Small Scale Vapor Pressure Deficit Changes Influence on Transpiration

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Honors Thesis

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The combined effects of climate change and population growth will undoubtedly affect the water resources upon which communities rely. It is therefore important to understand water's complete journey on Earth in order to assess the effects of possible drought on various ecosystems, and initiate studies to formulate solutions. Plants are an important part of our ecosystem, and plant transpiration strongly influences the amount of water vapor in the air. The purpose of this project was to observe how transpiration rates of canopy and vine species are affected by environmental variables. If we can better understand how various environmental variables affect transpiration, we may be able to better understand what could happen to plants during a prolonged drought caused by climate change.

Biosphere 2 is a unique lab and field setting in which to study plant life, and was utilized for this project. Relative humidity, temperature, time of day, location and sunlight availability were taken into account. Because of the multiple factors that affect transpiration rates, it was important to the effects of various climatic variables – not solely vapor pressure deficit - on transpiration. Multivariate analysis was used to analyze the trends between vapor pressure deficits and species transpiration rates. Since photosynthesis occurs when there is energy available, transpiration rates were naturally influenced by time of day and sunlight availability. Further analysis is needed to evaluate if vapor pressure deficits and transpiration rates can be correlated directly using only the current data set available.

Introduction

Water's journey through rainforest canopy trees is the center of this study. The connection between water potential of stems, stomatal conductance of leaves, and the vapor pressure deficit (VPD) inside the rainforest of Biosphere 2 will be analyzed. Distinguishing plant usage and release of water is important in understanding the water cycle as a whole. Information gathered on plant transpiration compared to VPD is important because VPD is affected by temperature change and humidity. It is commonly understood that increasing VPD results in an increase in transpiration until the VPD reaches a high VPD (relative to species). This can become problematic if VPD is extremely high over large periods of time. If transpiration is reduced, CO_2 is not efficiently utilized by a plant. With a changing climate and increase in CO_2 levels, high VPD can result in less CO_2 being used by plants, thus more CO_2 will accumulate and plants will not grow efficiently.

The confined rainforest of Biosphere 2 was utilized in this project to gather experimental data. This project consisted of gathering transpiration and water potential data directly from four different canopy trees of the same maturity: *Clitoria racemosa, Ceiba pentadra, Cissus sicyoides and Hibiscus elatus*. Even with well-calibrated hand-held porometers that clamp to leaves and measure transpiration in $mmol/m^2s$, transpiration readings are difficult to take accurately across the board. Measurements taken minutes apart on the same leaf, can yield different values. Part of this study is to gather a large amount of stomatal conductance data from each species in order to compare species average transpiration to one another. The next part is to verify the increase in transpiration with high vapor pressure deficits, and compare transpiration rates to measured water potential data.

Literature Review

Water is not simply absorbed by roots, utilized to create energy, and released as vapor into the air. The journey of water through trees is complicated by variations in temperature, times of day, stomata organization, climate, species, and other factors. The connection between transpiration, stomatal conductance, water potential, and vapor pressure deficits can be examined if these variations are understood.

Stomatal conductance is the rate of transpiration per unit area measured in mmol m^{-2} s^{-1}. Transpiration occurs on a leaf's surface. During photosynthesis a leaf opens its stomata to absorb CO_2 and simultaneously releases water vapor. Stomatal conductance is ideally directly proportional to transpiration because transpiration is the amount of water vapor being released from a leaf and stomatal conductance is the measure of water vapor moving though the stomata of a leaf. However, in most of the papers of this review, stomatal conductance and transpiration are treated as two separate entities. Monteith (1995) describes stomatal conductance as the rate of transpiration per unit area per unit gradient of water vapor concentration inside a leaf. The water vapor concentration inside a leaf is the same as the vapor pressure deficit (VPD) between a leaf and surrounding air if the inside of the leaf is saturated. Stomatal conductance (g) is explained by Monteith as the ratio of transpiration rate (E) to the vapor pressure deficit within the leaf (D); $g=E/D$.

Oren et al. (1999) conducted research on stomatal responses to changing vapor pressure deficits. Vapor pressure deficit (VPD) is defined as the amount of water vapor the atmosphere has capacity to hold. High VPD is paired with low humidity and results in more space in the atmosphere for water. It is a function of temperature and relative humidity. Oren et al. (1999) explain that a VPD increase creates an exponential decrease in stomatal conductance with incredibly high VPD. Here stomatal conductance follows the definition presented by Monteith. Oren et al. (1999) focus specifically on the magnitude of the decrease of stomatal conductance, which differs from species to species as well as within a species. They used sap flux estimations or total plant water flux estimations and a porometer to gather transpiration data directly from the species. A sensitivity analysis was conducted on stomatal conductance reaction to increased VPD to test whether or not sensitivity is proportional to the magnitude of stomatal conductance at low VPD. They concluded that plants with high stomatal conductance at low vapor pressure deficits show the greatest sensitivity.

Citing a paper by Lange et al. (1971) Oren et al. (1999) state "as the vapour pressure deficit between leaf and air increases, stomata generally respond by partial closure". Several researchers concur with this notion; McAdam and Brodribb (2015), Ocheltree et al. (2013) and Monteith (1995). Transpiration generally increases, plateaus and in some cases, decreases at high VPD. Oren et al. (1999) express that it is known that a plant can sense transpiration through the mechanism of changing water potential or water content of its leaf cells. On the cell level, details of this process are unknown.

McAdam and Brodribb (2014) explain that transpiration is controlled by the opening of stomatal pores on the leaf surface. The vapor pressure deficit between a plant and the air around it proves to influence the closure of stomata at high VPD and give way to opening of the stomata at low VPD. This is true for a large range of plant species.

Oren et al. (1999) state that water potential is a driving mechanism behind the stomatal response to VPD. In contrast, McAdam and Brodribb (2014) state there is no consensus as to the mechanism in regards to relation of stomatal conductance to VPD. Their study focuses on testing a possible mechanism that controls stomatal conductance sensitivity to VPD: biochemical regulation by the phyrohormone abscisic acid (ABA). This is a common explanation of the driving mechanism behind stomatal conductance response to VPD changes, but has not been proven. McAdam and Brodribb (2014) conducted an experiment in which ABA levels in different plants were recorded as a change in VPD was applied to the system. Through their research, they determined that in the angiosperm clade, a flower plant species, leaf ABA provides the signal for active stomatal responses to VPD. This result is a first step in pinpointing the driving mechanism for stomatal response to VPD.

Ocheltree et al. (2013) correlated the sensitivity of stomatal conductance to changes in VPD and determined the differences in hydraulic conductivity of leaves and roots of plants. Like McAdams and Rodribb (2015), Ocheltree et al. (2013) state that there is not yet a plant mechanism identified that detects a change in VPD. The authors also allude to the negative effects of increasing VPD on plant growth. Plants are not able to absorb the carbon dioxide necessary for growth when stomatal conductance reduces in response. Oren et al. (1999), McAdams and Rodribb (2015) and Ocheltree et al. (2013) agree that the sensitivity of stomatal conductance to VPD varies among species. Ocheltree et al. (2013) site research by Oren et al. (1999) in describing stomatal conductance sensitivity. Oren et al. (1999) published the relation between the magnitudes of stomatal conductance change with respect to VPD as the slope of stomatal conductance versus ln(VPD). This result can be used for many different plant species, but is still varied.

In most tree species, stomatal conductance is decreased in response to increasing VPD in order to minimize water loss (Oren et al. (1999), McAdams and Rodribb (2015) and Ocheltree et al. (2013)). However, using the definition of stomatal conductance synonymously with water vapor release or transpiration, stomatal conductance decrease with VPD increase is not expected when considering the basic definition of VPD. Higher VPD should theoretically result in a larger transpiration. The purpose of my present project is to provide data that can be analyzed in order to evaluate the VPD effect on transpiration of rainforest canopy tree species.

The water potentials of trees are also important to understand for this study. Water potentials can be measured in many different ways. For comparative data, water potentials were measured with a pressure bomb. Water potential is measured as a pressure, and fluctuates depending on the time of day. The symbol Ψ represents water potential and is usually given as a negative number in mega pascals (MPa). Water potential is the amount of water available for movement in trees. The most important measurements for this study are pre-dawn water potential measurements. Overnight, trees transpire very little due to lack of sunlight. Droughts can cause pre-dawn measurements to be very low. According to Eamus (1999), soil water content declines substantially, especially in the upper three meters during a dry season. The lack of water in the soil makes it extremely difficult for roots of plants to absorb any water. Because of this, water potentials are not replenished overnight while the trees continue to transpire. This can cause problems for the entire tree; however, each species deals with water unavailability differently. For instance, evergreen species maintain a more positive turgor potential at lower values of leaf potential compared to other species. This allows them to be able to maintain their cell functions at low soil water contents.

Site Description

Biosphere 2 was built to simulate Earth, which is understood to be Biosphere 1. It is, in a sense, a model of Earth whose ecosystem parameters can be controlled for research. Originally it was created to research self-sustaining space colonization technology. In 1991, eight scientists – called "Biospherians" by the media - were sealed inside for two years to see if the Biosphere 2 could sustain life. Today it is operated by the University of Arizona to better understand environmental phenomena like climate change and land evolution.

The five different areas at Biosphere 2 mirror these biomes, including rainforests, oceans, deserts, savannas, and marsh lands. The confined rainforest biome of Biosphere 2 was used for this study. The rainforest biome has controlled temperature, rainfall, and organism life. Vapor pressure deficits, temperature, humidity, rainfall, soil moisture, and other field characteristics can be measured. The top layer of soil within the rainforest biome is mainly sandy and clayey loam and the subsoil is a granite gravel material. Both were created from local soils to provide nutrients that are similar to the soils of an actual rainforest. The plants in the rainforest were planted in specific locations and were chosen to be planted for specific reasons. For instance, bamboo plants were planted near the door between the rainforest and the ocean biome in order to protect the rainforest from salty air. The species of banana inside the rainforest were specifically chosen to be planted by the Biospherians because they produce the sweetest fruit. The table below lists the dominating species that live in the rainforest biome. For this study, transpiration and water potential data will be taken from mature leaves of the *Clitoria racemosa*, *Ceiba pentadra, Cissus sicyoides* and *Hibiscus elatus.* It is also important to note that the rainforest biome underwent a drought for a portion of this project. Readings were taken during the drought, and again a month after water was brought back. The drought lasted for 2 months and had sporadic watering to avoid killing the plants .

Table 1: Dominating Biosphere Rainforest Species

Scientific Name	**Colloquial Description**
Clitoria racemose	Canopy tree
Ceiba pentandra	Canopy tree
Musa spp.	Banana tree
Arenga pinnata	Feather palm tree
Epipremnum pinnatum	Pothos vine
Syngonium podophyllum	Smaller plant
Cissus sicyoides	Vine
Hibiscus elatus	Canopy tree
Hura crepitans	Canopy tree

Methods

The canopy trees in this study reach over 20 meters high. A pulley system was used to hoist researchers to sample the top leaves. Once situated high in the structure of the rainforest biome, researchers collected transpiration rates using a porometer. A Decagon Lead Porometer® [1] is a lightweight, easy-to-carry electronic device that can measure transpiration. The porometer sensor head must be calibrated in the field in order to be in thermal equilibrium with the environment. A plastic plate with a precisely drilled hole, that has a known conductance of 240 mmol m-2s -1, is used with along with a deionized saturated filter paper and DrieRite® desiccant to get readings with an accuracy of 10Transpiration measurements were repeated three to five times depending on leaf size, and each reading was taken on a different spot of the leaf. After the transpiration data was recorded and saved to the porometer, the humidity and the temperature of the area directly around the leaf were recorded. Four to five leaves of each species were marked to allow for repeat measurements at subsequent data collection events.

Table 2: Factors Considered Throughout the Data Collection Process

Variable	**Importance**
Time of day	Leaves transpire more in the morning and less toward evening.
Level/Height	Leaves were compared to others of the same height from the ground, as well as to lower leaves.
Type of light	Direct light, partial light, shade, clouds, etc. all influence photosynthesis and thus have an effect on transpiration.
Area of leaf being measured	Different areas of the leaf may have different transpiration rates because of differences in stomatal density. The areas measured are recorded and the average is taken for comparisons.

Multiple graphs of the data were generated to compare the effects of different variables. Graphs of transpiration were created to evaluate changes at different times of day, different heights, and different types of lighting for each species. Transpiration rates were also plotted versus the corresponding vapor pressure deficit to determine the correlation for each species at each time of day. The graphs were analyzed for trends.

[1] Brand names are stated only for descriptive purposes, and do not necessarily constitute an endorsement by the researchers or The University of Arizona.

Results

Analysis was done on transpiration values collected from the *Clitoria racemos and Cissus sicyoides*. Though four plants were involved in the data collection process, the species above had the most abundant data to analyze. A multivariate, fully visual approach was taken when analyzing the data. Below is a list of the different graphs created.

- A graph that has the assumed independent variable on the y-axis, and the dependent on the x-axis
- Change in transpiration over time
- Time of day indicated by size and light availability indicated by color
- VPD color coded, x-axis being the date

The same data was looked at from different angles in order to best understand the information conveyed by the data set. The goal was to try and find the which variable caused irregularity of transpiration Below are the graphs created using the if/then statement function in Microsoft Excel.

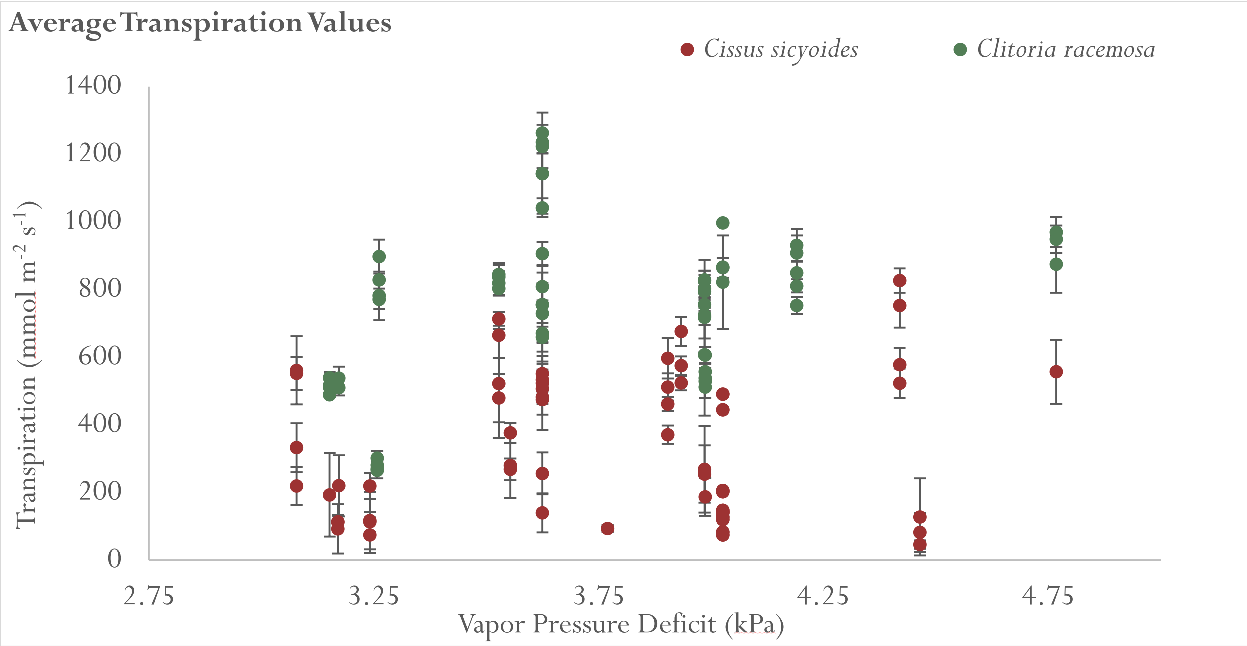

Figure 1: The above graph has average transpiration gathered over the semester plotted against the vapor pressure deficit at the time the transpiration reading was taken.

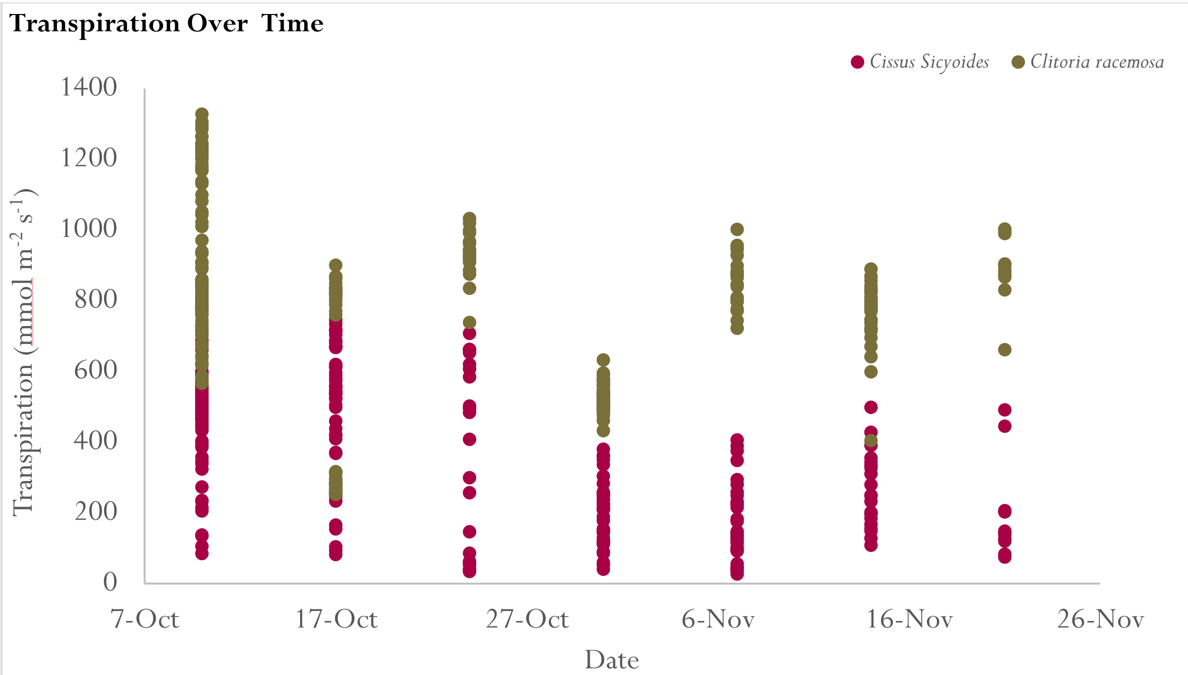

Figure 2: Transpiration was plotted against the date the reading was taken.

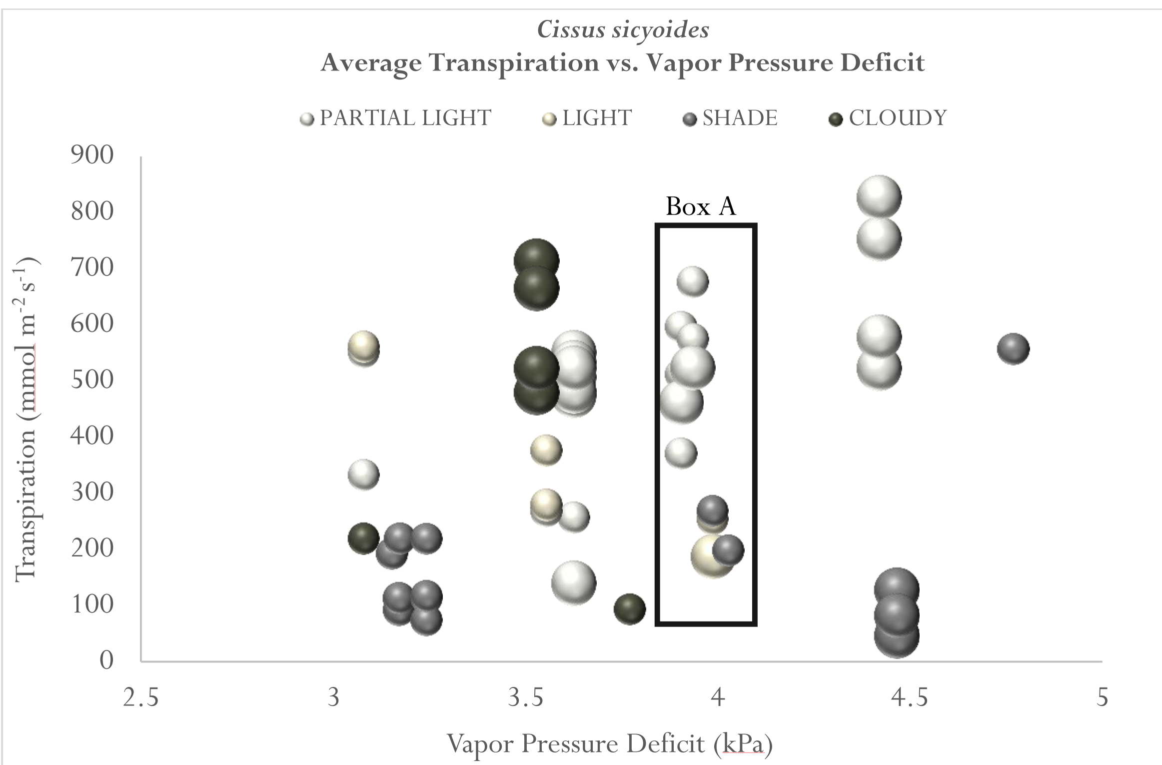

Figure 3: The above graph has average transpiration rates gathered from the Cissus sicyoides plotted against the calculated vapor pressure deficit. The color corresponds to the amount of light available, and the size shows the time of day in which the reading was taken.

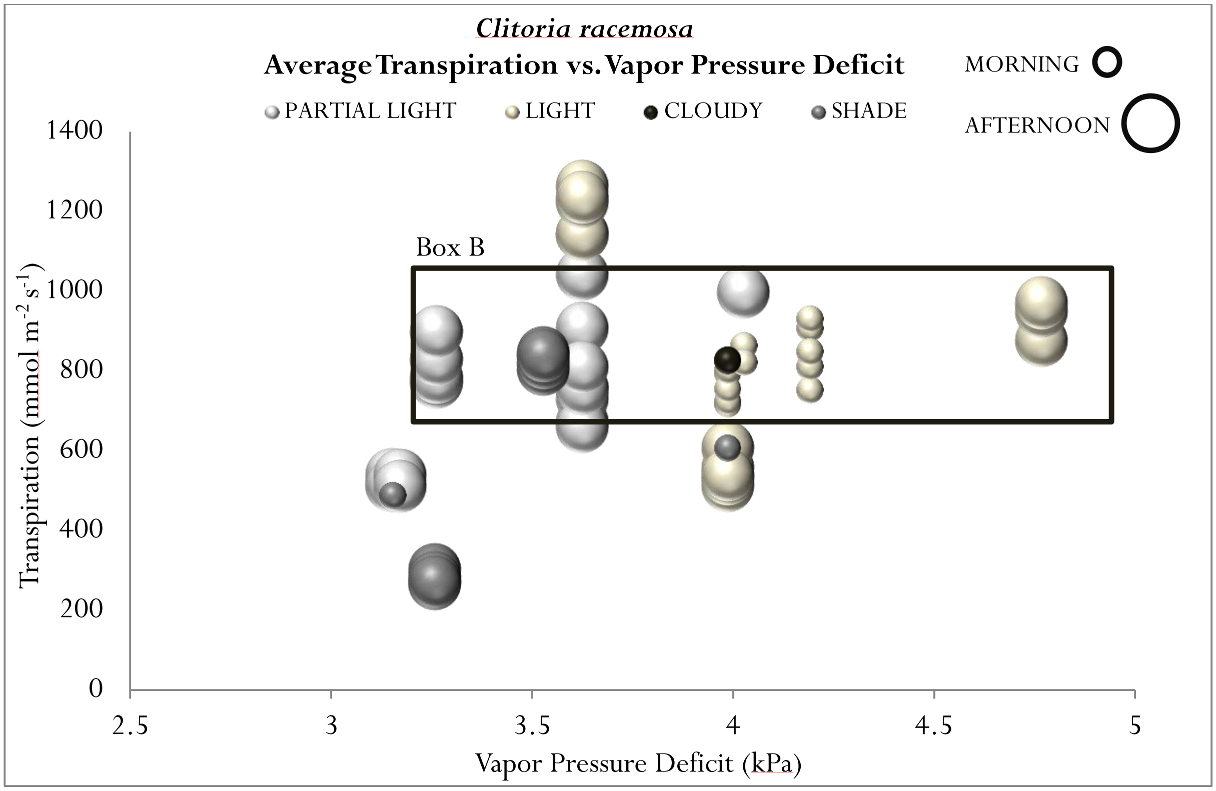

Figure 4: The above graph has average transpiration rates gathered from the Clitoria racemosa plotted against the calculated vapor pressure deficit. The color corresponds to the amount of light available, and the size shows the time of day in which the reading was taken.

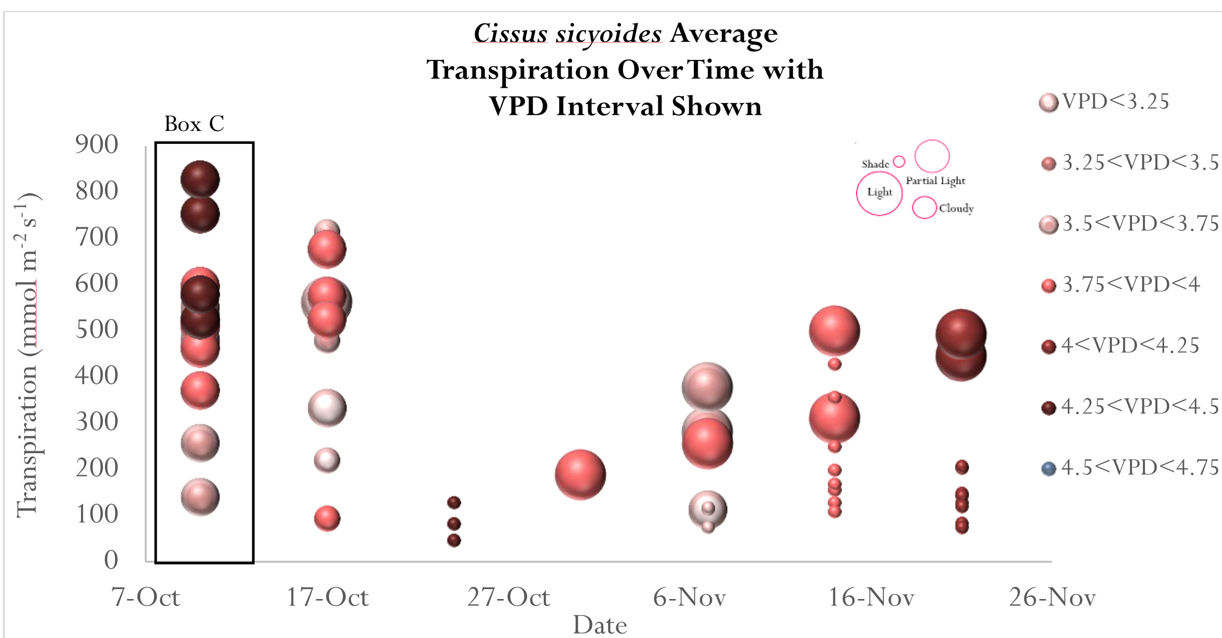

Figure 5: The above graph has average transpiration rates gathered from the Cissus sicyoides plotted against the date. The color corresponds to the vapor pressure deficit interval that goes with the given transpiration value, and the size shows the amount of light that was available to the leaf at the time the transpiration reading was taken.

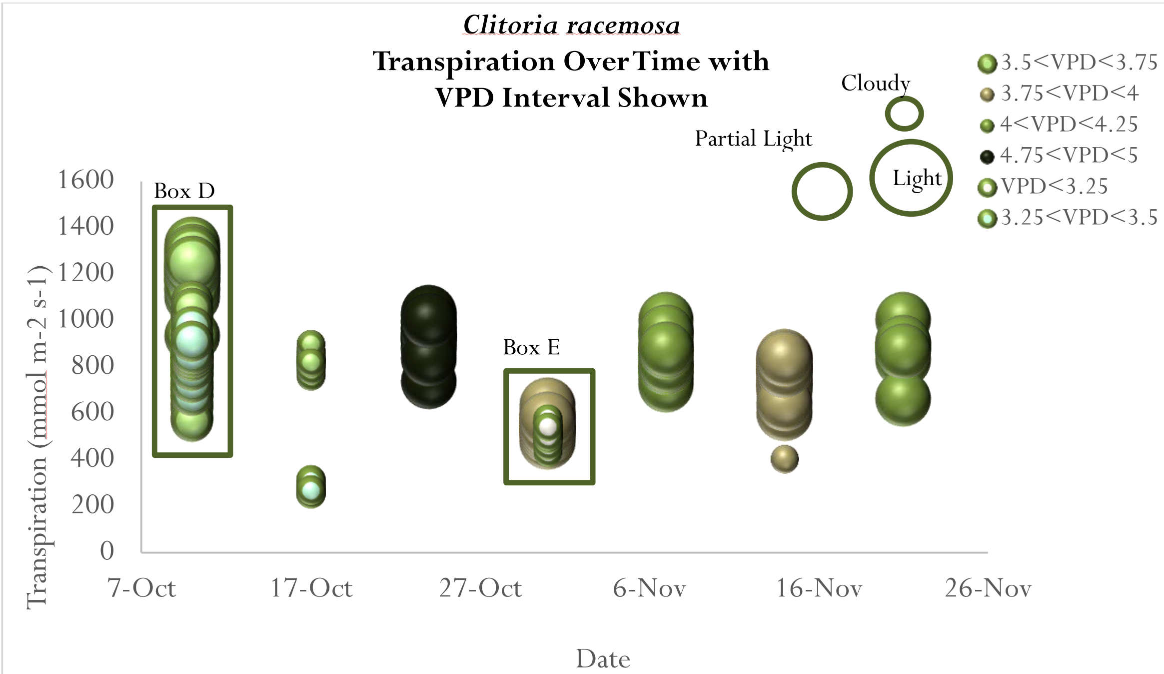

Figure 6: The above graph has average transpiration rates gathered from the Clitoria racemosa plotted against the date. The color corresponds to the vapor pressure deficit interval that goes with the given transpiration value, and the size shows the amount of light that was available to the leaf at the time the transpiration reading was taken.

Discussion and Conclusion

The data gathered were first plotted with the vapor pressure deficit as the independent variable and transpiration as the dependent variable to identify trends . As seen in *Figure 1*, there is no obvious correlation between transpiration and vapor pressure deficit given by the data set. To verify this observation, a multiple variate analysis was completed. Daily transpiration data was plotted to observe the transpiration changes over time. *Figure 2* shows this information for each species separately. Theoretically, because the leaves were re-measured over the data collection period, transpiration from each species should decrease as a whole due to damage of repeated handling and the approach of winter. However, there is not a dominating decreasing trend seen in the data of either species.

An analysis was completed on the variability in transpiration possibly caused by sunlight availability. Transpiration was again plotted against the vapor pressure deficit. *Figure 3* and *Figure 4* depict time of day and light exposure. Time of day and light availability were considered because they drive photosynthesis on a cell level. Data points with the same VPD and time of day were compared. Holding VPD constant allowed for comparisons between light availability. Box A in *Figure 3* refers to transpiration rates recorded in the same VPD range. Higher transpiration values are from leaves exposed to a greater amount of sunlight. However, looking at the entire data set given in *Figure 3*, this trend does not hold. Box B in *Figure 4* shows that different ranges of VPD gave nearly the same transpiration rates. For both species, the graphs showing variability of transpiration due to light availability did not produce a definite trend.

Box C in *Figure 5* shows overall higher transpiration values for higher VPD when there is constant light availability. There is overlap in Box C, which indicates the same transpiration rates are produced by leaves in different VPD ranges. Figure 5 as a whole show that different VPD ranges exposed to different amounts of sunlight gave the same range of transpiration rates as well. Overlap is seen in *Figure 6* in Box D and Box E as well. This shows that changes in VPD do not directly influence transpiration.

The VPD ranges did not directly affect transpiration rates of the leaves measured as we see in *Figure 5* and *Figure 6*. Sunlight availably was arbitrary. The data shown in *Figure 3* and *Figure 4* gave transpiration readings with high light availability being similar to those with low light availability. Neither the *Clitoria racemosa* nor the *Cissus sicyoides* transpiration values did not showed a consistent trend due to sunlight exposure. The information verified from this study it that the *Clitoria racemosa* consistently had higher readings than the Cissus sicyoides overall.

Understanding VPD as described by Monteith (1995), we understand that large increase in VPD can be detrimental to plant species. VPD is dependent on temperature and relative humidity. Climate change will effect a regions VPD. Depending on the biome in question, VPD will change differently. The plants that were measured were unaffected by increasing VPD values. Either species are resilient to the changes, or the actual increase was not great enough to create a significant increase trend, and then decrease in transpiration values. Further study is needed in order to understand this phenomenon further.

References

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Leaf Porometer Operator's Manual Decagon Devices, Inc. 2365 NE Hopkins Court Pullman, WA 99163 www.decagon.com Trademarks: "Leaf Porometer" is a registered trademark of Decagon Devices, Inc. © 2005-2010 Decagon Devices, Inc. All rights reserved.
Operator's Manual Version 7.0.

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