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# Biogenic volatile organic compound emissions from nine tree species used in an urban tree-planting program

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## HIGHLIGHTS

- MT and SQT ERs were determined from nine tree species in an urban planting program.
- The chosen tree species behaved as low emitters in the Colorado urban environment.
- Emission scenarios for low-emitting species were compared to high-emitting species.
- Model findings showed marked emission savings from planting low-emitting species.

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## ABSTRACT

The biogenic volatile organic compound (BVOC) emissions of nine urban tree species were studied to assess the air quality impacts from planting a large quantity of these trees in the City and County of Denver, Colorado, through the Mile High Million tree-planting initiative. The deciduous tree species studied were Sugar maple, Ohio buckeye, northern hackberry, Turkish hazelnut, London planetree, American basswood, Littleleaf linden, Valley Forge elm, and Japanese zelkova. These tree species were selected using the i-Tree Species Selector (itreetools.org). BVOC emissions from the selected tree species were investigated to evaluate the Species Selector data under the Colorado climate and environmental growing conditions. Individual tree species were subjected to branch enclosure experiments in which foliar emissions of BVOC were collected onto solid adsorbent cartridges. The cartridge samples were analyzed for monoterpenes (MT), sesquiterpenes (SQT), and other $C_{10}$–$C_{15}$ BVOC using thermal desorption-gas chromatography–flame ionization detection/mass spectroscopy (GC–FID/MS). Individual compounds and their emission rates (ER) were identified. MT were observed in all tree species, exhibiting the following total MT basal emission rates (BER; with a $1-\sigma$ lower bound, upper bound uncertainty window): Sugar maple, 0.07 (0.02, 0.11) $\mu g\ g^{-1}\ h^{-1}$; London planetree, 0.15 (0.02, 0.27) $\mu g\ g^{-1}\ h^{-1}$; northern hackberry, 0.33 (0.09, 0.57) $\mu g\ g^{-1}\ h^{-1}$; Japanese zelkova, 0.42 (0.26, 0.58) $\mu g\ g^{-1}\ h^{-1}$; Littleleaf linden, 0.71 (0.33, 1.09) $\mu g\ g^{-1}\ h^{-1}$; Valley Forge elm, 0.96 (0.01, 1.92) $\mu g\ g^{-1}\ h^{-1}$; Turkish hazelnut, 1.30 (0.32, 2.23) $\mu g\ g^{-1}\ h^{-1}$; American basswood, 1.50 (0.40, 2.70) $\mu g\ g^{-1}\ h^{-1}$; and Ohio buckeye, 6.61 (1.76, 11.47) $\mu g\ g^{-1}\ h^{-1}$. SQT emissions were seen in five tree species with total SQT BER of: London planetree, 0.11 (0.01, 0.20) $\mu g\ g^{-1}\ h^{-1}$; Japanese zelkova, 0.11 (0.05, 0.16) $\mu g\ g^{-1}\ h^{-1}$; Littleleaf linden, 0.13 (0.06, 0.21) $\mu g\ g^{-1}\ h^{-1}$; northern hackberry, 0.20 (0.11, 0.30) $\mu g\ g^{-1}\ h^{-1}$; and Ohio buckeye, 0.44 (0.06, 0.83) $\mu g\ g^{-1}\ h^{-1}$. The following trees exhibited emissions of other $C_{10}$–$C_{15}$ volatile organic compounds (VOC): Littleleaf linden, 0.15 (0.10, 0.20) $\mu g\ g^{-1}\ h^{-1}$; Ohio buckeye, 0.39 (0.14, 0.65) $\mu g\ g^{-1}\ h^{-1}$; and Turkish hazelnut, 0.72 (0.49, 0.95) $\mu g\ g^{-1}\ h^{-1}$. All tree species studied in this experiment were confirmed to be low isoprene emitters. Compared to many other potential urban tree species, the selected trees can be considered low to moderate BVOC emitters under Colorado growing conditions, with total emission rates one-tenth to one-hundredth the rates of potential high-BVOC emitting trees. The emissions data were used to estimate the impact of this targeted tree planting on the urban BVOC flux and atmospheric VOC burden. Selecting the low-emitting tree species over known high BVOC emitters is equivalent to avoiding VOC emissions from nearly 500,000 cars from the inner city traffic.



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## 1. Introduction

Many cities have adopted large-scale tree-planting initiatives to increase tree cover in an effort to sequester carbon, reduce the urban heat island effect, conserve energy for heating and cooling buildings, and beautify neighborhoods (McPherson et al., 2011; Morani et al., 2011). Urban tree planting is also a cost-effective means to improve air quality.

Many trees release significant amounts of biogenic volatile organic compounds (BVOC) into the atmosphere, including isoprene, monoterpenes (MT) and sesquiterpenes (SQT). The photochemical reaction of these compounds can contribute to the formation of ozone and secondary organic aerosol (Fehsenfeld et al., 1992; Finlayson-Pitts and Pitts, 2000; Hewitt, 1999; Ryerson et al., 2001). BVOC emissions can vary widely among tree species and even within species depending on physiological and environmental factors (Benjamin and Winer, 1998). Calfapietra et al. (2013) recently reviewed the current literature concerning BVOC and urban environments. Their assessment of existing research underlines the role tree selection plays when considering the potential for BVOC emissions.

One of the earliest studies to recognize the importance of selecting low volatile organic compound (VOC)-emitting tree species for large-scale tree-planting programs was performed by Benjamin et al. (1996). Some common tree species such as oak and pine emit large quantities of BVOC into the atmosphere; consequently, planting such tree species in large numbers could potentially worsen inner city air quality. These researchers developed a methodology based on taxonomic relationships to assign emission rates to trees in Southern California and ranked over 300 tree species on a scale of low-emitting to high-emitting species. The scale defined species emitting 0.01–1 μg g $dw^{-1}$ $h^{-1}$ VOC as low emitters, 1–10 μg g $dw^{-1}$ $h^{-1}$ as moderate emitters, and 10–1000 μg g $dw^{-1}$ $h^{-1}$ as high emitters.

A mesoscale meteorological and photochemical modeling study performed by Taha (1996) for the California South Coast Air Basin showed that increased tree-planting would result in a net decrease in ozone as long as the trees were low hydrocarbon emitters. These authors determined that tree species that emitted more than 2 μg $g^{-1}$ $h^{-1}$ isoprene and 1 μg $g^{-1}$ $h^{-1}$ MT (based on episode-specific simulations) would worsen ozone levels under urban ambient air conditions.

Donovan et al. (2005) used an atmospheric chemistry model to develop an urban tree air quality score (UTAQS) to rank trees in the Birmingham area of the United Kingdom in order of their potential to improve air quality (high, medium and low). A score was assigned based on the trees' BVOC emissions and capacity for pollutant deposition onto vegetative surfaces. The study's authors noted that tree planters anywhere could utilize the classification system with the appropriate input data for a particular location.

An alternative approach to ranking trees was developed for a tree-planting project in Sacramento, California, called the Tree BVOC Index (Simpson and McPherson, 2011). The authors presented a method to calculate BVOC emissions from urban trees that can be used by tree-planting programs seeking to transition to lower BVOC emitters in future plantings.

Several studies have investigated the benefits and costs of large-scale urban tree-planting programs with respect to such factors as energy savings and air quality improvements (McPherson et al., 1998, 2005; Soares et al., 2011). A recent review of urban tree literature by Roy et al. (2012) discusses tree benefits, costs, and assessment methods. In all the studies, limitations considered, benefits outweighed costs.

The City and County of Denver in Colorado have implemented a program, called the Mile High Million (milehighmillion.org) with the goal to plant a million trees within the Denver metropolitan region by 2025. The tree species selected for the Mile High Million were chosen based on their suitability for planting in Denver's urban environment, i.e. they have a history of successful growth in this climate, soil, moisture levels, wind and snow loads, their ability to remove air pollutants, and their standing as low emitters of BVOC. The tree species in this study were selected using the i-Tree Species Selector (itreetools.org), with the choice of these species based on a variety of criteria. These include their ability to provide building energy use reduction through shading, their ability to remove air pollutants, and be low BVOC emitters themselves, with the objective to limit introducing VOC sources into the inner city environment and their contribution to pollution formation, i.e. ozone and organic aerosols. While tree species in the present study were specifically selected for being low-emitting species using literature information, an objective in this work was to validate that the selected trees would behave as such under Colorado and inner city growing conditions. In addition, we were interested in determining what effect these tree species would have on the urban BVOC flux and atmospheric VOC burden if scaled up to simulate an urban tree planting initiative. For comparison, we also wanted to perform the same simulation on known high BVOC emitting species.

## 2. Experimental methods

### 2.1. Site description

The experiments were conducted from June 2 to October 8, 2010, at the Creekside Tree Nursery in Boulder, Colorado, USA, approximately 30 km NW of Denver. An enclosed trailer at the tree nursery was utilized as a mobile field laboratory. Trees were provided by the nursery and the City and County of Denver. Nine tree species were studied: sugar maple (*Acer saccharum* Marshall), Ohio buckeye (*Aesculus glabra* Willd.), northern hackberry (*Celtis occidentalis* L.), Turkish hazelnut (*Corylus colurna* L.), London planetree (*Platanus* × *acerifolia* Aiton Willd.), American basswood (*Tilia americana* L.), littleleaf linden (*Tilia cordata* Mill.), Valley Forge elm (*Ulmus americana* L. 'Valley Forge'), and Japanese zelkova (*Zelkova serrata* Thunb. Makino). All trees were between two and three meters tall and between three and five years old. The trees were watered daily and received full exposure to sunlight. No fertilizer was applied during the studies. Trees remained in their planting pots during the experiments.

### 2.2. Tree selection

Tree species were selected using the i-Tree Species Selector software from the USDA Forest Service (available at http://www.itreetools.org/species/index.php). An example of the input screen is shown in the Supplemental Materials. A value of 10 on the importance scale (where 0 represents the least important and 10 the most important) was input in the Air Pollutant Removal category for the following compounds: carbon monoxide, ozone, nitrogen dioxide, sulfur dioxide, and particulate matter. A value of 10 on the importance scale was also input in the categories of low VOC emissions and building energy reduction. Based on the report generated, selection was narrowed to deciduous trees with a track record of performing well in Denver's climate, soil, moisture levels,