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Volume 3 | Issue 1 Article 3

2014

The effect of short-term water stress on leaf isoprene emission

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ABSTRACT This study measured the photosynthetic rate and isoprene emission from red oaks (*Quercus rubra*) during drought stress conditions. Over a period of 30 days, the trees were grown outdoors on a rooftop. The experimental group was subject to drought stress while the control group was watered regularly. The measurements from each group were compared to determine differences. The results indicated that isoprene emissions do not increase directly from drought stress, and that whole plant increases are due to indirect increases in leaf temperature caused by drought conditions.

INTRODUCTION

Biogenic volatile organic compounds (BVOCs), such as isoprene, have effects on interactions in the atmosphere and can combine with air pollutants, leading to unwanted consequences for humans. BVOCs are compounds that originate from plants and easily enter the atmosphere in gaseous form. Because they originate from plants, many ambient factors, such as drought, affect the rate of emission. CO_2 is well known because of its anthropogenic sources and its direct greenhouse effect, but CO_2 is not the only gas that impacts climate change. When they do make it into the atmosphere, BVOCs can form aerosols that have direct and indirect climate effects (Laothawornkitkul et al., 2009). Although the effects of temperature and CO_2 concentration on BVOC emissions, in particular isoprene, have been well studied, the effects of drought have not (Li and Sharkey. 2013). Climatic factors directly affect the rate of isoprene emissions and in turn, climate is affected by isoprene. This complicated relationship must be understood in order to more accurately predict future climate change

Isoprene is a BVOC produced and emitted by many species of trees. A theory of the purpose of isoprene is that it is used as a mechanism by the plant to combat abiotic stresses, such as heat stress (Penuelas et al., 2009). Plants that emit isoprene have shown a higher tolerance to rapid changes in temperature caused by changes in the sunlight reaching the leaf, called heat flecks (Sharkey et al., 2008). Siwko et al. (2007) provided evidence that isoprene stabilized lipid membranes and blocking “heat induced phase transitions,” helping the plant regulate temperature. The yearly production of isoprene emissions by vegetation is estimated to be 600 Tg, or about one-third of all natural hydrocarbons released into the atmosphere – comparable to methane (Guenther et al., 2006). After release, isoprene is converted by free radicals present in the atmosphere into various species that aid in the creation of aerosols and haze. In the presence of nitric oxides (NO_x) it contributes to the formation of tropospheric ozone, which is harmful to human health and one of the leading

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Research Completed in Autumn 2013
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air pollutants in many countries. An abundance of isoprene can cause indirect negative effects on current and future air quality in an already-polluted atmosphere.

This study aims at understanding the relationship between drought stress and isoprene emission. This understanding is important because drought is becoming increasingly common in regions like the Southwestern United States, and the occurrence is expected to rise in the future as a response to a warming world. The effect that drought can have on isoprene emissions at the leaf level can directly affect air quality. Photosynthesis and isoprene emissions data during drought stress could provide a clearer picture in understanding how to model the future effects of isoprene in the atmosphere. This study investigates the effects of drought and the stimulation of isoprene emissions in a thirty-day time frame.

There were two main predictions. First, there would be no change in isoprene emissions at the leaf level caused directly by drought stress. Temperature and ambient moisture would be controlled at the leaf level and so isoprene emissions would remain the same. The positive effect of temperature on isoprene emission is well known and therefore temperature control is key. Second, leaf level photosynthesis and stomatal conductance would decrease. This is believed to happen as a response to water stress. While stomatal opening allows CO_2 to enter the leaf for photosynthesis, water escapes the leaf through the same opening. During drought stress, the tradeoff between allowing CO_2 to enter the leaf and allowing water vapor to exit the leaf is more critical. Transpiration increases because of the difference in water vapor between the air inside and outside the leaf, causing the stomata to close. The decrease in stomatal conductance causes an increase in the temperature within the leaf. Without the stomata being open evaporative cooling cannot occur. As photosynthesis and stomatal conductance decrease, measured isoprene emissions should remain the same.

Such results would support the hypothesis that stomatal closure causes leaf temperature to rise, and in turn, indirectly increases isoprene emissions (Figure 1). This whole plant rise in isoprene emission during drought stress (Potosnak et al., 2014a) is caused by the decrease in stomatal conductance, which increases leaf temperature and is not a direct response to drought stress (Figure 2). These findings would argue against the rise in isoprene emissions as a direct physiological response to drought.

At the leaf level, however, the predicted increase in isoprene emission would not be measured because the instrument controls the leaf temperature. The control in leaf temperature removes the direct cause for decreases in stomatal conductance and increases in internal leaf temperature (Figure 2).

METHODS

The experiment consisted of drought stressing trees and measuring the fluxes of photosynthesis and isoprene emissions. The trees were separated into experimental and control groups (n = 4); the experimental trees were subject to drought stress while the control trees were watered daily with approximately four liters of tap water. The drought stress consisted of wrapping the pots of the trees in a translucent plastic lining, and taping the lining so that the soil and pot could not be exposed to outside moisture, such as rain or accidental watering. This led to the plastic lining reaching from the stem of the trees to all around and under the pots. The point of the drought stress was to negate water from reaching the roots of the trees. Soil moisture measurements were recorded (Figure 3). Comparing the experimental group measurements to the control group allowed the comparison of photosynthetic rates and isoprene emissions due directly to drought stress. Standard errors for the measurements were calculated and plotted in order to determine differences.

This experiment was conducted on the rooftop greenhouse of the Environmental Science and Chemistry building (1110 West Belden Avenue). The location is in an urban setting and was subject to the local weather. Red oaks (*Quercus rubra*) were used in this study because of their high rate of isoprene emissions. The higher rate of isoprene emission enabled an easier detection of emission rates. There were eight oak trees in all and were sourced from the nursery Possibility Place, Monee, IL. The red oaks were similar in age (~1 year old) and growth (~1 meter). All of the trees had some oak blight present at the time of sourcing but did not seem to have a noticeable effect on measurements or relative health. The measurements were taken during the summer season from July 30th to August 23rd, 2013. Although the leaf-level measurements were taken inside the greenhouse, the trees were grown on the outdoor rooftop of the building and were subject to the elements. This was done in order to simulate the trees growing in the wild, and to gain measurements that more closely resembled a natural setting.

The measurements were taken using a leaf-gas exchange instrument, LI-6400XT Portable Photosynthesis System. The instrument provided readings by clamping an arm onto a leaf and providing an airtight chamber, six centimeters squared. Within the chamber, light, CO_2 concentration, temperature, and airflow were controlled. The instrument provided direct photosynthesis rate readings and indirect isoprene emission readings. Directly connected to the flow output of the chamber was a gas chromatograph (GC). The GC provided isoprene emission readings via a connected computer running the accompanying software. The GC measured the integrations of isoprene peaks and the data were used to determine the rates of isoprene emissions. The readings were recorded and input into Microsoft Excel for statistical analysis.

RESULTS/DISCUSSION

Figure 4 has isoprene emission and photosynthesis plots over the time drought stress was applied to the red oaks. Photosynthetic rates were similar for the beginning of the experiment, but towards the end there was a noticeable difference between groups. This effect was intuitive and was a direct response to the drought stress. As the drought stress progressed, stomatal conductance decreased and inhibited the drought stressed leaves from photosynthesizing at non-drought stressed rates.

Initial isoprene was higher for the experimental group as compared to the control group. Between measurements on Aug. 16th and Aug. 19th, isoprene from the experimental group began to decrease. This effect was predicted (Figure 2) and the delayed response was due to isoprene emissions using stored sources of sugars within the leaf after photosynthesis slows down. Photosynthesis in the experimental group began to decrease earlier than isoprene, between Aug.14th and Aug. 16th, which agreed with earlier predictions.

The results suggest the hypothesis that drought directly stimulates isoprene emission at the leaf level should be rejected. In the experimental group, photosynthesis began to decrease earlier in the simulated drought than isoprene emissions. This result suggests drought does not directly stimulate leaf-level isoprene, but instead suggests that droughts increase leaf temperature, which in turn increases leaf isoprene emission rates. Drought conditions may indirectly increase isoprene emissions, but in the absence of increased leaf temperatures drought conditions do not increase isoprene emissions. Elevated CO_2 rates have been shown to decrease isoprene emissions, and that effect is reduced by increases in temperature (Potosnak et al., 2014b). Increases in global temperature indicate increases in overall isoprene emissions that can lead to further deterioration of air quality. Along those lines, the increasing frequency of droughts and the adverse effects to air quality that are sure to follow should alarm climate scientists and policy makers alike. Worsening air quality caused by increasing isoprene in the atmosphere can have strong negative effects on human health and should become a focus of environmental policy makers. Because of the strong focus on greenhouse gases like CO_2, attention is drawn away from other harmful gases like isoprene. A better understanding of how isoprene emissions can be controlled or have its atmospheric effects mitigated could lead to increases air quality for humans. A follow-on experiment that examines how isoprene emissions fluctuate due to air moisture could provide a more comprehensive picture of how isoprene emissions react to the plants environment.

Figure 1 Predicted whole plant isoprene emission and photosynthesis at the leaf level. This study was conducted during thirty days.

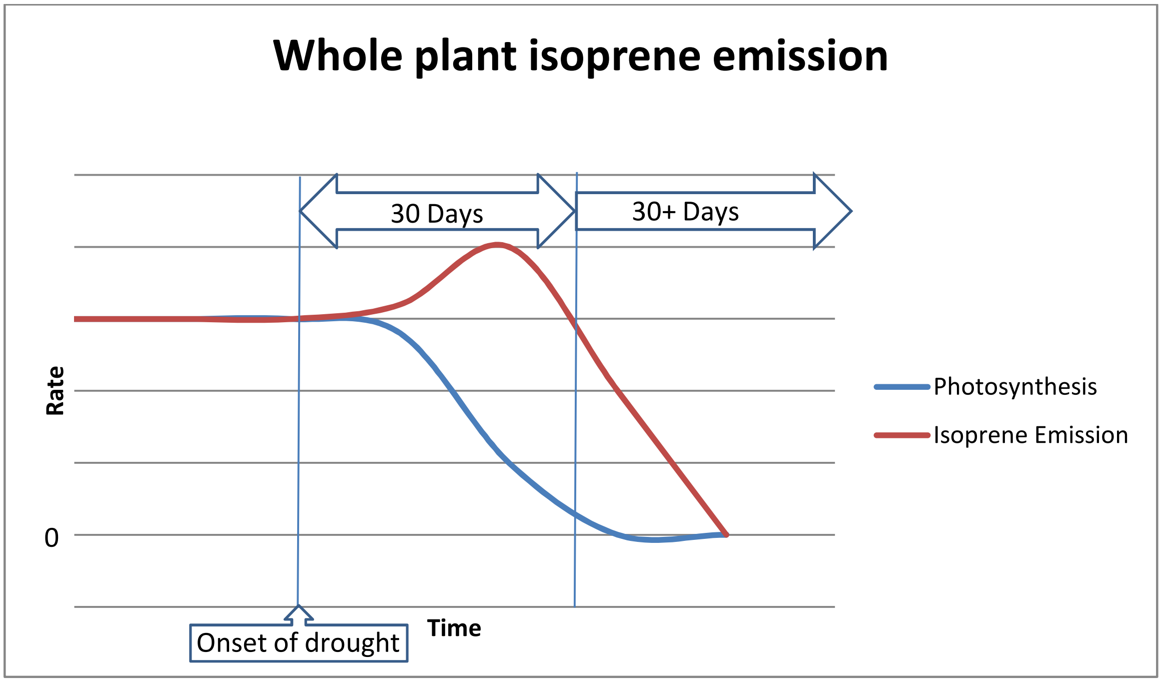


Figure 2 Predicted leaf level isoprene emission measurement curve. This prediction is based on findings by Potosnak et al. (2014a).

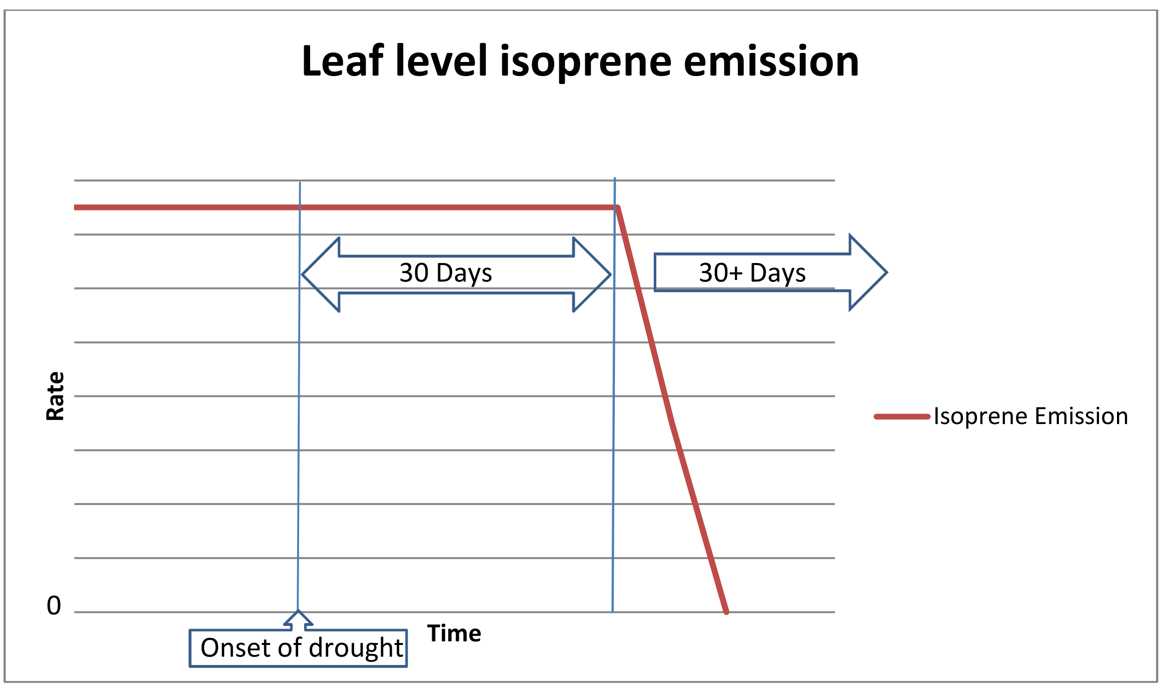


Figure 3 Measured soil moisture from August 7th to August 23rd as Volumetric Water Content (volume of water/total volume).

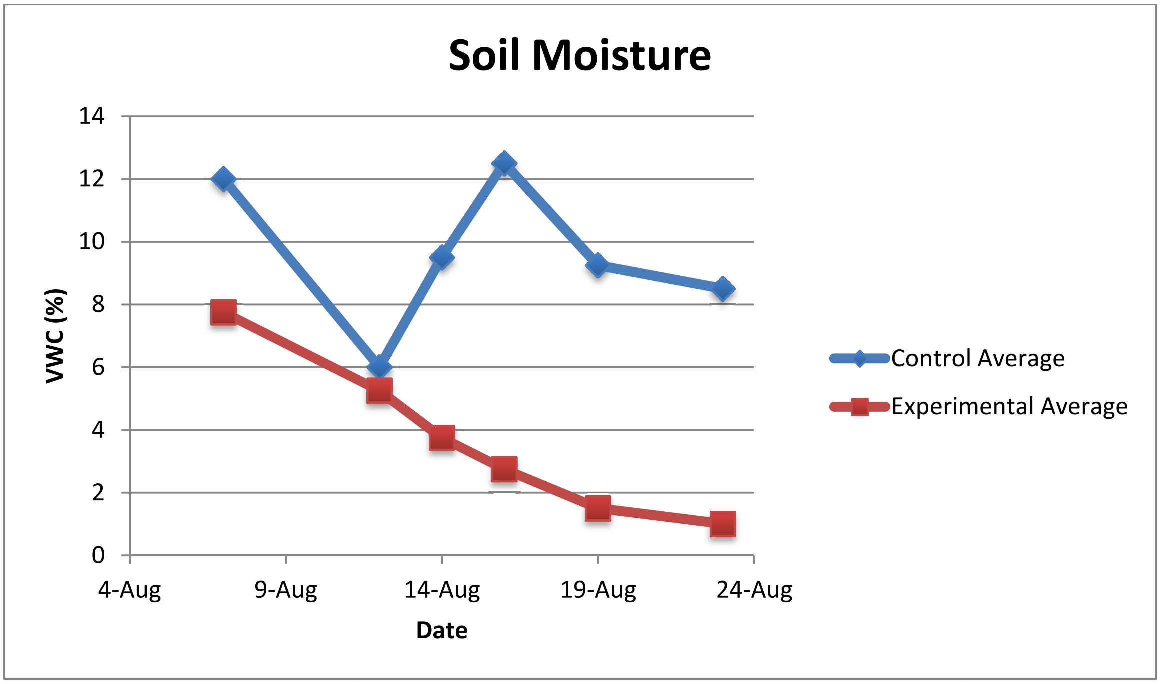
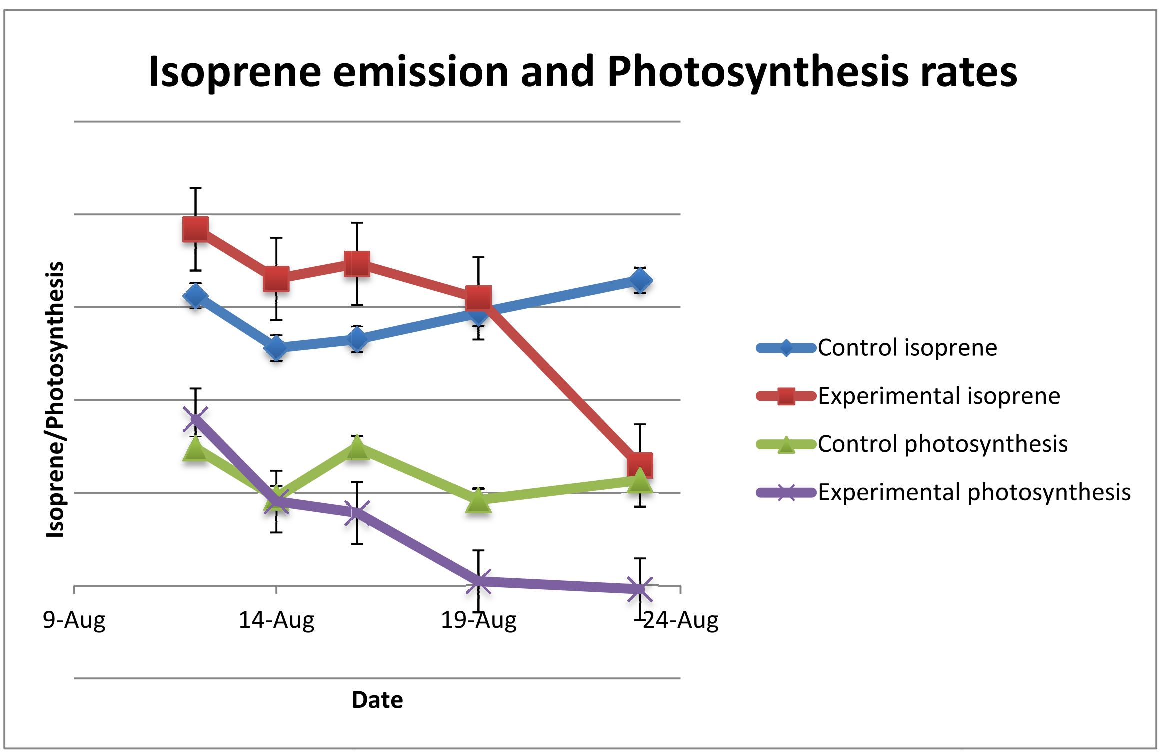


Figure 4 Measured photosynthesis (μmol m^{-2} s^{-1}) and isoprene emissions (nmol m^{-2} s^{-1}) and error bars are standard errors.



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