Making a Difference for California

University of California
Agriculture and Natural Resources

UC PEER REVIEWED

http://anrcatalog.ucdavis.edu

Publication 8484 | March 2012

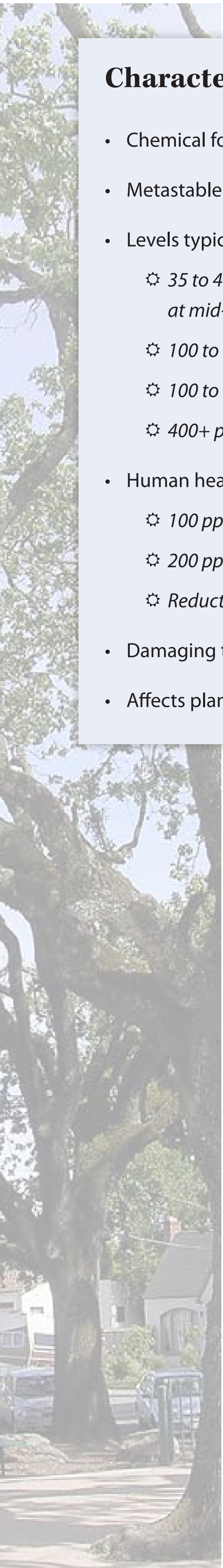
Urban Trees and Ozone Formation: A Consideration for Large-Scale Plantings

JOHN F. KARLIK, Environmental Horticulture/Environmental Science Advisor, University of California Cooperative Extension, Kern County; and **DENNIS R. PITTENGER,** Area Environmental Horticulture Advisor, University of California Cooperative Extension, Los Angeles County and UC Riverside.

Trees are valued in California's urban areas for the many benefits they provide, including modification of the local environment. Besides serving as a source of oxygen and water vapor, trees give off other chemical compounds into the atmosphere, including volatile organic compounds (VOC) that can react in the atmosphere and contribute to the formation of ozone, a principal air quality problem in California. In this publication we will briefly describe how ozone near the Earth's surface is formed and how trees can affect the formation of ozone, and we will suggest ways to take this aspect of tree biology into consideration when selecting trees for planting in large numbers in urban areas.

How Ozone Pollution Occurs, and the Role of Plants

Trees need air to grow. Their leaves take in carbon dioxide and their roots take in water, and in turn the trees release water vapor and oxygen through their leaves into the air. Trees are exposed to many chemical compounds that occur as gases in the atmosphere. Some of these compounds are known air pollutants and may adversely affect plants, even at relatively low concentrations. Of the air pollutants present in California, ozone is the most damaging to plants, and it also affects human health. Many plants are susceptible to injury from ozone at the concentrations typically found in the air (see sidebar, *Characteristics and Effects of Ozone*). Other air pollutants may also injure vegetation, resulting in leaf damage and reduced growth (see UC ANR Publication 3420, *Abiotic Disorders of Landscape Plants*).



Characteristics and Effects of Ozone

- Chemical formula: O_3
- Metastable form of oxygen
- Levels typically found in various locations:
  - *35 to 40 parts per billion (ppb): clean atmosphere, such as found at mid-ocean*
  - *100 to 120 ppb: Central California (summer)*
  - *100 to 140 ppb: Los Angeles, California (summer)*
  - *400+ ppb: Mexico City (summer)*
- Human health effects:
  - *100 ppb: eye irritation*
  - *200 ppb: coughing*
  - *Reduction in pulmonary function and physical performance*
- Damaging to some materials (e.g., rubber)
- Affects plants starting at approximately 60 ppb

Ozone is formed close to the Earth's surface when VOC react with oxides of nitrogen (NOx) in the presence of sunlight:

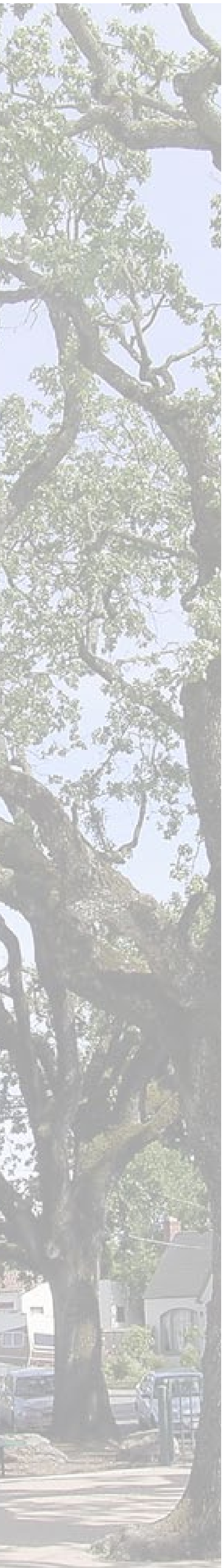
$$\text{VOC} + \text{NOx} + \text{sunlight} \longrightarrow \text{ozone}$$

Ozone concentrations are affected by the relative concentrations of VOC and NOx as well as by air temperature, weather, and topography. Although low, non–plant-injuring levels of ozone naturally occur in the air, elevated levels are found where both VOC and NOx concentrations are high, sunlight is intense, an air mass is trapped (for instance, by surrounding mountains), and air temperature is high. These conditions are common during summer in California's Los Angeles Basin, Inland Empire, and Central Valley regions. Since ozone in the lower atmosphere affects human health, the California Air Resources Board is responsible for developing regulations to bring ozone concentrations down to acceptable levels.

NOx emissions are produced at high temperatures, and the principal source of NOx emissions is the internal combustion engine. NOx is produced inside the engine's cylinders during operation, so NOx levels tend to be high in city centers where motor vehicles are plentiful. In rural areas there are stationary engines as well, such as those used for irrigation pumps, and they also to contribute NOx levels.

The identities and sources of VOC are more diverse. Some VOC are *anthropogenic*; that is, they are released as a result of human activity. For example, they may enter the atmosphere through the evaporation of solvents, motor fuels, and lubricants. Researchers now know that significant amounts of VOC are also emitted from vegetation, including urban forests and landscapes, agricultural crops, and natural plant communities in non-irrigated areas such as chaparral and forests. The VOC emitted by plants are known as *biogenic* VOC, or simply BVOC. The total VOC volume in the atmosphere is the sum of anthropogenic VOC and biogenic VOC.

In the global atmosphere, BVOC emissions are the dominant component of total VOC, and BVOC play an important role in atmospheric chemistry and balancing the global carbon cycle. In local or regional air basins, however, there is variation in the relative importance of BVOC and anthropogenic VOC. An accurate estimate of the magnitude of BVOC is important to the formulation of strategies to reduce peak ozone concentrations, since an effective strategy must take into account the relative strength of NOx and total VOC emissions. Modeling studies by the California Air Resources Board indicate that the development of specific strategies for reducing ambient ozone concentrations in some areas of California depends upon source



strengths of BVOC. These studies showed that emissions of hydrocarbons from vegetation can determine whether NOx emission controls or VOC emission controls are most effective for reducing ozone concentrations. (For more information on biogenic emissions and California air quality policy, refer to the California Air Resources Board website, www.arb.ca.gov.)

It is important to distinguish ozone near the Earth's surface—which directly contacts people and plants—from ozone in the upper atmosphere (stratosphere), beginning about 6 miles above the Earth's surface. Although it is the same molecule in both cases, ozone in the stratosphere is produced by chemical mechanisms quite different from VOC and NOx reactions. Stratospheric ozone provides an important benefit by shielding Earth's surface from short-wavelength ultraviolet light. The ozone that we breathe, however, acts as an air pollutant that can cause a reduction in human lung function, shortness of breath, injury to vegetation, and damage to materials, such as rubber. Although ozone absorbs long-wave radiation, it is not among the most important greenhouse gases and is not considered a principal contributor to climate change. Warmer atmospheric temperatures may, however, lead to increases in ozone concentration.

Types of Plant BVOC

Plants give off more than 1000 different BVOC compounds, but only a few are emitted in relatively large quantities. The BVOC emitted in greatest quantity by plants is isoprene (C_5H_8). Plants can emit 2 percent of the carbon they fix during photosynthesis in the form of this compound, and it is very reactive. Isoprene is produced as a direct by-product of photosynthesis, which means that it is not produced by plants at night. When plants do emit isoprene, the emission rate increases exponentially with increases in light and temperature.

Monoterpenes ($C_{10}H_{16}$) are compounds that plants emit primarily from stored supplies, so they can be emitted at night as well as during the day. The emission rate increases exponentially with temperature. A few plants show monoterpene emissions that are light dependent.

Sesquiterpenes ($C_{15}H_{24}$) are highly reactive and difficult to measure, so less is known about them. Plant emission rates for sesquiterpenes are lower than for monoterpenes or isoprene.

Plants can also emit a number of organic compounds that contain oxygen, including alcohols, ketones, aldehydes, and carboxylic acids. Harvest events such as cutting hay or mowing a lawn may release pulses of these compounds. Emission rates for these oxygenated compounds usually are low, but methylbutenol is an important oxygenated biogenic emission for some pines.

In general, broadleaved plants such as oaks and eucalyptus have isoprene as their largest BVOC emission, whereas pines and other conifers have monoterpenes as their largest BVOC emission.

BVOC Reactivity

Vegetative emissions are about three times more reactive than the common exhaust and evaporative VOC emissions that come from motor vehicles, so plant emissions can have a greater ozone-forming potential. A useful way to compare reaction rates is to note the atmospheric lifetimes of several BVOC as compared to anthropogenic VOC (table 1). A shorter lifetime indicates higher reactivity and therefore a higher ozone-forming potential.

Table 1. Atmospheric lifetime for several volatile organic compounds (VOC)

VOC hydrocarbon	VOC lifetime with respect to reaction with OH*
Biogenic	
Isoprene	1.8 hours
d-Limonene	1.1 hours
a-Pinene	3.4 hours
Myrcene	52 minutes
Anthropogenic	
n-Octane	3 days
n-Butane	9 days

* OH is the hydroxyl radical. Times given here assume a temperature of 28°C (82°F) and a 12-hour daytime average OH radical concentration of $1.5 \cdot 10^6$ mol · cm^{-3} (Winer, Fitz, and Miller 1989).

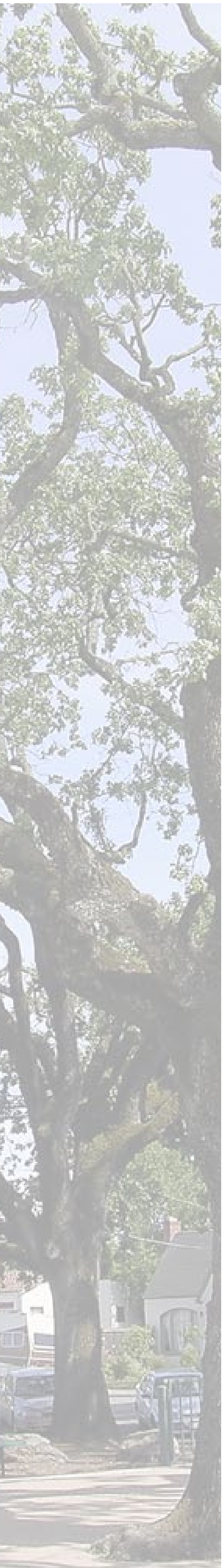
Plant BVOC Emission Rates

Under standard conditions of light and temperature, the BVOC contribution of an individual plant is proportional to its BVOC emission rate and the size of its canopy, as measured by its leaf mass. The larger the plant, the greater its leaf mass, so large plants with high emission rates tend to dominate the BVOC emission inventory in a given landscape. BVOC emissions for two individual plants can differ by as much as a factor of 10,000 if both emission rate and leaf mass are taken into account. Although the environment around developing leaves can affect a plant's BVOC emission potential, the fundamental controlling factor for emissions is genetics—in other words, the genus and species of a plant. Once leaves are fully developed, the emission rate may be strongly influenced by light or temperature or both, but emission rates are affected little by typical landscape management practices such as fertilizer application and irrigation.

BVOC emission rates usually are expressed as micrograms of BVOC emitted per gram of dry leaf mass per hour. The rate is sometimes expressed as micrograms of carbon rather than micrograms of the individual BVOC to make it easier to compare and sum the contributions of different BVOC. While a microgram is a very small amount, the total emissions of trees can become significant when we consider the leaf mass of a large tree, longer time periods, and the presence of many trees.

As an example, we might consider isoprene emission from American sweetgum *(Liquidambar styraciflua),* a common shade tree in California. For a sweetgum tree about 50 feet (15 m) tall with an 8-foot (2.4 m) crown radius, dry leaf mass as determined in field studies would be approximately 18 pounds (40 kg). Such a tree, having an isoprene emission value of 26 micrograms of isoprene per gram of leaf mass per hour ($26\ \mu g \cdot g^{-1} \cdot hr^{-1}$) as measured in California studies, will emit about 0.04 ounces (1 g) of isoprene per hour under standard conditions of temperature and light: 86°F (30°C) and photosynthetically active solar radiation (PAR) of 1000 mol $\cdot\ m^{-2} \cdot sec^{-1}$. The tree's hourly emission rate is approximately equivalent to that of 0.15 fluid ounces (4.5 mL) of gasoline evaporated per hour, when we consider the reactivity of isoprene and we use a conversion factor to account for the density of gasoline. Under warmer temperatures and higher light intensities that are typical during summer in California's Central Valley and Inland Empire regions, the emissions will be greater.

The magnitude of the BVOC contribution for a tree species increases dramatically when the number of trees is large, such as an entire city's urban forest. For example, 10,000 sweetgum trees of this size, under standard conditions of light and temperature, would emit a quantity of isoprene every hour that is roughly equivalent to the evaporation of 12 gallons (45 L) of gasoline.



BVOC for Plant Families, Genera, and Species

Since the 1980s, researchers have taken quantitative and semi-quantitative measurements of VOC emissions for hundreds of plant species, including many tree species found in California agriculture, urban landscapes, and native plant communities. It is now possible to infer BVOC emission rates for many unmeasured species based on the measurements recorded for closely related plants (same family or genus), though there are exceptions.

In this publication we will look mostly at isoprene, since it is the BVOC of largest magnitude. For additional quantitative data on specific genera and species, you may consult summary databases such as the one at the National Center for Atmospheric Research (http://bai.acd.ucar.edu/Data/BVOC). Additional measurements made in the future may change the categorization of the plants we present here, but the recorded measurements for some, like eucalyptus, are already very numerous so surprises are less likely there than for other genera where few measurements have been made. For now, we will take a look at plant families in California that seem to have the most uniform BVOC emission rates for isoprene.

Based on recorded measurements, several plant families common to California appear to include plants with very low BVOC emissions. Those families include many common fruit, shade, and ornamental trees:

- Aceraceae (maple)
- Anacardiaceae (cashew, sumac, smoketree, Brazilian pepper tree, Chinese pistache)
- Bignoniaceae (jacaranda, catalpa, chitalpa, desert willow)
- Caprifoliaceae (honeysuckle)
- Compositae (aster, daisy, sunflower)
- Cupressaceae (cypress, juniper)
- Cycadaceae (sago palm)
- Ericaceae (heathers, azalea, rhododendron, strawberry tree, manzanita)
- Juglandaceae (walnut, pecan)
- Magnoliaceae (magnolia)
- Oleaceae (olive, ash, lilac, jasmine, privet)
- Rhamnaceae (ceanothus, buckthorn)
- Rosaceae (rose, apple, pear, pome fruit, stone fruit, raspberry, strawberry, serviceberry, toyon, pyracantha, hawthorn)
- Taxodiaceae (coast redwood)

On the other hand, some families (such as Salicaceae and Myrtaceae) include plants with high emissions, such as poplars, willows, and *Eucapyptus* spp., which in addition to being high emitters are typically large plants with large leaf mass.

Unfortunately, generalization is not possible for some plant families, such as Leguminosae (legumes) and Fagaceae (beech). These families include many genera and species found in California landscapes.

Emission behavior patterns are more consistent at the genus level than at the family level. Genera that have been found to have low BVOC emissions include *Acer* (maples), *Alnus* (alder), *Betula* (birch), *Fraxinus* (ash), *Prunus* (plums), *Rhus* (sumac), and *Ulmus* (elms). A listing of several such genera is found in table 2.

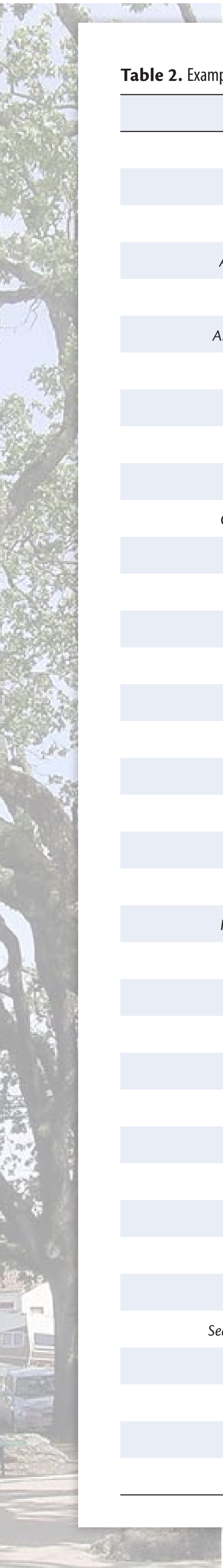


Table 2. Examples of genera that include plants having low emission rates for biogenic volatile organic compounds (BVOC)

Genus	Example species	Common name	Family
Ailanthus	*altissima*	Tree of heaven	Simaroubaceae
Albizia	*julibrizzin*	Mimosa	Leguminosae
Alnus	*rhombifolia*	White alder	Betulaceae
Amelanchier	*alnifolia*	Serviceberry	Rosaceae
Arbutus	*unedo*	Strawberry tree	Ericaceae
Arctostaphylos	*manzanita*	Manzanita	Ericaceae
Betula	*alba*	White birch	Betulaceae
Carpinus	*betula*	European hornbeam	Betulaceae
Casuarina	*cunninghamiana*	Beefwood	Casuarinaceae
Celtis	*occidentalis*	Western hackberry	Ulmaceae
Cercocarpus	*beuloides*	Mountain mahogany	Rosaceae
Chilopsis	*linearis*	Desert willow	Bignoniaceae
Chitalpa	*tashkentensis*	Chitalpa	Bignoniaceae
Corylus	*cornuta californica*	Western hazelnut	Betulaceae
Cotinus	*coggygria*	Smoketree	Anacardiaceae
Crataegus	*laviegata*	English hawthorn	Rosaceae
Elaeagnus	*pungens*	Silverberry	Elaeagnaceae
Fraxinus	*uhdei*	Shamel ash	Oleaceae
Garrya	*elliptica*	Coast silktassel	Garryaceae
Gingko	*biloba*	Ginkgo	Gingkoaceae
Gleditsia	*triacanthos inermis*	Thornless honey locust	Leguminosae
Heteromeles	*arbutifolia*	Toyon	Rosaceae
Magnolia	*grandifolia*	Magnolia	Magnoliaceae
Malus	*domestica*	Apple	Rosaceae
Olea	*europea*	Olive	Oleaceae
Pistacia	*chinensis*	Chinese pistache	Anacardiaceae
Prunus	*ilicifolia*	Catalina cherry	Rosaceae
Pyracantha	*coccinea*	Pyracantha	Rosaceae
Rosa	spp.	Rose	Rosaceae
Sapium	*sebiferum*	Chinese tallow tree	Euphorbiaceae
Schinus	*terebinthifolius*	Brazilian pepper tree	Anacardiaceae
Sequoia	*sempervirens*	Coast redwood	Taxodiaceae
Sequoiadendron	*gigantea*	Giant sequoia	Taxodiaceae
Tamarix	*pentandra*	Tamarisk	Tamaricacae
Ulmus	*parvifolia*	Chinese elm	Ulmaceae
Vauquelina	*californica*	Arizona rosewood	Rosaceae
Ziziphus	*jujuba*	Jujube	Rhamnaceae

Other genera appear to contain more plants with high emission rates (table 3). For example, *Eucalpytus*, as noted above, contains species with uniformly high emission rates for isoprene. These high rates, together with the large stature of many eucalypts, make these trees important contributors to the BVOC inventory where they are found.

Table 3. Genera that include plants having high emission rates for biogenic volatile organic compounds (BVOC)

Genus	Example species	Common name	Family
Cupaniopsis	*anacardioides*	Carrotwood	Sapindaceae
Eucalyptus	*globulus*	Blue gum	Myrtaceae
Liquidambar	*styraciflua*	Sweetgum	Hamamelidaceae
Platanus	*racemosa*	California sycamore	Platanaceae
Populus	*alba*	White poplar	Salicaceae
Salix	*babylonica*	Weeping willow	Salicaceae

BVOC Emissions for Oaks

Perhaps the most important genus for BVOC inventories in California, in terms of geographic range, plant size, and variability of emissions, is *Quercus,* the oaks. Oaks are prevalent in the natural landscape as well as in urban forests, and a number of species have high emission rates. In general, oak emissions seem to parallel their subgenus classification. California natives (e.g., *Q. douglasii* [blue oak] and *Q. agrifolia* [coast live oak]) as well as oaks from the eastern United States (e.g., *Q. rubra* [red oak]) have high isoprene emission rates, whereas oaks native to the Mediterranean region (e.g., *Q. suber* [cork oak]) do not (table 4).

Needle Evergreens

Most but not all needle evergreens are monoterpene emitters rather than isoprene emitters, and monoterpene emission rates tend to be lower than isoprene emission rates. The genus *Picea* (spruce) has been reported as a low isoprene emitter, but it is not a common tree in urban forests in California. Isoprene emissions from pines and cypress tend to be negligible. Several California pines in the yellow pine group, though, including *Pinus torreyana* (Torrey pine), *P. sabiniana* (digger pine), and *P. coulteri* (coulter pine) have been found to emit the oxygenated BVOC methylbutenol at very high rates.

Palms

Some palms are isoprene emitters, although palm leaf mass for a mature tree is lower than for many large broadleaf or deciduous trees. Isoprene emission has been measured for *Washingtonia filifera,* but it is difficult to generalize emission behavior for palms.

Considerations for Urban Tree Planting Programs and Specifications

Although many trees have significant BVOC emission rates, we do not mean to imply that tree planting programs are counterproductive or deleterious to the environment or that individual species ought to be omitted or removed from planting programs. Rather, we are suggesting that when thousands or millions of trees are to be planted in a tree-planting project or in large developments in the Los Angeles Basin, Inland Empire, and Central Valley regions, or in other locations that experience high ozone levels, the trees' BVOC emission rate should be among the horticultural characteristics considered in the selection process. Trees from genera known to produce low levels of BVOC should be given preference in these situations. When considering specific species for such a planting, we suggest that decision makers consult with and consider the data available from an authoritative website such as that offered by the National Center for Atmospheric Research (http://bai.acd.ucar.edu/Data/BVOC).

Table 4. Oak species, arranged by subgenus classification, with isoprene emission rate

Subgenus	Botanical name	Common name	Isoprene emission rate*
Cerris	*Quercus cerris*	Turkish oak	L
	Q. suber	Cork oak	L
Lobatae	*Q. agrifolia*	Coast live oak	H
	Q. coccinea	Scarlet oak	H
	Q. rubra	Red oak	H
	Q. wislizenii	Interior live oak	H
Lepidobalanus (= *Quercus*)	*Q. alba*	White oak	H
	Q. douglasii	Blue oak	H
	Q. englemanni	Englemann oak	H
	Q. garryana	Oregon white oak	H
	Q. lobata	Valley oak	H
	Q. robur	English oak	H
	Q. virginiana	Southern live oak	H
Protobalanus	*Q. chrysolepis*	Canyon live oak	M
Sclerophyllodrys (= *Ilex*)	*Q. coccifera*	Kermes oak	L, but high monoterpene
	Q. ilex	Holly oak, Holm oak	L, but high monoterpene

* Emission rates here are considered to be low (L) if < 5 µg · g^{-1} · hr^{-1} isoprene, medium (M) if from 5 to 20 µg · g^{-1} · hr^{-1} isoprene, and high (H) if > 20 µg · g^{-1} · hr^{-1} isoprene, all measured as a branch-level measurement.

Bibliography

Arey, J., D. E. Crowley, M. Crowley, M. Resketo, and J. Lester. 1995. Hydrocarbon emissions from natural vegetation in California's South Coast Air Basin. Atmospheric Environment 29:2977–2988.

Arey, J., A. M. Winer, R. Atkinson, S. M. Aschmann, W. D. Long, C. L. Morrison, and D. M. Olszyk. 1991. Terpenes emitted from agricultural species found in California's Central Valley. Journal of Geophysical Research 96:9329–9336.

Benjamin, M. T., M. Sudol, L. Bloch, and A. M. Winer. 1996. Low-emitting urban forests: A taxonomic methodology for assigning isoprene and monoterpene emission rates. Atmospheric Environment 30:1437–1452.

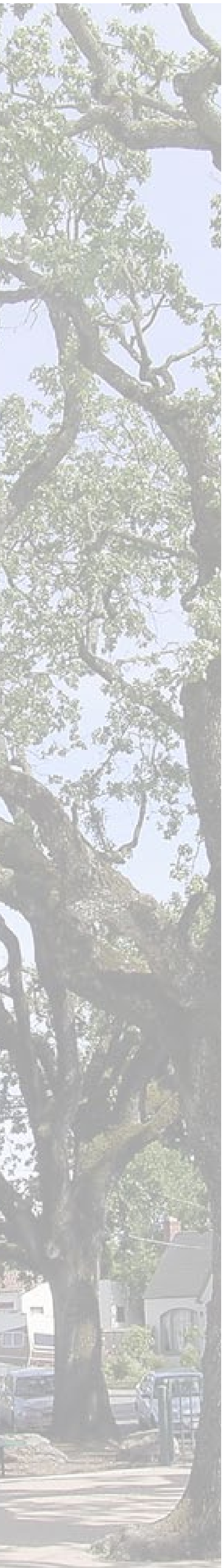
Benjamin, M. T., M. Sudol, D. Vorsatz, and A. M. Winer. 1997. A spatially and temporally resolved biogenic hydrocarbon emissions inventory for the California South Coast Air Basin. Atmospheric Environment 31:3087–3100.

Carter, W. P. L. 1994. Development of ozone reactivity scales for volatile organic compounds. Journal of the Air and Waste Management Association 44:881–899.

Csiky, O., and G. Seufert. 1999. Terpenoid emissions of Mediterranean oaks and their relation to taxonomy. Ecological Applications 9:1138–1146.

Fehsenfeld, F., J. Calvert, R. Fall, P. Goldan, A. B. Guenther, C. N. Hewitt, B. Lamb, L. Shaw, M. Trainer, H. Westberg, and P. Zimmerman. 1992. Emissions of volatile organic compounds from vegetation and the implications for atmospheric chemistry. Global Biogeochemical Cycles 6(4):389–430.

Geron, C., P. Harley, and A. Guenther. 2001. Isoprene emission capacity for U.S. tree species. Atmospheric Environment 35:3341–3352.



Guenther, A. 2008. Are plant emissions green? Nature 452(10):701–702.

Guenther, A., C. Hewitt, D. Erickson, R. Fall, C. Geron, T. Graedel, P. Harley, L. Klinger, M. Lerdau, W. McKay, T. Pierce, B. Scholes, R. Steinbrecher, R. Tallamraju, J. Taylor, and P. Zimmerman. 1995. A global model of natural volatile organic compound emissions. Journal of Geophysical Research 100:8873–8892.

Harley, P., V. Fridd-Stroud, J. Greenberg, A. Guenther, and P. Vasconcellos. 1998. Emission of 2-methyl-3-buten-2-ol by pines: A potentially large natural source of reactive carbon in the atmosphere. Journal of Geophysical Research 103:25,479–25,486.

Karlik, J. F., A. H. McKay, J. M. Welch, and A. M. Winer. 2002. A survey of California plant species with a portable VOC analyzer for biogenic emission inventory development. Atmospheric Environment 36:5221–5233.

Karlik, J., and A. M. Winer. 2001. Measured isoprene emission rates of plants in California landscapes: Comparison to estimates from taxonomic relationships. Atmospheric Environment 35:1123–1131.

Lerdau, M., A. Guenther, and R. Monson. 1997. Plant production and emission of volatile organic compounds. BioScience 47(6):373–383.

Nixon, K. C. 1993. Infrageneric classification of *Quercus* (Fagaceae) and typification of sectional names. Annales de Science Forestières 50: Supplement 1, 25s–34s.

Nowak, D. J., R. E. Hoehn, D. E. Crane, J. C. Stevens, J. T. Walton, J. Bond, and G. Ina. 2006. Assessing urban forest effects and values: Minneapolis's urban forest. USDA Northeastern Research Station Research Bulletin NE-166.

Went, F. W. 1960. Blue hazes in the atmosphere. Nature 187:641–643.

Winer, A. M., J. Arey, S. M. Aschmann, R. Atkinson, W. D. Long, C. L. Morrison, and D. M. Olszyk. 1989. Hydrocarbon emission from vegetation found in California's Central Valley. Report for California Air Resources Board, contract no. A732-155.

Winer, A. M., D. R. Fitz, and P. R. Miller. 1983. Investigation of the Role of Natural Hydrocarbons in Photochemical Smog Formation in California. Final Report, Air Resources Board, Contract No. AO-056-32, Statewide Air Pollution Research Center, Riverside, California.

For More Information

To order ANR products or download free publications, visit the ANR Communication Services online catalog at http://anrcatalog.ucdavis.edu or phone 1-800-994-8849. You can also place orders by mail or FAX, or request a printed catalog of our products from

University of California
Agriculture and Natural Resources
Communication Services
1301 S. 46th Street, Building 478 – MC 3580
Richmond, California 94604-4600
Telephone: 1-800-994-8849 or 510-665-2195, FAX: 510-655-3427
e-mail inquiries: anrcatalog@ucdavis.edu

An electronic copy of this publication can be found at the ANR Communication Services Web site, http://anrcatalog.ucdavis.edu.

Publication 8484
ISBN-13: 978-1-60107-798-1

UC PEER REVIEWED This publication has been anonymously peer reviewed for technical accuracy by University of California scientists and other qualified professionals. This review process was managed by the ANR Associate Editor for Environmental Horticulture, Janet Hartin.

web-3/12-WJC/RW