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The Correlation between Basal Isoprene Emissions and Climate of the Native Range across Oak Species

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ABSTRACT Isoprene is a biogenic volatile organic compound that is emitted by various plant species and plays an important role in the chemistry of the atmosphere. When it reacts with pollutants in the air, such as nitrogen oxides, the precursor to ozone (O_3) is formed. In this experiment, we measured leaf emissions from 20 different oak species at the Morton Arboretum (Lisle, Illinois). The aim was to better understand differences in isoprene emissions across oak species. Since emissions have been found to protect leaves against brief periods of heat stress, we hypothesized that oaks native to areas with greater variations in temperature will have higher isoprene emissions than species native to regions with smaller variations in temperature. This study did not find evidence to support this hypothesis, though it could be due in part to lack of adequate climate data and information about the specific geographical ranges of species. When we continued to analyze the data, we found a positive correlation between isoprene emissions from oaks and actual temperature at the Morton Arboretum on the days that isoprene emissions were measured. This result, however, only looks at the measurements pooled across all species, and does not consider individual species.

INTRODUCTION

Isoprene, a biogenic volatile organic compound (BVOC), is emitted by various plant species and plays a crucial role in the chemistry of the atmosphere (Sharkey et al. 2014). Once it is there, isoprene readily reacts with nitrogen oxide (NOx) pollutants. When there is a significant amount of NOx present, the reactions will produce ozone (O3) and further increase air pollution (Fiore et al. 2011). Isoprene emissions will vary depending on season and region. Emissions are found to be the highest during the summer and in tropic zones (Fiore et al. 2011). Many studies have suggested that isoprene acts as a leaf temperature defense mechanism (Sharkey et al. 2014). There is also evidence that there is a correlation between isoprene emissions

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and photosynthesis function when in the presence of ozone, which points to a role for isoprene as protection against oxidative stress (Loreto et al. 2001).

Oaks are one genus in particular that are known isoprene emitters. Along the equator, oaks generally have higher isoprene emissions in comparison to oaks in other regions. (Pearse et al. 2012). There is also evidence from Fiore's study that shows emissions significantly increase at northern mid-latitudes, when influenced by actual temperature and light (Fiore et al. 2011). When analyzing the emissions in this experiment, we are looking at the basal rate of isoprene emission (BER) by fixing temperature and light. The conditions for BER are 30°C and 1000 μmol m^{-2} s^{-1} light.

One area of research that has not yet been thoroughly explored is the genetic relationship between the native range of oak species and basal isoprene emissions (Steinbreacher et al. 2013). We have already seen results from experiments that support the claim that plants emit varying levels of isoprene based on temperature and climate (Fiore et al. 2011, Potosnak et al. 2014, and Sharkey et al. 2014). However, we are unaware of how much of this is due to genetic traits inherited over generations where the species grow natively. The goal of this experiment is to better understand how basal isoprene emissions differ in oak species. The emissions can protect leaves against brief periods of heat stress, so we will look at how temperature variations affect isoprene. We hypothesize that oaks native to regions with greater variations in temperature will have higher isoprene emissions than species native to areas with lesser variations in temperature.

METHODS

SAMPLE COLLECTION

Twenty different oak species were selected for measurement on the grounds of the Morton Arboretum in Lisle, Illinois. They were grouped into five groups of four based on similar location within the arboretum. Each tree was visited three times, and during each visit two leaves per tree were measured. The leaves selected for measurement were sunlit and south facing, near the ground, relatively mature, and largely free of insect damage. LI6400 (LI-COR Biosciences, Lincoln, NE) was the instrument used to take the samples. It has a chamber connected to it, which measures photosynthesis and controls environmental conditions. Air samples were collected from the air exiting the leaf chamber and contained in 1-liter sized SamplePro® FlexFilm Sample Bags, and later analyzed for isoprene. Conditions were routinely set at the beginning of each collection so that the temperature of the leaf is 30°C, CO_2 is at 400 ppm, and PAR (Photosynthetically Active Radiation) is 1000 μmol m^{-2} s^{-1}. These are the conditions for measuring the BER. The measurements were taken by placing a leaf in the LI-COR's measuring chamber. Each leaf was given 10 minutes to adjust to the set conditions because they may have slightly differed from the outside. After the waiting period, the sample and reference cells were matched to eliminate small differences in CO_2 response before each measurement, and photosynthesis levels, temperature, and CO_2 concentration were recorded. Once recorded, a SamplePro® FlexFilm Sample Bag of air was collected by attaching it to the LI-COR outlet.

SAMPLE MEASUREMENT

In the lab, individual bags were connected to a gas chromatograph with a flame ionization detector (GC/FID, model 8610, SRI Inc., Torrance, CA). The gas from the bags was sent through the gas chromatograph. The instrument measured the amount of isoprene in the air sample by concentrating the sample on a solid absorbent trap. The trap is then heated and the sample is injected onto the column of the GC, as shown in Figure 1. Results were given in a graphical format using the program PeakSimple, which integrated the peaks from the GC/FID. Isoprene values (relative response from integrating area of the FID signal) were recorded so that individual species can be compared.

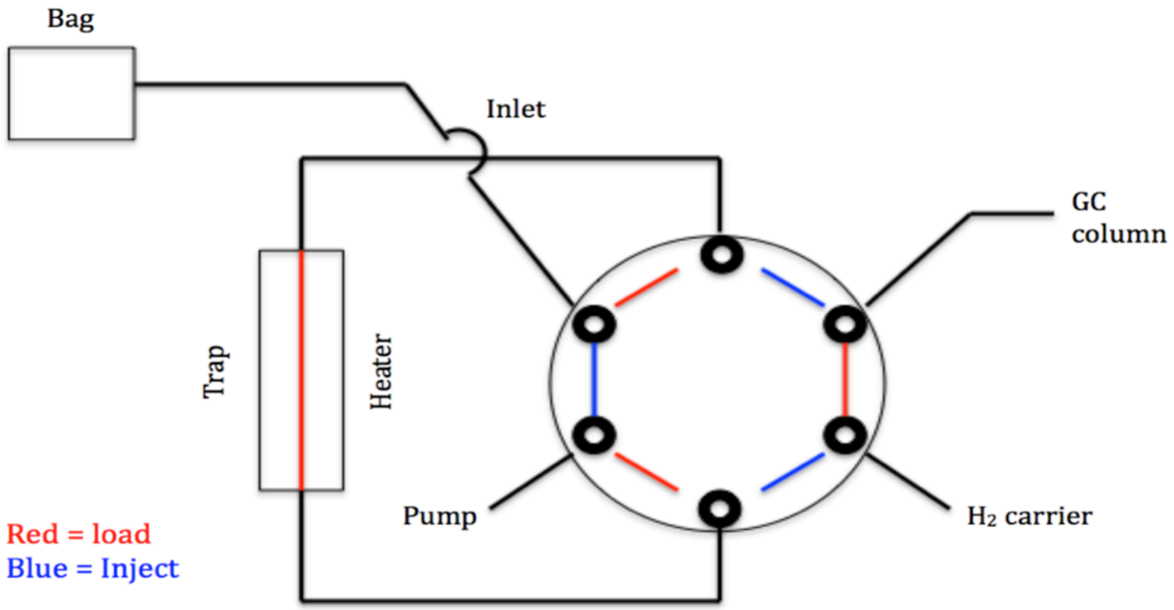

Figure 1: Schematic of the instrumental setup.

The website "Weather Underground," was used to determine the actual temperature on the day of sample collection. The station that measured the temperature was called Valley View KILGLENE9, and was within 1.5 km of the trees. Detailed species information, including the native range, was accessed using the *Quercus* collection database from the Morton Arboretum (http://quercus.mortonarb.org).

RESULTS

First we compared the average isoprene levels emitted from species that grow in native climates with different variations in temperature regimes. The mean isoprene emissions and information about the temperature where each species grows natively is listed in Table 1. We looked at how these emission levels were affected by the temperature ranges where each species can be found natively. Figure 2 shows that the results from this experiment did not produce a significant correlation that supports the hypothesis.

We decided to additionally analyze the temperature at the Morton Arboretum each day that isoprene samples were collected. This was done to relate isoprene levels to day-to-day weather. In this comparison, we did not look at individual species, but rather what effect the actual temperature has on oaks in general. A positive correlation was found between these variables in Figure 3. As the temperature on the day of collection increased, the average isoprene levels also increased.

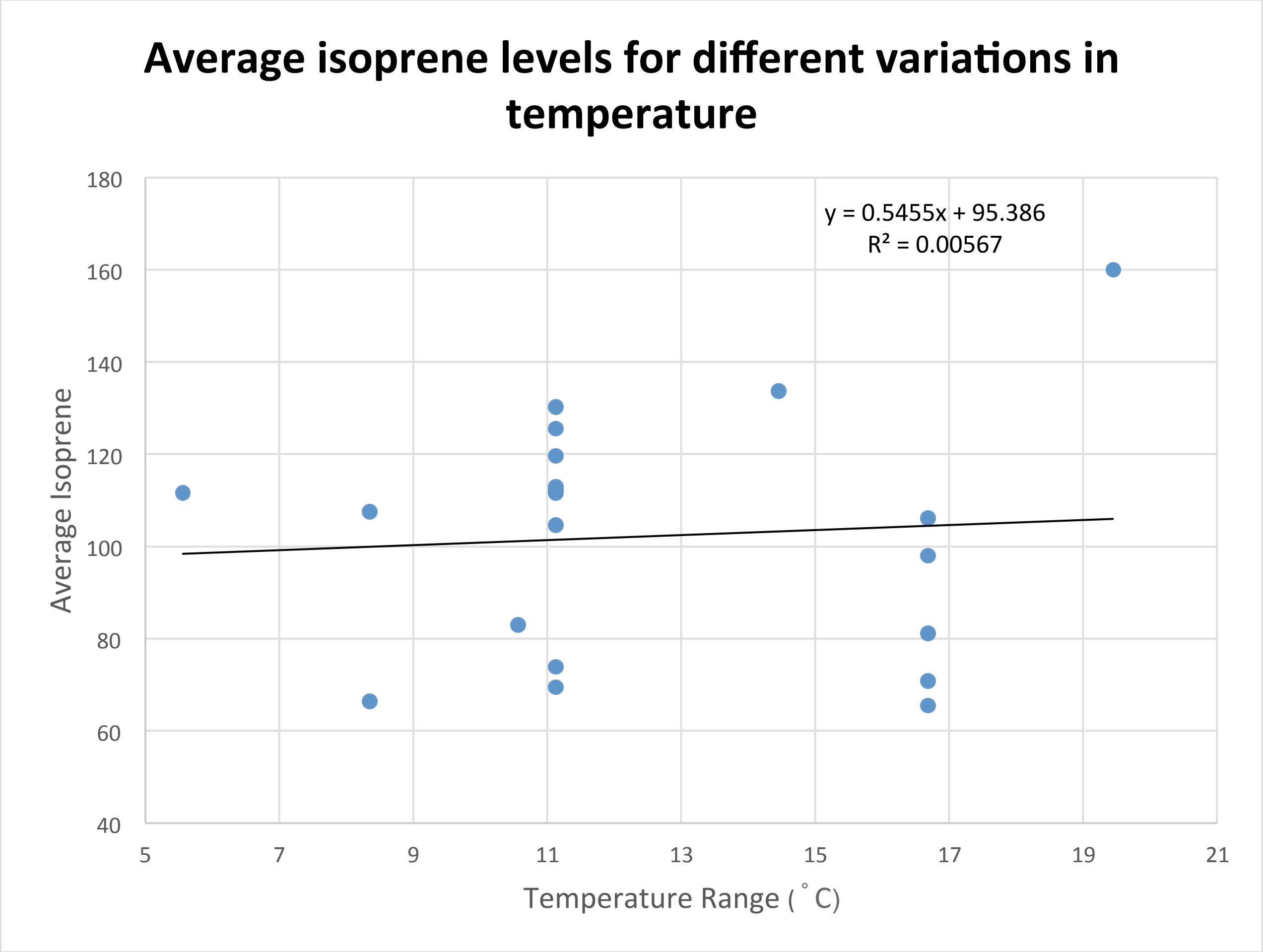

Figure 2: This figure shows no correlation between isoprene levels and temperature differences in ranges where species grow natively.

Table 1: This table details how many measurements were taken and the mean isoprene emissions for each species, with standard deviation. It also lists information about the temperature where each species grows natively.

Species	Number of measurements	Isoprene mean	Standard deviation	Temp. min. (°C)	Temp. max. (°C)	Temp. range (°C)
White *(Q. alba)*	6	70.83	22.02	4.44	15.56	11.12
Oriental white *(Q. aliena)*	5	107.6	15.58	10.00	15.56	5.56
Bebb's *(Q. benniana)*	5	111.6	56.11	4.44	12.78	8.34
Scarlet *(Q. coccinea)*	6	133.7	45.27	4.44	21.11	16.67
Deam's *(Q. deamii*	5	66.42	15.94	4.44	12.78	8.34
Hill's *(Q. ellipsoidalis)*	4	83.00	53.70	4.44	15.56	11.12
Hartwiss' *(Q. hartwissiana)*	5	130.2	66.75	5.00	15.56	10.56
Jack's *(Q. jackiana)*	5	104.6	26.62	4.44	15.56	11.12
Crystal* *(Q. K.B. crystal)*	6	119.6	21.55	4.44	15.56	11.12
Bur *(Q. macrocarpa)*	6	106.1	30.98	4.44	15.56	11.12
Blackjack *(Q.marilandica)*	5	73.94	14.37	4.44	21.11	16.67

Swamp Chestnut *(Q. michauxii)*	5	65.52	7.852	4.44	21.11	16.67
Mongolian *(Q. mongolica)*	6	112.3	52.65	-4.44	15.00	19.44
Chestnut *(Q. montana)*	5	160.0	33.76	4.44	15.56	11.12
Chinkapin *(Q. muehlenbergii)*	5	98.04	32.22	4.44	21.11	16.67
Pin *(Q. palustris)*	5	81.16	13.06	4.44	15.56	11.12
Northern red *(Q. rubra)*	6	69.43	20.47	1.11	15.56	14.45
Saul’s *(Q. saulii)*	5	111.7	23.68	4.44	15.56	11.12
Shumard’s *(Q. shumardii)*	6	125.6	24.25	4.44	15.56	11.12
Black *(Q. velutina)*	5	112.8	34.62	4.44	21.11	16.67

Table 2: The temperature is listed for each day that measurements were taken. The average isoprene emissions for each day is also shown.

Date collected	Average Temperature on day collected (°C)	Average isoprene
June 30	20.00	86.2
July 1	20.00	51.6
July 6	20.56	80.0
July 13	20.56	85.5
July 14	20.56	93.2
July 15	21.11	72.5
July 20	21.11	102.5
July 21	21.67	87.0
July 22	21.67	115.1
July 27	22.22	106.5
July 28	22.22	117.2
July 29	22.22	137.0
July 30	22.78	122.3
July 31	22.78	112.0

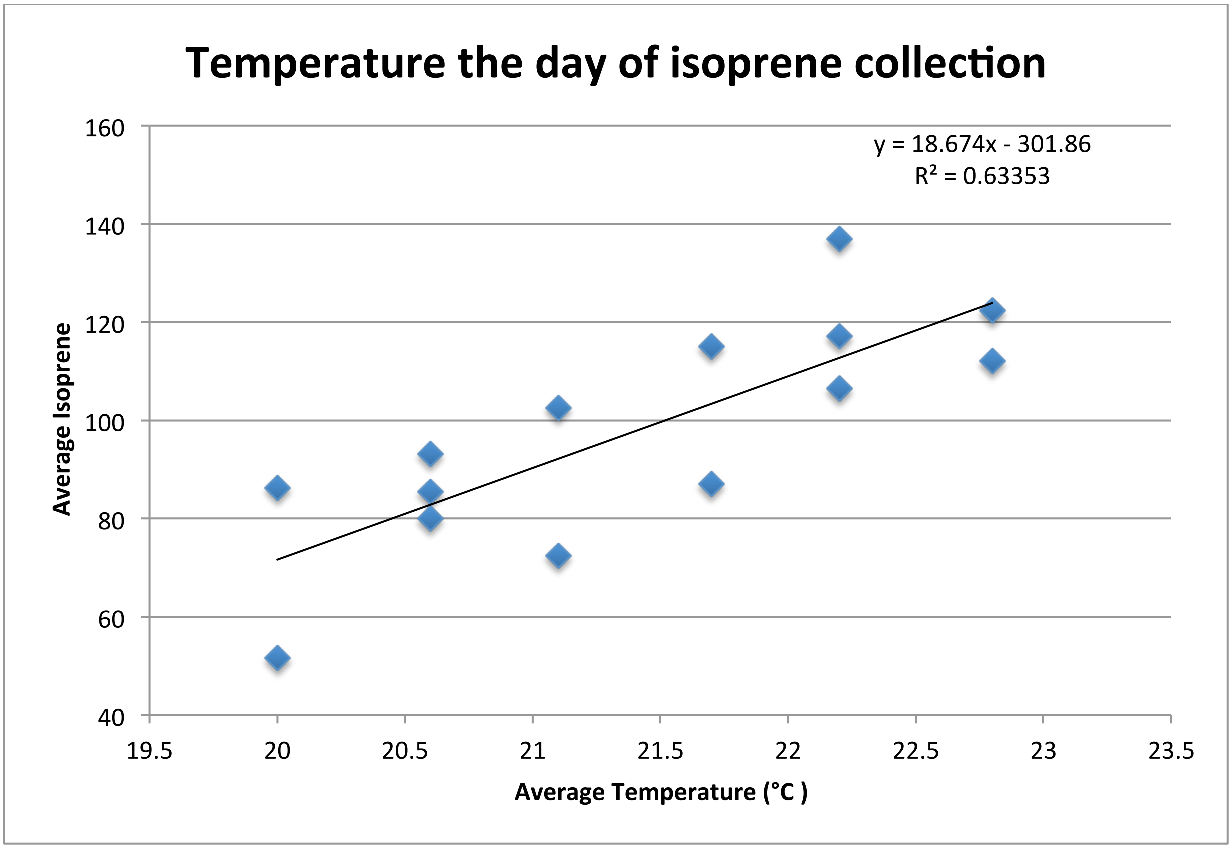

Figure 3: This figure shows a positive correlation between the average temperature on the day of collection and average isoprene levels.

DISCUSSION

When looking at the effect of different variations in temperature of the native ranges of species on isoprene emissions, this experiment did not show any correlation. However, this could be due to insufficient knowledge about where each species grows. The native range of each oak species was obtained from information about the *Quercus* collection at the Morton Arboretum. Species that appeared in the U.S. were listed by state, whereas other areas only had the country listed. This creates a broader range of temperature, which could explain why we do not see evidence that supports a correlation. We also did not have access to a global climate database, so obtaining information from many different sources could have additionally affected the result.

Since the hypothesis was rejected, we decided to analyze other variables that could have played a role in affecting isoprene emissions. Since light and temperature play a strong role in emission levels (Fiore et al. 2011), we looked at temperature data for the days that isoprene emissions were collected. Both the average temperature and isoprene emissions for each day that measurements were taken are shown in Table 2. Here we did find a positive correlation between the average isoprene levels and the actual temperature at the Morton arboretum. However, those relationships are focusing on temperature's effect on all oak species, and not looking at individual ones. Evidence of this correlation has been seen before in other experiments such as the ones conducted by Sharkey et al. (2014) and Pétron et al. (2001).

Looking forward, we see that further research on isoprene is needed in order to understand how basal isoprene emissions differ in oak species.

This is especially important because emissions affect both human and environmental health globally. We still have to learn more about the factors that play a role in controlling isoprene emissions. A future methodology that might simplify the experiment could involve utilizing growth chambers by growing two different species, one from a native environment with highly variable temperatures and another from a native environment with minimal variations in temperature. Isoprene emissions could then be measured at basal emission rate (30°C and 1000 µmol m-2 s-1 light). Another possibility might include testing other variables such as soil and light conditions. Looking at other factors will give a more complete understanding of the role that isoprene plays for a variety of species under different conditions.

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AUTHOR CONTRIBUTIONS

All authors contributed extensively to this research project. M.J.P.designed the experiment and analyzed the data. M.J.B collected the data and wrote the paper.

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