Benefits of Trees Watershed, Energy, and Air

By E. Gregory McPherson

City trees are living umbrellas that protect us from the elements, clean the air and water, and nurture a sense of well-being.

Over the past 20 years, research has revealed the value of these benefits to the health and pocketbooks of city dwellers. Just as all arborists should understand basic tree biology, they should also know how city trees improve quality of life. Moreover, arborists should understand why the services trees provide are important and how selection and management can optimize benefits.

This article provides information that will help you make wise choices, thereby increasing the potential of trees to add value to your customers' landscapes. It focuses on watershed, energy, and air benefits. Future articles will explore other economic, social, and environmental benefits.

Learning objectives—
The arborist will be able to

- describe how trees produce watershed, energy, and air quality benefits.
- explain why these benefits are important.
- select, locate, and manage trees to increase these benefits.

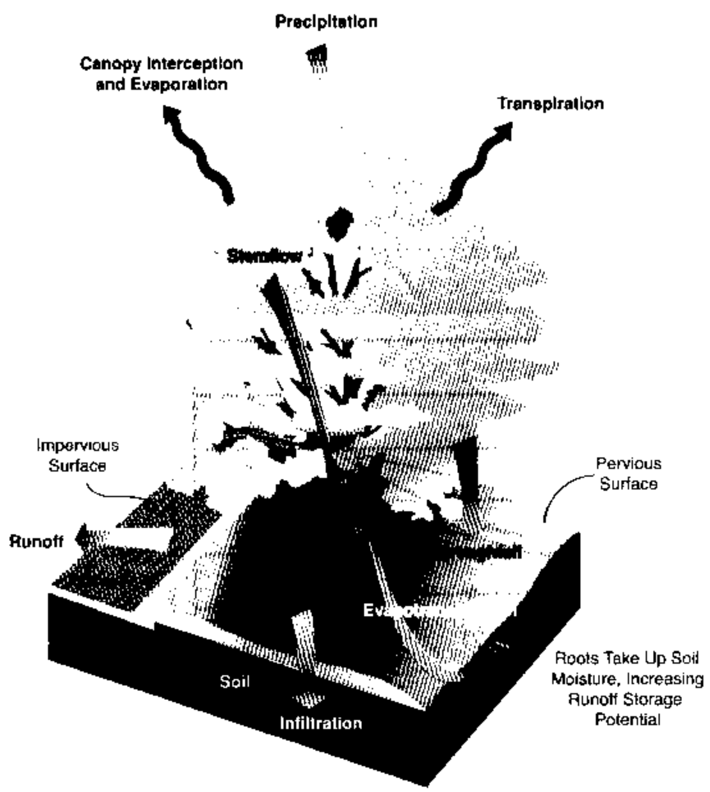

Figure 1. Trees intercept a portion of rainfall that evaporates and never reaches the ground. Some rainfall runs to the ground along branches and stems (stemflow), and some falls through gaps or drips off leaves and branches (throughfall). Transpiration increases soil moisture storage potential.

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Watershed Benefits

Urban stormwater runoff is a major source of pollution entering wetlands, streams, lakes, and oceans. Healthy trees can reduce the amount of runoff and pollutant loading in receiving waters. This reduction is important because federal law requires states and localities to control nonpoint source pollution, such as from pavements, buildings, and landscapes. Trees are mini-reservoirs, controlling runoff at the source: Their leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows (Figure 1). Rainfall interception by large trees is a relatively inexpensive first line of defense in the battle to control nonpoint pollution. Other ways that trees provide watershed benefits:

- Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.

- Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.
- Transpiration through tree leaves reduces soil moisture, increasing the soil's capacity to store rainfall.

Are these watershed benefits offset by irrigation costs? Usually, watershed benefits do exceed irrigation water costs. For example, in the Arizona desert city of Glendale, a mature mesquite intercepts 1,600 gallons annually and consumes about 1,100 gallons through irrigation (McPherson et al. 2004). Because the price of irrigation water is one-fourth the cost of controlling stormwater per gallon, the annual watershed benefit is more than four times greater than the irrigation cost ($7.70 versus $1.85 per tree).

Rainfall that is stored temporarily on canopy leaf and bark surfaces is called interception. Intercepted water evaporates, drips from leaf surfaces, and flows down stem surfaces to the ground (Figure 1). Saturation generally occurs after 1 to 2 inches of rain has fallen (Xiao et al. 2000). During heavy storms, rainfall exceeds the amount required to fill tree crown storage, about 50 to 100 gallons per tree. The benefit is limited to this amount of interception, as well as delaying the time of peak flow. Trees protect water quality by substantially reducing runoff during less extreme rainfall events. Small storms, for which tree interception is greatest, are responsible for most pollutant washoff. Therefore, urban forests generally produce more benefits through water quality protection than through flood control (Xiao et al. 1998).

The amount of rainfall trees intercept depends on their architecture, the rainfall patterns, and the climate. Tree crown characteristics that influence interception include trunk, stem, and surface areas; textures; number and size of gaps; foliation period; and dimensions (that is, height and diameter). Trees with coarse-textured surfaces retain more rainfall than ones with smooth surfaces. Large trees generally intercept more rainfall than small trees because of greater surface areas and higher evaporation rates (Figure 2). Tree crowns with few gaps reduce throughfall to the ground. Species that are in leaf when rainfall is plentiful are more effective than deciduous species that have dropped their leaves. In Mediterranean climates, winter rainfall patterns accentuate the value of evergreen species.

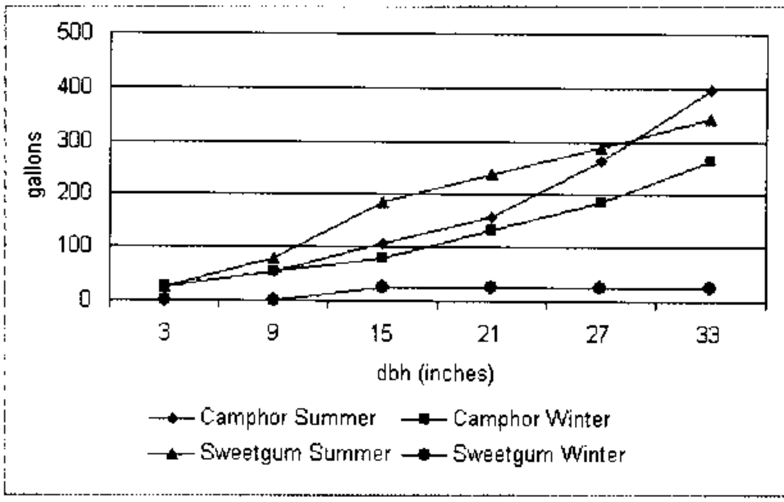

Figure 2. Modeled rainfall interception for different-sized broadleaf evergreen camphors *(Cinnamomum camphora)* and deciduous sweetgums *(Liquidambar styraciflua)* during similar summer (44 hours, 0.8 inch) and winter (41 hours, 0.85 inch) rainfall events in Santa Monica, California. Interception is greatest during summer and least for the leafless sweetgum during winter (Xiao and McPherson 2003).

Energy Benefits

Energy fuels economic growth and is an essential ingredient for quality of life. Conserving energy by greening our cities is important because it is often more cost-effective than building new power plants. For example, planting 50 million more shade trees in California cities would provide savings equivalent to seven 100-megawatt power plants (McPherson and Simpson 2003). The cost of peak load reduction is $63 per kilowatt, considerably less than the $150-per-kilowatt benchmark for cost-effectiveness.

Trees modify climate and conserve building energy use in three principal ways (Figure 3):

- shading, which reduces the amount of radiant energy absorbed and stored by built surfaces.
- transpiration, which converts liquid water to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
- wind speed reduction, which reduces the infiltration of outside air into interior spaces and conductive heat loss, especially where thermal conductivity is relatively high (for example, with glass windows).

By reducing demand for electricity, trees reduce emissions of air pollutants at power plants, as well as their use of water in cooling towers. These avoided emissions can be comparable to annual pollutant uptake rates for a mature tree.

Shade trees can provide another secondary benefit—lower concentrations of ozone. The rate of ozone formation increases as air temperatures increase. By cooling the air and shading impervious surfaces (such as pavement and roof tops), trees can reduce ozone concentrations. Temperature differences of more than 9°F have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992).

For individual buildings, strategically placed trees can increase energy efficiency in the summer and winter (Sand 1994; Simpson 1998). The west side of a house is the most important side to shade; evergreens provide both summer shade and winter wind protection. The east side is the second most important side to shade. Deciduous trees on the east provide summer shade and more winter solar heat gain than do evergreens. In the winter, solar access on the southern side of buildings can warm interior spaces (Figure 4). Solar-friendly trees reduce blocking of winter sunlight. Such trees have open crowns during winter, leaves that are early to drop and late to leaf out, relatively small size, and a slow growth rate. Examples include most species and cultivars of maple (*Acer* spp.), honeylocust (*Gleditsia* spp.), and ash (*Fraxinus* spp.).

To maximize summer shade and minimize winter shade, locate shade trees about 10 to 20 feet south of the house. As trees grow taller, prune lower branches to allow more winter sun to reach the house if doing so will not weaken the tree's structure. At other locations, keep trees at least 5 to 10 feet from the house to avoid conflicts with it, but within 30 to 50 feet to effectively shade windows and walls.

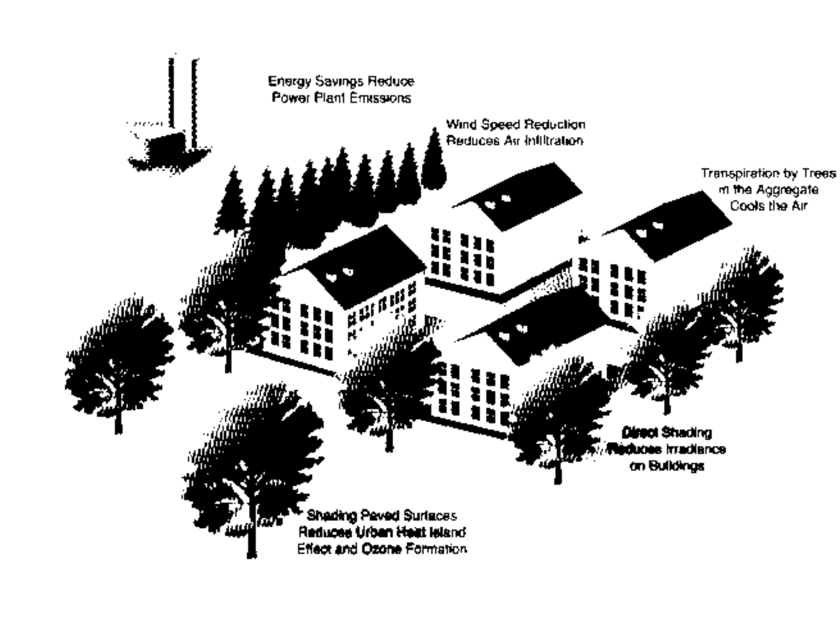

Figure 3. Trees save heating and cooling energy by shading buildings, lowering summertime temperatures, and reducing wind speeds. Secondary benefits from energy conservation are reduced water consumption and pollutant emissions by power plants.

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Paved patios and driveways can become heat sinks that warm a house during the day. Shade trees can make them cooler and more comfortable spaces. If a house is equipped with an air conditioner, shade and cooler air temperatures can increase its efficiency—but do not plant vegetation so close that it will obstruct the flow of air around the unit.

Trees planted as windbreaks can reduce heating costs in temperate-climate cities. Windbreaks reduce wind speed and resulting infiltration of cold air by up to 50 percent, translating into potential annual heating savings of 10 to 12 percent (Heisler 1986). Windbreak design is influenced by lot size: Many lots are not large enough to plant evergreen windbreaks. Ideally, the windbreak should

- be longer than the building being sheltered,
- be planted perpendicular to the prevailing wind, about 25 to 50 feet from the building, and
- consist of dense evergreens that will grow to twice the height of the building they shelter.

Figure 4. Locate trees to shade west and east windows, while providing solar access to the south.

USDA FOREST SERVICE, CENTER FOR URBAN FOREST RESEARCH, DAVIS, CA.

Most conifers can be spaced about 6 feet on center, with rows spaced 10 to 12 feet apart. Remember that snow collects behind a windbreak, which can be a problem if the driveway is located between the trees and the house.

The amount of energy savings from trees varies regionally, as well as by site (Figure 5). Savings are greatest in regions with the largest cooling and heating loads. A computer simulation of annual cooling savings for an energy-efficient home in Tucson found that three 25-foot-tall trees saved $100 each year for cooling, a 25 percent reduction (McPherson et al. 1993). In Denver, two 25-foot-tall trees saved $15 each year for heating (4 percent savings) and $30 for cooling (24 percent). The total $45 savings represented a 9 percent reduction in annual heating and cooling costs.

Air Quality Benefits

Fifty-four percent (159 million) of the U.S. population live in areas where ozone concentrations violate federal air quality standards. Air pollution is a serious health threat to many city dwellers, causing coughing, headaches, respiratory and heart disease, and cancer. Impaired health results in increased social costs for medical care, greater absenteeism, and reduced longevity.

Trees, sometimes called the "lungs of our cities," are important because of their ability to remove contaminants from the air. Air quality management districts have funded tree planting projects to control dust and other small particles. (Particulate matter 10 micrometers [PM_{10}] in diameter and smaller is considered inhalable.) Although the U.S. Environmental Protection Agency has not yet recognized tree planting as a measure for reducing ozone, they are likely to do so, which will create new opportunities

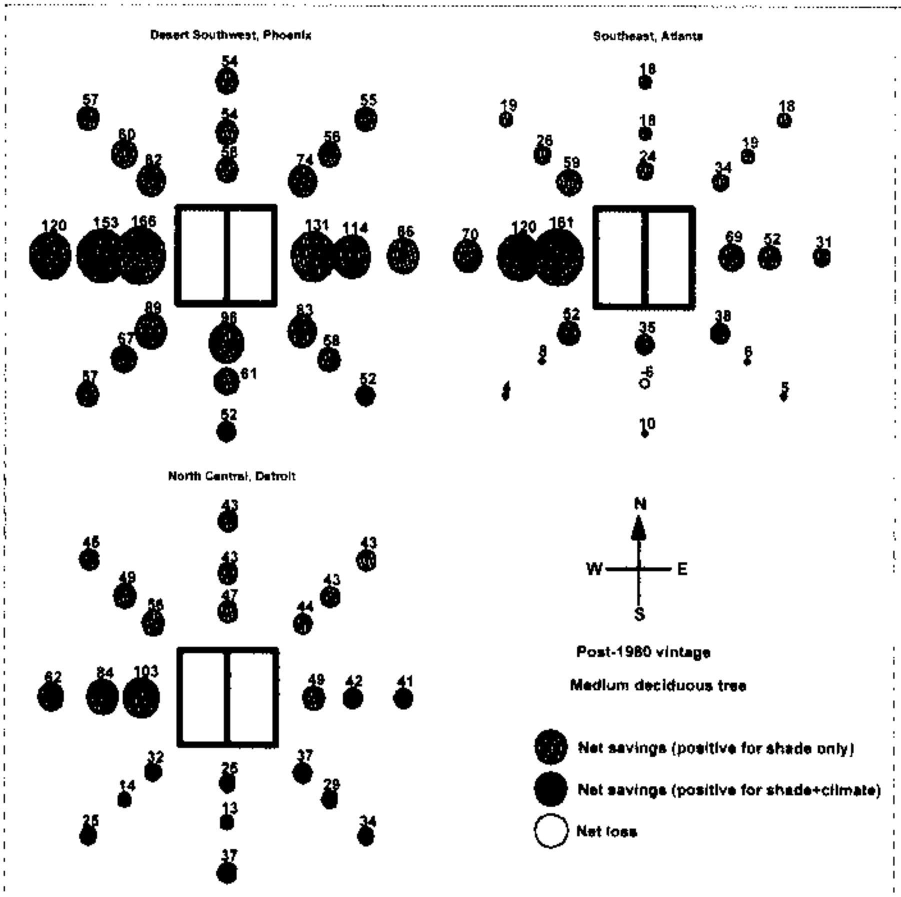

Figure 5. Heating and cooling savings vary by tree location and region. Savings are greatest in warmer climates, for trees opposite west- and east-facing walls, and for trees closest to the building (Simpson and McPherson 2001).

to plant and care for trees as an air pollution control technology (Luley and Bond 2002). Trees provide air quality benefits in five ways (Figure 6):

- absorbing gaseous pollutants (such as ozone, nitrogen oxides, and sulfur dioxide) through leaf surfaces.
- intercepting particulate matter (such as dust, ash, pollen, and smoke) on plant surfaces.
- releasing oxygen through photosynthesis.
- transpiring water and shading building surfaces and paving, which lowers local air temperatures, thereby reducing ozone levels and power plant emissions.
- reducing evaporative hydrocarbon emissions from parked vehicles.

Trees, however, can adversely affect air quality. Most trees emit biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can contribute to ozone formation. The contribution of BVOC emissions from city trees to ozone formation depends on complex geographic and atmospheric interactions that have not been studied in most cities (Nowak et al. 2000).

Trees absorb gaseous pollutants through leaf stomates (Smith 1990). Secondary methods of pollutant removal include adsorption of gases to plant surfaces and uptake through bark pores. Once gases enter the leaf, they diffuse into intercellular spaces, where some react with inner leaf surfaces and others are absorbed by water films to form acids. Pollutants can damage plants by altering their metabolism and growth. At high concentrations, pollutants cause visible damage to leaves, such as stippling and bleaching. As well as plant health hazards, pollutants can be sources of essential nutrients for trees, such as nitrogenous gases.

Trees intercept small, airborne particles. Some particles are absorbed, but most adhere to plant surfaces. Species with hairy or rough leaf, twig, and bark surfaces are efficient interceptors. Intercepted particles often are resuspended

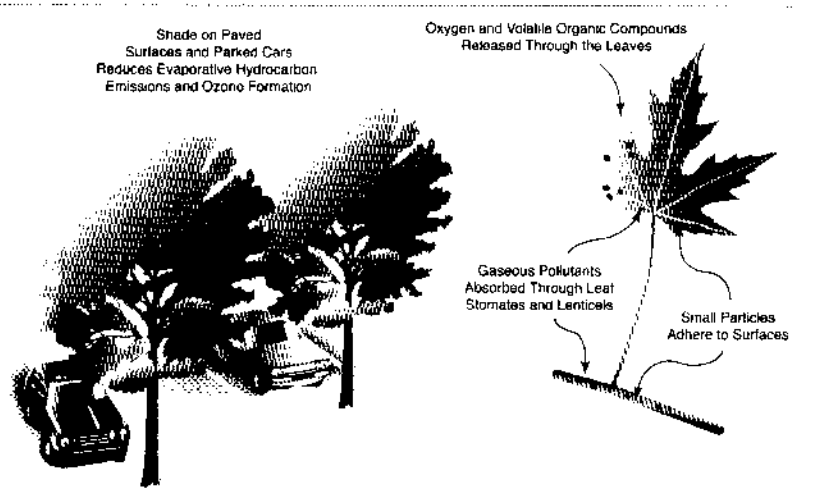

Figure 6. Trees absorb gaseous pollutants, retain particles on their surfaces, and release oxygen and volatile organic compounds. By cooling urban heat islands and shading parked cars, trees can reduce ozone formation.

DRAWING BY MIKE THOMAS

to the atmosphere when wind blows the branches.

The ultimate fate of contaminants transferred from the atmosphere depends on the pollutant. For example, absorbed sulfur dioxide has been associated with sulfur movement throughout the entire tree, including diffusion from roots into the soil (Smith and Dochinger 1976). Heavy metals, chloride, and fluoride are less mobile, accumulating in leaves until they fall. Materials adhering to plant surfaces are washed off by rainfall, contaminating the soil or stormwater runoff below the crown. Stormwater management and leaf collection and disposal practices influence the fate of these contaminants.

Urban forests freshen the air we breathe by releasing oxygen into the air as a byproduct of photosynthesis. Net annual oxygen production varies depending on tree species, size, health, and location. A healthy tree, such as a 32-foot-tall ash, produces about 260 pounds of net oxygen annually. A typical person consumes 386 pounds of oxygen per year. Therefore, two medium-sized, healthy trees can supply the oxygen required for a single person over the course of a year. Once the trees die, oxygen will be released through decomposition.

The amount of gaseous pollutants and particulates removed by trees depends on tree size and architecture, as well as local meteorology and pollutant concentrations. Uptake rates are high when pollutant concentrations and leaf surface areas are high (Figure 7). For example, in western Washington, where air pollutant concentrations were low, annual ozone uptake rates for a 20-year-old red oak *(Quercus rubra)* and purple-leaf plum *(Prunus cerasifera)* were 0.35 pound and 0.13 pound, respectively (McPherson et al. 2002). In Los Angeles, where concentrations were higher, uptake rates for the Shamel ash *(Fraxinus uhdei)* and crapemyrtle *(Lagerstroemia indica)* were 1.26 pounds and 0.19 pound, respectively (McPherson et al. 2001).

The Chicago region's 50.8 million trees were estimated to remove 234 tons of PM_{10}, 210 tons of ozone, 93 tons of sulfur dioxide, and 17 tons of carbon monoxide annually in 1991, and this environmental service was valued at $9.2 million (Nowak 1994).

Parking lots occupy about 10 percent of the land in our cities and act as miniature heat islands and sources of motor vehicle pollutants. By shading cars and lowering parking lot temperatures, trees can reduce evaporative emissions of hydrocarbons (HCs) that leak from fuel tanks and hoses (Scott et al. 1999). Hydrocarbon emissions are involved in ozone formation, and parked cars contribute 15 to 20 percent of total motor vehicle HC emissions. Parking lot tree planting is one practical strategy communities can use to meet and sustain mandated air quality standards.

Greenhouse Gas Benefits

Human activities, primarily fossil-fuel consumption, are adding greenhouse gases to the atmosphere, resulting in gradual temperature increases. This warming is expected to have a number of adverse effects. With 50 to 70 percent of the world's population living in coastal areas, a predicted sea level rise of 6 to 37 inches could be disastrous. Increasing frequency and duration of extreme weather events will tax emergency management resources. Some plants and animals may become extinct as habitat becomes restricted.

Urban forests have been recognized as important storage sites for carbon dioxide, the primary greenhouse gas (Nowak and Crane 2002). At the same time, private markets dedicated to economically reducing carbon dioxide emissions are emerging (McHale 2003). Carbon credits are selling for $0.11 to $20 per metric tonne, while the cost for a tree planting project in Arizona was $19 per tonne (McPherson and Simpson 1999). As carbon reductions become accredited and prices rise, carbon credit markets could become monetary resources for community forestry programs. Urban forests can reduce atmospheric carbon dioxide in two ways (Figure 8):

- Trees directly sequester carbon dioxide as woody and foliar biomass while they grow.
- Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

On the other hand, vehicles, chain saws, chippers, and other equipment release carbon dioxide during the process of planting and maintaining trees. And eventually, all trees die—and most of the carbon dioxide that has accumulated in their woody biomass is released into the atmosphere through decomposition. In the short-term, carbon dioxide released due to tree planting, maintenance, and other program-related

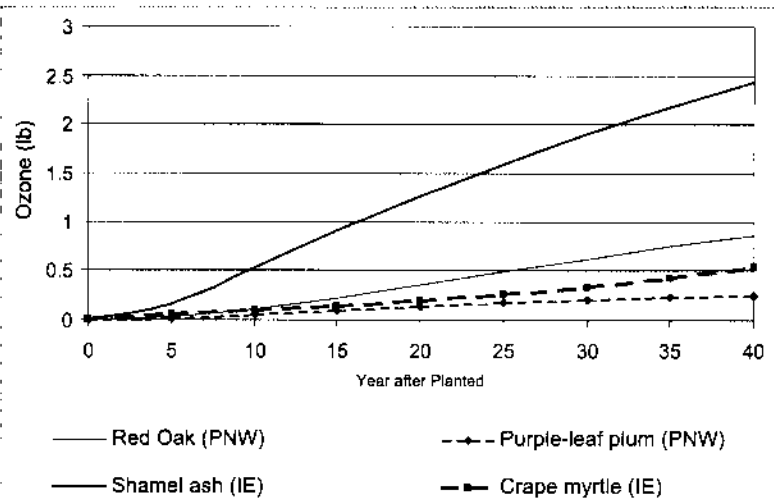

Figure 7. Ozone uptake rates reflect tree size, as well as pollutant concentrations. Rates are higher for the large-stature trees (red oak and Shamel ash) than for small-stature trees. Trees in the more polluted Inland Empire (IE) region of Southern California absorb more ozone than similar-sized trees in the less polluted Pacific Northwest (PNW).

activities is about 2 to 8 percent of annual carbon dioxide reductions obtained through sequestration and avoided power plant emissions (McPherson and Simpson 1999).

The rate that trees sequester carbon dioxide depends on their growth and mature size (Figure 9). Large-stature oak and ash in climates with long growing seasons (such as the U.S. Pacific Northwest and southwestern deserts) sequester the most carbon dioxide. Small-stature trees such as crabapple (*Malus* spp.) in regions with shorter growing seasons (northern mountain and prairie) sequester the least (McPherson et al. 2002, 2003, 2004). Sequestration can range from 35 pounds per year for small, slow-growing trees to 800 pounds per year for larger trees growing at their maximum rate (Nowak 1994).

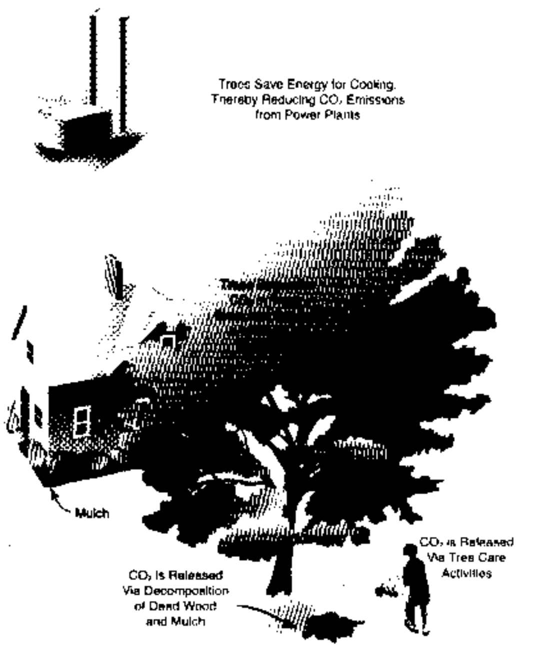

Figure 8. Trees sequester carbon dioxide as they grow and indirectly reduce carbon dioxide emissions from power plants through energy conservation. Carbon dioxide is released through decomposition and tree care activities that involve fossil-fuel consumption.

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Regional variations in climate and the mix of fuels that produce energy can have a tenfold effect on carbon dioxide emission reductions from power plants. Cities in states with relatively high carbon dioxide emission rates (such as North Dakota, Wyoming, Kentucky, and Indiana) will have greater carbon dioxide benefits from tree-related electricity savings than those in states with low emission rates (such as Vermont, Idaho, Washington, and Oregon).

One of the most comprehensive studies of atmospheric carbon dioxide reduction by an urban forest found that Sacramento, California's six million trees removed approximately 335 thousand tons of atmospheric carbon dioxide annually, with an implied value of $3.3 million (McPherson 1998). Of the total amount removed, 76 percent was sequestered (average 77 to 95 pounds per tree by sector), and 25 percent was due to avoided power plant emissions. Carbon dioxide released by tree care activities was 3 percent of the total sequestered and avoided annually. Carbon dioxide reduction by Sacramento's urban forest offset 1.8 percent of total carbon dioxide emitted annually as a byproduct of human consumption. This savings could be substantially increased through strategic planting and long-term stewardship that maximize future energy savings from new tree plantings.

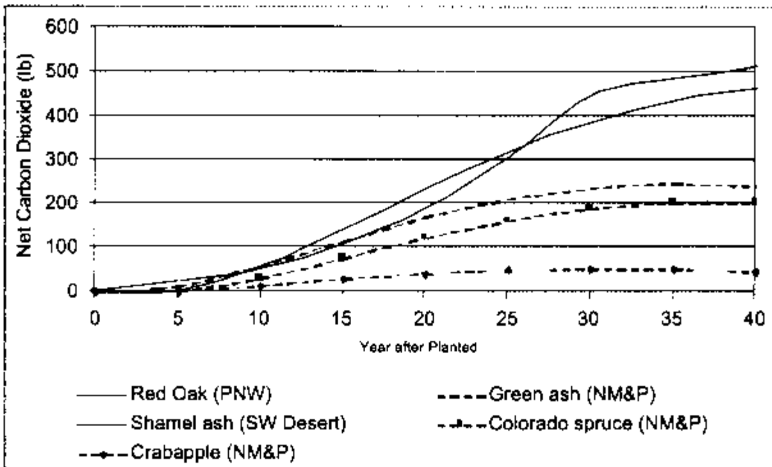

Figure 9. Net carbon dioxide uptake rates for public trees that do not shade buildings reflect the importance of tree growth. Large-stature oak and ash in climates with long growing seasons (Pacific Northwest [PNW] and Southwest Desert [SW Desert]) provide the greatest net carbon dioxide benefits. The small-stature crabapple in the Northern Mountain and Prairie (NM&P) region provides the least.

City trees work ceaselessly, providing environmental services that directly improve human health and quality of life. Although the annual monetary value of each service is small, $2 to $15 per tree, total benefits usually exceed tree care costs ($5 to $40 per tree). The value of other social, economic, psychological, ecological, and spiritual benefits may well exceed the value of environmental benefits. Trees are proving to be a cost-effective means to improving human well-being in our cities.

The benefits of trees are directly related to their size. Larger trees provide greater benefits than smaller trees, other things being equal. Therefore, providing adequate growing space for large-stature trees is critical. When space is limited, select the largest tree that the site can reasonably support. Follow-up care is essential because healthy and vigorously growing trees are productive trees. By planting the right tree in the right place, and providing the right long-term care, benefits are sure to follow.

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CEU TEST QUESTIONS

To receive continuing education unit (CEU) credit (1 CEU) for home study of this article, after you have read it, darken the appropriate circles on the answer form on the insert card in this issue of *Arborist News.* (A photocopy of the answer form is NOT acceptable.) A passing score for this test is 16 correct answers.

Next, complete the registration information on the answer form and send it to ISA, P.O. Box 3129, Champaign, IL 61826-3129. Answer forms for this test on **Benefits of Trees: Watershed, Energy, and Air** may be sent for the next 12 months.

You will be notified only if you do not pass. CEU codes for the exams passed will appear on the CEU updates in March and September. If you do not pass, ISA gives you the option of taking the test as often as necessary.

1. Rainfall interception occurs when trees
   a. allow rainfall to pass through their crowns
   b. store rainfall on leaf and bark surfaces
   c. cause rainfall to drop from saturated surfaces
   d. promote stemflow to the ground

►

2. Trees reduce stormwater runoff, which is important because
   a. local law requires control of runoff
   b. trees provide greater runoff reduction than do other stormwater management practices
   c. federal law requires control of nonpoint source pollutants
   d. trees are the most cost-effective stormwater control measure
3. Trees that intercept the most rainfall have
   a. large surface area, coarse-textured surfaces, many crown gaps
   b. small surface area, fine-textured surfaces, few crown gaps
   c. small surface area, coarse-textured surfaces, many crown gaps
   d. large surface area, coarse-textured surfaces, few crown gaps
4. Trees modify climate by
   a. shading built surfaces
   b. cooling the air by transpiration
   c. reducing wind speeds
   d. all of the above
5. Conserving electricity through strategic tree planting is important because
   a. trees always save energy
   b. trees can conserve energy at less cost than generating it at power plants
   c. electricity prices will go down
   d. once a tree is planted, its value appreciates
6. Which two are secondary benefits of shade trees? (Select **two** answers.)
   a. increased absorption of solar energy by trees reduces energy use for heating
   b. reduced demand for electricity reduces emissions of pollutants from power plants
   c. reduced wind speeds accelerate dispersion of pollutants
   d. reduced summertime air temperatures can reduce the rate of ozone formation
7. If you had only one tree to plant for cooling savings, you would want to plant it opposite the wall facing
   a. south
   b. west
   c. north
   d. east
8. Raise the crowns of trees near south-facing building surfaces to
   a. provide better views
   b. increase shade on the roof during winter
   c. improve clearance for lawn mowers
   d. increase winter solar access to windows and walls
9. Energy savings from trees varies by site but tends to be greatest in regions with
   a. high heating loads
   b. high cooling loads
   c. low cooling loads
   d. low cooling and low heating loads
10. Trees adversely affect air quality by
   a. reducing air temperatures and increasing ozone levels
   b. filtering air pollutants under their canopies
   c. emitting BVOCs
   d. all of the above
11. About how many mature trees are required to produce oxygen equivalent to the amount consumed by a healthy person?
   a. 2
   b. 6
   c. 10
   d. 20
12. Trees in parking lots improve air quality by
   a. absorbing ozone
   b. lowering air temperatures and reducing ozone formation
   c. reducing evaporative hydrocarbon emissions
   d. all of the above
13. Pollutant removal is greatest when
   a. trees are small; pollutant concentrations are high
   b. trees are large; pollutant concentrations are low
   c. trees are small; pollutant concentrations are low
   d. trees are large; pollutant concentrations are high
14. Which two ways do urban forests reduce atmospheric carbon dioxide? (Select **two** answers.)
   a. trees release oxygen, which destroys carbon dioxide
   b. trees emit carbon monoxide, which scavenges carbon dioxide
   c. trees directly sequester carbon dioxide during photosynthesis
   d. trees reduce emissions of carbon dioxide at power plants by conserving energy
15. Carbon dioxide is released when
   a. trees decompose
   b. gasoline-powered equipment is used for pruning and chipping
   c. trees respire at night
   d. all of the above
16. Annual carbon dioxide sequestration rate is the greatest for
   a. a young ginkgo in Atlanta, Georgia
   b. a mature pear in Brooklyn, New York
   c. a young pistache in San Antonio, Texas
   d. an old hemlock in Seattle, Washington
17. Which factor influences carbon dioxide reduction from power plants?
   a. fuel mix
   b. power plant size
   c. tree architecture
   d. all of the above
18. Atmospheric carbon dioxide reductions through urban forestry are important because
   a. city trees offset all emissions
   b. emerging carbon credit markets could fund shade tree programs
   c. carbon credit markets will fund rural forestry programs
   d. trees are the most cost-effective means to combat climate change
19. Solar-friendly trees
   a. leaf out late, drop leaves early, and grow slowly
   b. leaf out late, drop leaves late, and grow quickly
   c. leaf out early, drop leaves early, and grow slowly
   d. leaf out early, drop leaves late, and grow quickly
20. Removing air pollutants from the atmosphere and avoiding pollutant emissions are important because
   a. pollutants have a negative effect on human health
   b. reduced costs for medical care and absenteeism could accrue if urban dwellers are healthier
   c. the potential exists for funding tree planting programs to help control air pollution
   d. all of the above