to enable immediate propagation. Too few initial stock plants result in a time lapse while the nurseryman produces a stock block. Annually in December, the cooperators are requested to submit data on the total number of plants propagated.

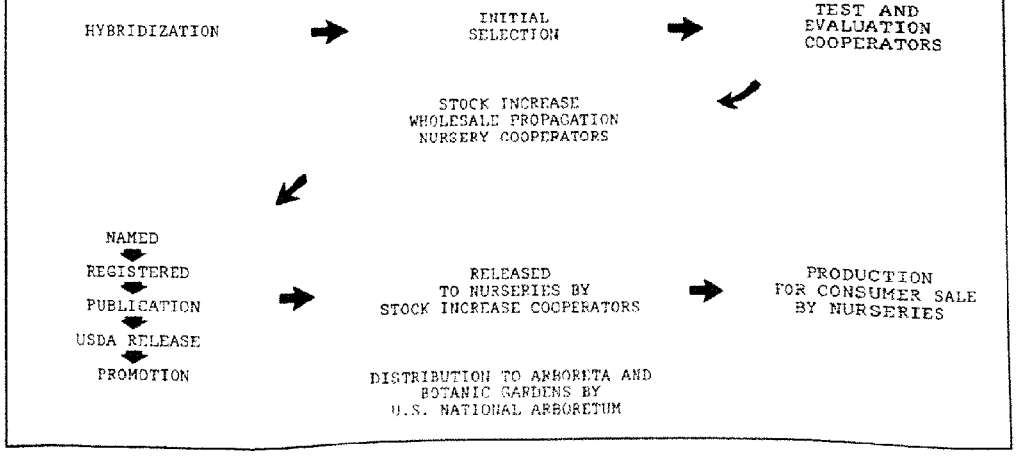
Only those nurseries that will produce liners in quantity for sale to other nurseries are an asset to a stock-increase program. A nursery that primarily propagates liners for its own production of specimen plants is of limited use in the promotion of a new cultivar. Experience has shown that it is most beneficial to rigidly restrict the number of stock-increase cooperators and to supply each with a greater number of plants—rather than have more cooperators who receive fewer plants. It is not economically feasible for a nurseryman to gear up for production and to initiate promotion of a new plant unless the numbers are in the hundreds or thousands. Likewise, the nurseryman as a shrewd businessman cannot afford to gamble on an unknown new plant. Again, the merits of a well-executed evaluation program that has "sold" the plant to the nurseryman will guarantee immediate large-scale propagation. Evaluation "sell" and stock increase must be intrinsically coordinated if a new cultivar is to be mass-propagated rapidly prior to introduction.

CULTIVAR INTRODUCTION

The timing for naming, releasing, and promoting a new cultivar is the final step to successful introduction. Early naming and publication that are previous to an adequate supply of stock create a demand for plants that largely dissipates by the time the plants are available for sale. The immediate impact of cultivar naming and publication can be exploited by synchonization with stock availability. For shrubs that are readily propagated and sold in small sizes, the naming can be made a few years after stock increase distribution; but for trees, which are slower to propagate and sold in larger sizes, the naming will be delayed.

When a predetermined number of plants of a particular National Arboretum

Figure 1.—The U.S. National Arboretum Introduction Program.



introduction has been produced, the cultivar is named and released by the Agricultural Research Service, U.S. Department of Agriculture. The details of naming, registration, and publication have been presented in another symposium paper and thus are omitted from this discussion, but are diagramatically presented in the National Arboretum Introduction Program (fig. 1). It is only after naming and release that the plants propagated by the stock-increase cooperators may be offered for sale.

The attainment of the goal of wide acceptance by the nursery trade and the public can be expedited by effective promotion. In order to further "sell" the new cultivar to other nurserymen, brief, factual information is released to the trade journals. In the meantime, the plants in evaluation and demonstration plantings have matured and continue to promote "sell" to the public. The distribution by the National Arboretum to cooperating arboreta, botanic gardens, and research institutions further encourages public demonstration plantings. When the cultivar is listed in nursery catalogs, the Information Division of the Agricultural Research Service distributes press releases to further publicize the new cultivar.

The National Arboretum Introduction Program, with its many ramifications, has proved an effective procedure for the promotion "sell" and introduction of new plants from the diverse shrub- and tree-breeding projects. The experiences of the past decade have evolved into a planned program, which in its entirety or in part could be a model for utilization by other research institutions.

SUMMARY

Briefly, the current procedure of cultivar introduction into the nursery trade, and subsequently to the consumer, is as follows:

1. Research involving hybridization, seedling production, testing, and initial selection is conducted at the U.S. National Arboretum.

2. The selected plant is propagated and sent to cooperators in other geographic regions for evaluation under a Standard Form Memorandum of Understanding for Evaluation of Potential New Cultivars of Ornamental Shrubs and Trees.

3. Propagation stock of the plant selected for introduction is distributed under code number to cooperating wholesale propagation nurseries for volume stock increase under a Standard Form Memorandum of Understanding for Increasing the Planting Stock of Vegetatively Propagated Plants Furnished the Nursery.

4. The selection is given a cultivar name that is registered and published, and official release is made by the Agricultural Research Service, U.S. Department of Agriculture.

5. After stock increase, publicity in the form of brief factual information is released by the National Arboretum to the trade journals.

6. The cultivar is released for distribution by cooperating wholesale propagation nurseries to other wholesale and retail nurseries.

7. The cultivar is distributed by the National Arboretum to cooperating arboreta, botanic gardens, and research institutions.

8. When a cultivar is listed in at least three retail nursery catalogs, the Information Division of the Agricultural Research Service distributes press releases to publicize the merits and the availability of the cultivar to the consumer.

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THE CHALLENGE: AN INDUSTRY TOGETHER

by ROBERT F. LEDERER, *Executive Vice President, American Association of Nurserymen, 230 Southern Building, Washington, D.C. 20005.*

ABSTRACT. The allied landscape industry encompasses more than a marketing chain from nurseryman to consumer: it is a chain with many links. One link is the research community that seeks to develop trees and other plants for a variety of landscape uses. The need for cooperation and communication throughout the industry is emphasized.

A NEW MARKETING CONCEPT, developed 5 years ago by the American Association of Nurserymen, has become known as *Green Survival.* When we sat down to outline just exactly what this program would be, we knew we had to have a position paper, and that that paper had to be concerned with the various functions of plant material.

One of the first things we did to explain Green Survival to our various publics was to create a slide-and-sound presentation. As we look at that production now, we see that, just 5 years ago, our minds and our imaginations produced a really limited number of ideas about how plants affect the environment. Our presentation to condition the viewer's mind to accept plants as a contribution to his environment bore heavily on other aspects where our connection is limited—water pollution, litter, and so on.

A few months ago we introduced a new Green Survival audio-visual presentation that deals exclusively with the things that plants can do to improve our environment. This program strongly reflects how our emphasis has changed in a very short time. Today the Green Survival story talks about actually selecting plant material for its capabilities in noise abatement, or specifically to be used in screening, or in reducing gaseous and particulate matter from the atmosphere, or in modifying microclimates, or in just being around us, contributing to our mental stability.

What a long way all of us have come in a short time!—all of us in what we call "the allied landscape industry".

Not very long ago I looked at this industry of ours as an entity that started with the grower and ended with the consumer. I was wrong. And if anyone in this room thinks that anything starts or ends in him, he is wrong; and I hope he will join me in a very great changing of the mind.

It may be too simple an explanation to look at this industry as a chain—an endless one which, if we follow it link for link, will lead us back to the beginning. And

each of us in that chain—research scientist, producer, seedsman, plant propagator, landscape firm, retail firm, salesmen at all levels, regulatory personnel, educator, maintenance man, arborist, legislator, planner at one of the levels of government, architect, trade and consumer press, supplier—has only a very short-term interest in any particular plant. If we are furnishing containers to the industry, the container we sell will have a functional use to the plant for a terribly short time. A grower who may hold a shade tree for 8 to 10 years has an interest in that plant for a relatively short time. A plant breeder who discovers a plant that has commercial application makes his contribution quickly in relation to the long period of the life of all of the plants that will be propagated as a result of his creation.

No matter where you start in the endless chain that describes this industry, and no matter in which direction you move, you will find each link dependent on the one before and the one after. We have a great advantage as an industry—we are friends. We are deeply interested and involved with the links on the chain closest to us; and as we developed in these past few years, our interest and understanding of links of the chain farther and farther removed has become stronger and stronger. I defy anyone to show that any link of our chain is separate from the industry or that one link is more important than the others. I must argue with those who, through word of mouth or printed word, try to separate us. We depend on each other.

IMPORTANCE OF LANDSCAPE INDUSTRY

Our market for nursery products is growing tremendously. In 1965-66 the Horticultural Research Institute, an independent research organization with offices in Washington, D. C., determined that the retail market for nursery products amounted to about 1.6 billion dollars. Five years later, in 1970-71, that figure had grown to 2.1 billion dollars, and it is our estimate that right now the market for nursery products at retail amounts to 3 billion dollars. That is big business, and much of it has been made possible by research. But in my opinion, we haven't seen anything yet—IF we really begin to apply ourselves in a business-like manner to the market.

I know it is a little alien to many involved in research to think in terms of the market place, but let me tell you that with the limited dollars available for research, we must apply ourselves to those research efforts that offer the greatest opportunity to provide new products and services to the customer. Not only do I urge you as researchers to aim at the consumer in your research efforts, but I urge you to begin to give serious thought to the quickest way there. And the way to start is by knowing what is needed and, as you move toward final development, by sharing your knowledge along the way with those who can best use it.

One of the most serious problems in our chain is communication between the various links. I have been close to the nursery industry for 17 years. I know thousands of nursery businessmen. I have been close to the research community for nearly that long, and I know dozens of research scientists. All of the nursery businessmen I know need the results of the efforts of all of the research scientists I know. In order to be properly oriented, research scientists need the opinion of the nursery businessmen.

But I ask you: How often do the two get together? When you come up with results, often they are held back waiting for publication in a scientific journal where your credits as a scientist can be made. Often good usable results never arrive at that point where they can be put into operation, because people who can use them are certainly not those who read your scientific journals. We need a compromise. Certainly, you have the right to gain recognition in your particu-

lar sphere of the allied landscape industry; but, certainly, the industry has a right to be able to take advantage of your efforts quickly. *Publish or perish*, I guess, is here to stay. However, I urge you to publish in a way that the results of your efforts won't perish, but rather will be used as stepping stones toward a better product for the consumer.

The primary goal of the Horticultural Research Institute is to serve as a communications link between the research community and those who take your developments and move them on to the final consumer. The Institute's grant program, its various publications, its new Horizon's Day at our annual convention, are all aimed at trying to become an entity through which researchers will be willing to funnel information to the nursery industry. Both the American Association of Nurserymen and the Horticultural Research Institute are deeply interested in helping industry work with government.

For decades our organization testified each year against the plant-production programs of the Forest Service. Along came a single individual many of you knew—Dick Lane, who was dedicated to teaching us how we could cooperate with the Forest Service, and the Forest Service with us. He set up a relationship between us that exists to this day, and it has created tremendous good for both of us. Whether we liked it or not, we suddenly found out that we knew a great deal about Forest Service research. Through my chairmanship of the Northeastern Forest Research Advisory Committee, visits to Forest Service laboratories, and personal exchanges with scientists, we became big supporters of their activities—all thanks to one interested individual.

COOPERATION AND COMMUNICATION

For a good many years now we have grasped every branch of cooperation held out to us by government. Service on the Arboretum Advisory Committee by nursery businessmen, symposiums like this one, the recent meetings held with scientists of the Agricultural Research Service—all have been big steps in improving communications all the way along the chain. The arborists, the growers, the landscape contractors, the seedsmen, and the architects all meet on a regular basis to exchange information on what each segment of the industry is doing. These meetings are relatively new and are effective in communicating between other links of the chain. It is all so easy when the effort is made, and that effort depends on a few people, many of them participants in this symposium.

All of us in our nursery industry chain are dedicated to furnishing the best possible product to our customer, and the only way that can be done is through all of us working together. We must get better at telling you what that customer needs, and you must get better at listening. When you develop your research program, keep very much in mind that your inclination may be to develop projects that are of most interest to you. Overcome that inclination. Base your projects on what will be of most practical value to producing better products, better chemicals, and better plants for our customer, because we are all urban farmers with a practically untapped market waiting for our products. Nurseries are not research institutions. Just as you must publish or perish, they must profit or perish. Certainly, many nurseries have achieved significant research results, but in the long run we must depend on you because you have the time, the money, the land, and the labor necessary for making a broad approach to the development of better trees and shrubs and chemicals.

Because we have such a virgin market before us, we surely do not need that part of the market that is involved in selling nursery stock to replace trees that have failed because of some inherent weakness to the stresses imposed by nature or Man. We want and need products we can guar-

antee will become established easily and will last for decades. To do that will require the cooperation of us all, beginning, in this instance, with the geneticist and breeder who is spending his days building the trees and shrubs of tomorrow. Pathologists, entomologists, physiologists, and every other specialist must play an important part in this building. And as you build—communicate.

The American Association of Nurserymen is in constant communication with 1,200 growers, 1,300 landscape firms, and 1,300 retailers. There is a lot of practical knowledge in our constituency, but I do not remember ever being asked to survey our members as prelude to developing a research project. They have occasionally been questioned in the course of various studies; but, as far as I know, their opinions and needs have not been sought in the planning of the research. I ask you: Why work in a vacuum? If your goal is to develop a fine Norway maple, the place to start may very well be by asking the municipal arborist or forester or all of our northern growers to share with you the best Norway maple they know of. He can take you to it right away: he has been watching it for years, but nobody ever asked him about it. Certainly, it may turn out that it was "planted over a dead horse", but on the other hand, it may turn out to be a way of saving 50 years of development simply by communicating.

CONCLUSION

In closing, let me urge you that, for the good of all of us and for the good of those we serve, each of us look backward and forward at the links of the chain, behind and ahead of us, to see what is really needed and to map out a plan of research for the future that relates to need above all other considerations.

It all depends on communication.
