

**THE SIZE, DESIGN AND MANAGEMENT
OF PLANTING SITES REQUIRED
FOR HEALTHY TREE GROWTH ¹**

by Thomas O. Perry
School of Forest Resources
North Carolina State University

INTRODUCTION

Too many plantings of trees and shrubs fail within 5 to 10 years after they are established. Cooperative studies sponsored by the United States Forest Service (Southeastern Forest Experiment Station) have attempted to identify the causes of failure and the measures that need to be taken to insure planting programs that yield healthy trees that grow well and function to improve urban environments. The major subject of this paper is the size and design and management of planting sites and containers required for the development of healthy trees of various sizes. However, proper size and design alone are not sufficient to insure success of the tree planting. Current observations indicate the major causes of the failure of tree plantings are:

- (1) Improper size, design, after care, and maintenance of the planting and the planting site.
- (2) The use of species, races, and varieties that are not genetically adapted to the planting site or the region of planting.
- (3) Improper lifting, transporting, and storage and handling of the plants during the planting process.

Unless all of these deficiencies are corrected the trees and shrubs of urban plantings will be stunted and short-lived.

TYPICAL TREE ROOTS

An understanding of the problems of growth of tree roots is essential to the proper design of tree planting sites. The following descriptions are presented as a prelude to more detailed specifications for the design of planting sites.

Careful studies reveal that the feeder roots of typical trees are located in the uppermost inches of soil (Krajicek, 1961; Schnur, 1937; Schumacher and Coile, 1960) and grow upward from a system of transport roots that grow horizontally between 4 and 11 inches below the surface. The tree's root system extends outward from the trunk to include a circle that includes diameter several times the height of the tree--far beyond the rain drip. The roots of seven or more trees crisscross to occupy

¹Metro. Tree Impr. Alliance (METRIA) Proc. 3:1-14, 1980.

the same square foot of soil surface. Even the roots of open-grown trees extend far beyond the tips of their branches.

It is possible to grow a tree with its roots confined to an area which corresponds to the extent of its crown. But trees "free to grow" do not conform to such a pattern. Digging, transplanting and root-confining activities commonly result in the death of the upper portion of the crown and reduction of leaf size and leaf area to 1/4 of its former extent. This is particularly true of trees that have been formerly free to grow. Pruning of tree crowns and provision of extra resources to the residual root system can partially compensate for these effects. In general, it is difficult to constrain a tree's root system to the area outlined by its branch tips without producing a stunted and chlorotic leaf system and dead branches.

Most tree roots conform to this typical pattern of development because the major supplies of oxygen, water and nutrients are confined to the surface layers of the soil. In typical soils of the eastern United States the surface layers are wetted by rains during the growing season while the lower layers of soil are depleted of available moisture by the end of the first weeks of spring.

Roots will penetrate to greater depths in the soil under special circumstances that provide adequate supplies of oxygen and moisture to these lower layers. Some species of trees like longleaf pine have evolved a 2-layered root system to take advantage of sandy soils in surface layer and seasonal fluctuation in the levels of oxygen and water in the lower layers of the soil. Other species like Cypress have developed root systems with special anatomies and biochemistries that permit growth in swampy soils which are characterized by low oxygen supplies. Cypress, spruce, willow and similar species tolerate shallow soils and poor oxygen supplies. However, the roots of these species will penetrate as deeply as those of any desert shrub when the patterns of water and oxygen supply permit.

THE SIZE AND SHAPE OF PLANTING SITES

Healthy trees and shrubs grow rapidly and the planting site must be large enough to accommodate this growth. The data from research on the dimensions and spacings of forest-grown and open-grown trees permit us to improve on the rule of thumb that calls for planting holes with one foot of diameter for each inch of tree caliper plus one foot (Krajicek, 1961; Schnur, 1937; Schumacher and Coile, 1960). This rule of thumb specification merely accommodates the root ball of the transplant and does not allow for growth.

Examination of yield tables developed for many forest tree species growing under full competition reveals the surprising result that the minimum space requirements of different species are very similar and

that within wide limits these space requirements are independent of site quality.

For example, the yield table data for loblolly pine (Schumacher and Coile, 1960) reveal the number of trees vs. diameter relationship that can be described by the equation:

$$\log N = 3.8668 - 1.4774 \log \text{DBH}$$

For loblolly pine trees 10 inches in diameter, this corresponds to 245 trees per acre, 178 square feet per tree, or a spacing of 13.3 feet.

The yield table data for upland oaks and hickories (Schnur, 1937) reveal that the relationship between the number of trees per acre and diameter can be described by a very similar equation:

$$\log N = 3.8638 - 1.4987 \log \text{DBH}$$

For oak and hickory trees 10 inches in diameter this corresponds to 231 trees per acre, 189 square feet per tree, or a spacing of 13.7 feet between trees.

The 0.4 foot difference in spacing requirements for oaks and pines is less than 3 percent of the average value.

As mentioned earlier, open-grown trees have more leaves and longer and wider crowns than forest-grown trees of comparable diameter. Krajicek, et al (1961) measured the crown widths (CW) and trunk diameters (DBH) of open-grown oaks, hickories, and other hardwoods and described their relationship with the equation:

$$cw = 3.183 + 1.829 (\text{DBH})$$

These equations were used to calculate the space requirements of forest and open-grown trees as listed in Table 1. More time may be required for trees to achieve a given size on different sites, but the minimum space requirements of trees of a given size and habit appears to be relatively unaffected by differences in species or differences in quality of the site.

Review of texts on orchard management give some idea of the space requirements for maximum production of fruit and nut crops. Pears which are slightly fastigiate are commonly planted at spacings between 18 and 25 feet; peaches at spacings between 20 and 25 feet; apples at spacings between 25 and 30 feet. Walnuts and larger pecans are planted at spacings of 60 feet or more (18 trees per acre, Chandler, 1951; Childers, 1954; Gourley and Howlett, 1941).

In general, trees of the family Rosaceae, ornamental cherries, crab-apples, mountain ashes, and the like, should be planted at spacings of

Table 1. Spacing required for trees of various diameters based on yield table data of Schnur 1937, Schumacher and Coile 1966, and Krajieck et al 1961 published with permission of Thomas O. Perry.

DBH	<u>Open Grown Trees</u>			<u>Forest Grown Trees</u>		
	Number of Trees Per Acre	Square Ft. Per Tree	Spacing Between Trees*	Number of Trees Per Acre	Square Ft. Per Tree	Spacing Between Trees**
1	2209	19.7	5.011	7308	6	2.4
5	365	119.3	12.3	655	67	8.1
10	120	362	21.4	231	189	13.7
15	59	736	30.6	126	346	18.5
20	35	1241	39.8	82	531	23.0
25	23	1878	48.9	59	741	27.2
30	16	2647	58.0	45	975	31.2
35	12	3546	67.2	35	1228	35
40	10	4577	76.3	27	1500	38.7

*Assumes a circular crown. To calculate spacing for a square crown:

$$\text{Spacing} = \sqrt{\text{Square Ft./Tree}}$$

**Assumes a square shaped crown. To calculate spacing for a circular crown:

$$\text{Spacing} = s/4 \text{ (Square Ft./Tree)}$$

20 to 25 feet and oaks and hickories and other large trees should be planted at spacings of 40 to 60 feet if the full effects of their open-grown form is desired. Initial spacings may be closer than this but thinning should be anticipated in the planting design. Olmsted stressed that the best friend of the landscape architect is the ax (Olmsted and Kimball, 1970) and recommended heavy thinnings in the early plantations in Central Park.

Planting designs should allow for growth and thinning. It is disappointing to observe planting beds with trees at the comers which need to be thinned. A tree planted in the center of the bed would have allowed opportunity for thinning without leaving an asymmetric effect.

Trees can develop in holes smaller than specified in the accompanying table. However investigations of these exceptional trees usually reveals a near-by storm sewer or other subterranean device that provides a water supply and aeration and allows escape from otherwise adverse surroundings.

Many of the tree planters along city streets and around shopping malls or tree lawns are deeper than necessary. As described earlier, the roots of most trees are located in the surface foot or so of soil and commonly run horizontally or upward to the surface. Unless special provisions are made to provide oxygen to the deeper layers of soil, there is little reason to have containers deeper than 30 inches. Thirty inches is the height of a typical table and 16 to 18 inches is the height of a typical chair. Containers of this 'depth are pleasant to the eye and accessible for leaning and sitting.

SOILS IN THE PLANTING SITE

Too often, urban soils represent a complex mix of bricks and broken glass, or dense clay which has been compacted to meet the engineering and load-bearing specifications for buildings or road rights-of-way. roots of planted trees often grow outward from the planting ball and are unable to penetrate this disturbed bulldozer mixture. Instead they die or procede to grow in a circle around the confines of the planting hole. Percolation is poor and runoff from the surrounding streets can accumulate in the undrained planting hole so the trees suffer alternately from drought and lack of oxygen.

Care should be taken to insure that the space assigned to each tree (not just the planting hole) is provided with soil of proper texture and structure pore space should be adequate for easy penetration of oxygen, water and tree roots. This specification means that the soil must be of a bulk density of about 1.3 with a particle size and organic matter content sufficient to sustain a vigorous mifroflora and fauna.

IRRIGATION AND DRAINAGE

Special programs of watering are an essential part of any intensive horticultural operation. Planting and growing trees in urban situations is no exception. Patterns of water flow through the soil and over the land, are drastically altered during urban development and the contour and drainage of any planting site should accommodate this alteration.

Knowledge of the rates of water lost from forested land and other situations and the sizes of trees and the number of trees per acre permits estimation of the number of gallons of water consumed per day by trees of various sizes. In order to maintain healthy plants the water lost from the system must be replaced whether the loss was through the plant, by evaporation from the soil, or through the soil by drainage.

U. S. Weather Bureau data show that during the summer months an average of 550 - 650 calories of energy strike the earth per square centimeter of surface. This is sufficient to evaporate more than a gram of water which in turn is equivalent to evaporating a layer of water from the surface of the land which is one centimeter or 4/10 of an inch thick. Vertical percolation and down-slope movement account for additional losses so that in very moist soils the water losses per day can approach $2\frac{1}{2}$ centimeters or one inch.

Various workers estimate the rates of water loss through forested ecosystems (Broadfoot, 1958; Brown, 1965; Hewlett, 1961; Metz and Douglas, 1959; Satoo, 1958). The accompanying tables 2, 3, and 4 are based on three possible rates of water consumption; 1/10 of an inch per day, 1/4 of an inch per day, and one inch per day. One tenth of an inch per day is probably representative of rates of water loss in June or July after five or more days without rain. One quarter of an inch per day is representative of rates of water loss observed in typical eastern forest situations of the United States, (Metz and Douglas, 1959). One inch loss per day represents an extreme situation with an ample water supply in a planting site which is excessively drained and has a western exposure or reflector-oven effect from surrounding buildings and pavement.

Irrigation and drainage must be adequate to allow regular flushing of the planting site. City water supplies with high pH's like New Orleans, high alkali contents like Denver, Colorado, high chlorine contents like New York City can produce lethal salt concentrations in the confines of the planting site—a phenomenon similar to that observed with plants that have been kept in the same pot for several years in a residential home. It is recommended that planting sites in confined or paved situations be flushed out 2 or 3 times during the growing season.

SOIL AERATION

Roots must have adequate oxygen supplies and sufficient aeration to

Table 2. Gallons of Water Used Per Day for Varying Rates of Transpiration.

<u>Acre inches of water lost per day</u>	<u>Gallons of water lost per acre/day</u>	<u>Cubic feet of water lost per acre/day</u>
0.1	2.72×10^3	3.63×1
0.2	5.42×10^3	7.25×10^2
0.25	6.78×10^3	9.06×10^2
0.3	8.12×10^3	1.09×10^3
0.4	1.08×10^4	1.45×10^3
0.5	1.36×10^4	1.81×10^3
0.6	1.63×10^4	2.18×10^3
0.7	1.90×10^4	2.54×10^3
0.8	2.17×10^4	2.90×10^3
0.9	2.44×10^4	3.27×10^3
1.0	2.72×10^4	3.63×10^3

Table 3. Water Use of Forest-grown Trees.

Diameter Inches	Gallons of Water Consumed Per Tree Per Day Assuming the Following Acre Inches of Water Consumed Per Day		
	0.1	0.25	1.0
1	0.1358	0.89	3.58
5	3.78	9.4	37.8
10	10.7	26.6	107
15	19.7	49.2	197
20	29.3	72.8	293
25	40.6	101	406
30	53.5	133	535

Table 4. Gallons of Water Consumed Per Day by Open-grown Trees

DBH Inches	Gallons of Water Consumed Per Tree Per Day Assuming the Following Acre Inches of Water Consumed Per Day		
	0.1	0.25	1.0
1	1.85	4.63	18.5
5	9.94	24.9	99.4
10	29.7	74.3	297
15	64.7	162	647
20	103.3	258	1033
25	156.5	390	1565
30	214.8	536	2148

prevent the development of toxic concentrations of carbon dioxide, methane, and other gasses. Provision of a good soil and proper drainage will do much to provide this aeration. Care should be taken to avoid sealing the surface with bricks or pavement or black plastic.

Special arrangements of wood, iron, and concrete can be used to allow pedestrians to walk up to the base of a tree without compacting the soil. Cast-iron tree-grates are commonly used for this purpose but at the disadvantage of accumulating cigarette butts, old drink cartons and other trash. Such trash is nearly impossible to remove even with the traditional tongs and nail-pointed sticks of sanitation workers.

Support of the sidewalk on steel girders with a segmented arrangement that allows for easy removal is much more pleasing and easy to maintain than the arrangement of grates. In Denver, the sidewalks surrounding trees are supported 4 to 6 inches above the soil and a bark mulch near the tree trunk prevents trash from slipping into the planting hole. Irrigation is provided beneath the sidewalk. Figure 1 is a representation of such a planting site. Such arrangements are expensive but essential to successful tree plantings in parking lots and sidewalks.

Bricks, cobblestones, and porous concrete devices have been placed directly on the surface of the planting site with the assumption that oxygen and water can penetrate such structures. In most instances the plants in such "semi-paved" situations show severe crown dieback and root growth is confined to the crevices between the bricks and other paving devices. Forestry research has consistently shown the strong negative correlation between tree vigor and the percent stone in the A-horizon.

The combination of a wet fermenting layer of bark mulch and the underlayment of black plastic is consistently lethal to trees. True, weeds will not grow through the plastic--neither will trees!

PROTECTION OF THE PLANTING SITE

The planting site should be protected from de-icing salt, the heat and drying effects of air conditioners and building vents, abnormal lights, steam lines, and other insults.

Sometimes, protection from de-icing salt can be provided by placing the sides of containers above the general grade of pavement. Near highways and bus stops this may be impossible. The salt that comes from the spray of splashing can kill leaves as effectively as the salt that comes from leaching into the planting hole.

Indeed there are many sites where sustained growth of healthy plants is impossible. Records of mortality and replacement can serve to identify such locations of poor risk. Use of plant materials should either

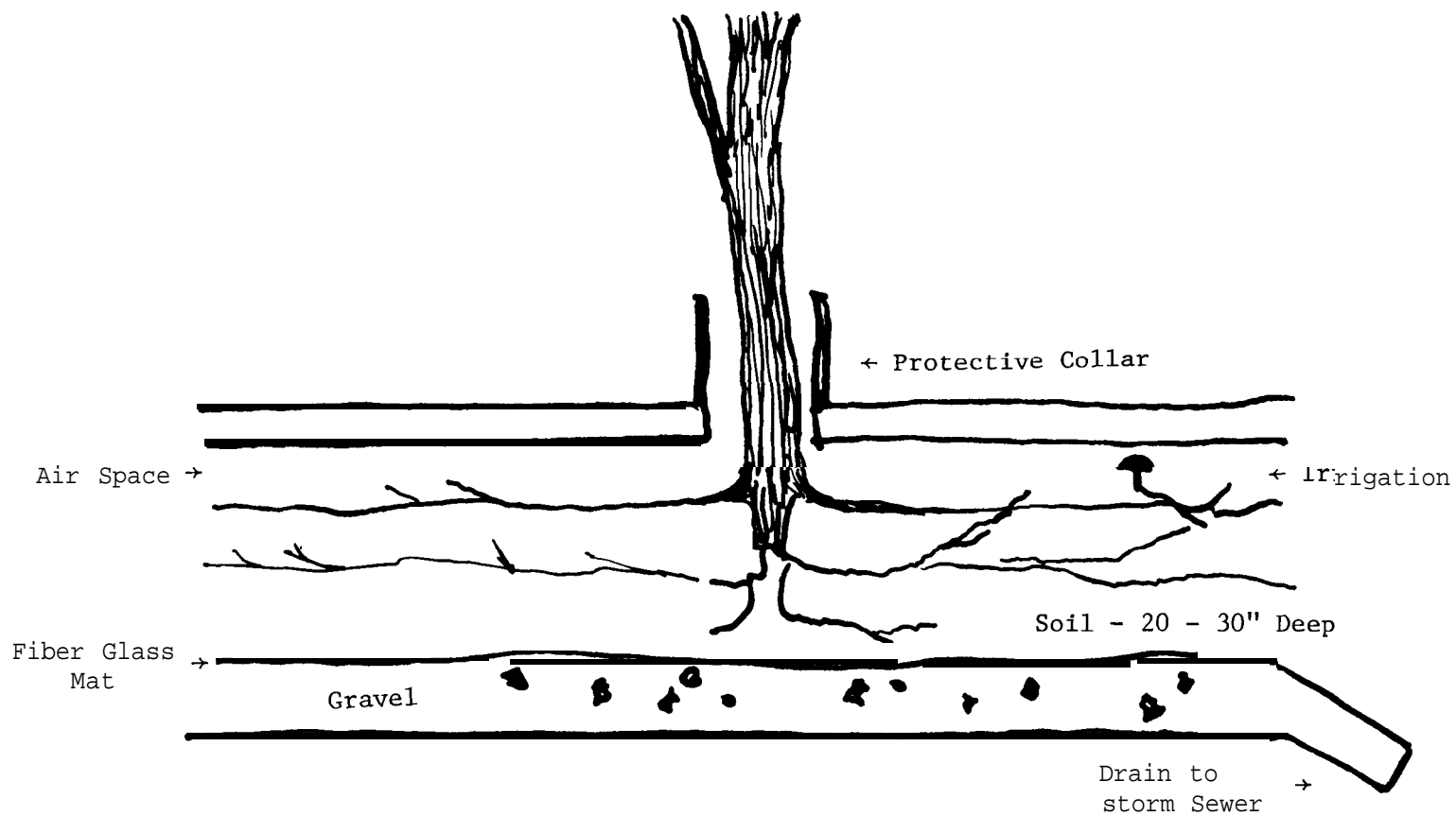


Figure 1. General layout of a proper planting site in paved situations.

be abandoned in such situations or the site design should provide for easy and frequent replacement of the plants.

Scuffling feet and leaning bicycles and thumps by passing cars are a special hazard to the sidewalk planting situation. Protective grills should be higher than the crossbar of a bicycle. Protective collars at the base of the trees should have drain holes in them to prevent trapping of water and should be easily removed for cleaning out of trash.

CONTROL OF COMPETITION

Planting space is precious in urban situations and it is not uncommon to observe groundskeepers and maintenance crews planting prostrate juniper, liriope, ivy, and various flowering annuals in the same space that was assigned for a tree or perennial shrub. Death of the tree is a common result of such over zealous horticulture. A square foot of land can only provide a limited amount of oxygen, water, nutrients and other essentials of life. Hence, the amount of leaves and supporting roots is limited to about 6 square units of leaf surface per square unit of land surface. Tearing up the soil and root system of a tree to plant tulips, petunias, and chrysanthemums can only decrease the vigor and size of the tree. There will be a direct competition between the tree's roots and the plant roots for oxygen and water and nutrients. Figure 2 shows an effective arrangement for separating tree roots from the roots of the bedding plants. The bedding plant container should be large enough so that the plants cannot be stolen easily by vandals. Both the raised planter and the tree planter should be provided with adequate water, aeration, and drainage.

PROPER MAINTENANCE

Automatic irrigation systems plug up, salts accumulate, and plants grow too large for their containers. A regular system of inspection and maintenance and replacement should be part of any sidewalk, downtown mall, formal park, or tree lawn planting.

Maintenance requires money. Politicians and businessmen get caught-up in the glories of urban renewal, Arbor Days, and other projects without providing the funds necessary for maintenance. Too many cities have used federal money for elaborate landscape schemes without providing funds for maintenance. Urban plantings should not be undertaken unless such funds are provided. Indeed the federal government should require demonstration of ability to maintain and manage plantings and landscape projects before giving funds to the local governments.

Proper maintenance of trees and other plantings require skilled employees who are literate and who care about the plants they are responsible for. Unfortunately most maintenance workers employed by local governments are marginally literate and unskilled. Two urban

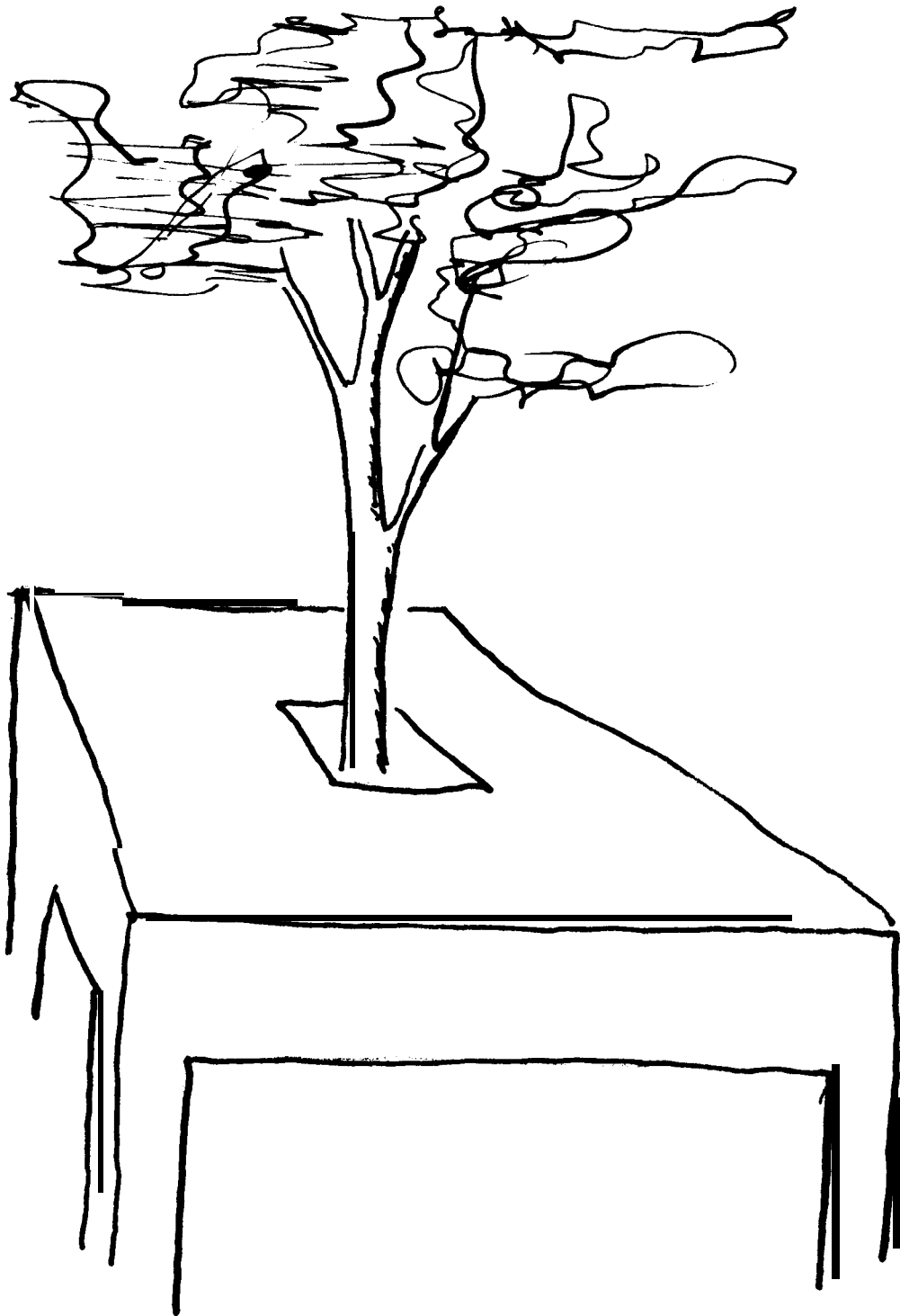


Figure 2. Elevated planter to eliminate competition of roots of bedding plants and trees.

trees out of three show scars of careless use of mowers, weed eaters, and other maintenance equipment. Herbicides are a special hazard in the hands of an untrained worker. Valuable trees were being killed in every city examined in this study because untrained and irresponsible workers were charged with the use of herbicides.

Special training programs plus systems of rewards and penalties for urban employees would do much to improve the health and longevity and beauty of urban plantings.

SUMMARY

Urban planting sites are often very abnormal and require special design and maintenance if the trees placed in them are to grow and be healthy and beautiful. Water needs, design and maintenance practices required for healthy plant growth are described.

LITERATURE CITED

- Broadfoot, W. M.
1958. A Method for Measuring Water Use by Forests on Slowly Permeable Soils. J. For. 56:(5) p. 361.
- Brown, W. E. and J. R. Thompson
1965. Summer Water Use by Aspen, Spruce, and Grassland. J. For. 64:756-760.
- Chandler, W. H.
1957. Deciduous Orchards. 3rd ed. Lea and Febiger, Philadelphia. 492 p.
- Childers, N. F.
1966. Fruit Science; Orchard and Small Fruit Management. 3rd ed. Rutgers State Univ. 893 p.
- Gourley, J. H. and F. S. Howlett
1941. Modern Fruit Production. Macmillan Co., NY 579 p.
- Hewlett, J. D. and A. R. Hibbert
1961. Increases in Water Yield after Several Types of Forest Cutting. Quarterly Bull. International Assoc. Sci. Hydrol. p. 5-17.
- Krajicek, J. E., K. E. Brinkman, S. F. Gingrich
1961. Crown Competition - A Measure of Density. Forest Science 7:35-42.

- Olmsted, F. L. and T. Kimball
1970 ed. Frederick L. Olmsted, Landscape Architect 1877-1903.
Edited by F. L. Olmsted Jr. and Theodora Kimball. B. Blom, NY.
- Metz, L. J. and J. E. Douglas
1959. Soil Moisture Depletion Under Several Piedmont Cover Types.
Tech. Bull. 1206. 23 p. USDA Forest Service.
- Satoo, T.
1958. Estimation on the Amount of Water Loss by Transpiration of
Conifers. Kogaku 28:205.
- Schnur,
1937. Yield, Stand, and Volume Tables of Even-aged Upland Oak
Forests. Tech. Bull. 560, 87 p. USDA Forest Service. Reprinted
1961.
- Schumacher, F. V. and T. S. Coile
1960. Growth and Yields of Natural Stands of Southern Pines. 97 p.
T. S. Coile, Inc.