Cantaurus, Vol. 20, 51-55, May 2012 © McPherson College Division of Science and Technology

The Effects of Increased CO_2 Concentration on the Rate of Photosynthesis in Corn

Andrew Skinner

ABSTRACT

Global warming is becoming an increasingly controversial issue in today's society and knowing the potential impacts on agriculture is necessary for future decisions. CO_2 is being emitted into the atmosphere at a greater rate than ever before and is expected to increase even more. Knowing how this increased concentration of CO_2 will affect corn, which is a major crop in the world, will be of great importance. A Li-COR 6200 portable photosynthesis system was used to test 27 corn plants' photosynthesis response to elevated levels of CO_2. This was done by measuring the change in CO_2 in the leaf chamber during an approximately 2.5 hour time period. The plants tested were found to have significantly increasing rates of net photosynthesis as the concentration of CO_2 increased, with $p<0.001$. The mean slope of the increase in net photosynthesis as CO_2 concentration levels increased was found to be 0.0213 μmol s^{-1} m^{-2} and an average CO_2 compensation point was found to be 465.44 ppm. Obviously, results will be much different under natural conditions due especially to light intensity that will allow corn to do photosynthesis at lower levels of CO_2. My results were found in a lab setting with a particular light intensity of 33-40 μmol s^{-1} m^{-2}, while natural sunlight is between 200-2000 μmol s^{-1} m^{-2}. Measuring at this lower light intensity decreased the photosynthesis and increased the CO_2 compensation point that what would be observed in a natural setting. Increased levels of CO_2 in the future will lead to corn doing increased photosynthesis. This however, could be counter balanced by the possibility of increased future temperatures.

INTRODUCTION

An important issue in today's society is the environment and the impact humans have on it. CO_2 is a greenhouse gas that is being emitted into the environment in larger quantities than ever before. According to the Carbon Dioxide Information Analysis Center (2011), the carbon dioxide levels in the atmosphere are approaching 390 parts per million. Atmospheric CO_2 levels are expected to increase even more rapidly in the century to come (Bernacchi et al., 2003). With these facts in mind, knowing how increased CO2 effects crops is important to future agriculture planning. The demand for corn is very large in the world. In terms of production, corn is the third most important food crop globally (Leakeyet al., 2004). Also, corn and similar C_4 photosynthesis plants are playing a particularly greater role as biofuel (Leakey, 2009). The demand is expected to increase in the future (Leakey, 2004). Therefore, my objective is to find how elevated CO_2 affects the rate of net photosynthesis in corn.

There is much speculation about the effects increasing levels of CO_2 will have on the rate of photosynthesis in corn, as well as similar C_4 photosynthesis plants. In similar studies, the results seem to be inconsistent. I have found studies indicating significant changes in the rate of photosynthesis directly related to the increased levels of CO_2 (Poorter, Roumet, Campbell, 1996; Wand et al., 1999; Wand and Midgely, 2004). Other studies did not find the rate of photosynthesis to be directly influenced from the increased concentration of CO_2 (Leakey et al. 2006; Soo-hyung et al. 2006). Some explanations of this variation include differences in root depth, the genotype studied, and the reasoning that in earlier studies the ambient CO_2 concentration was lower than what it is today. This would account for the possibility of threshold concentration level that has been reached. This could affect photosynthesis in two ways. The first way is, a concentration saturation point inside the plant has been met and no significant effect will come from increasing CO_2 concentrations around the plant. The second possible way is if the CO_2 concentration is raised to a certain point or threshold and a significant effect on photosynthesis occurs (Leakey, 2009). An explanation of the inconsistencies in studies could possibly arise from the drought stress levels in the plant. Some studies have found the positive correlation of photosynthesis and CO_2 concentration to be evident only when the C_4 plant is water stressed (De Souza, et al., 2008; Knapp et al., 1993). Continued study must be done to reach consistency of C_4 responses to levels of CO_2.

Theoretically, CO_2 should not directly affect the rate of photosynthesis in corn if the plant has reached a saturated point of CO_2 (Leakey et al., 2004; 2009). Corn is a C_4 plant. This type photosynthesis differs mechanically from that of a C_3 plant, such as wheat, sugar beet, and potatoes. The primary difference between these types of photosynthesis is the enzyme the plants use to accept CO_2 from the air. In C_4 plant photosynthesis, the plant uses the enzyme PEP carboxylase, which only takes in CO_2 and not O_2. These two molecules,

CO_2 and O_2, don't have to compete with one another to get inside the plant (Galston, Davies, and Satter, 1980). Experiments involving C_3 plants such as wheat and the sugar beet have found the rate of photosynthesis to increase as the levels of CO_2 increase (Alonso, et al., 2008; Romanova, et al. 2005). Results from experiments involving C_3 photosynthesis plants have shown more consistency in results compared to C_4 photosynthesis plants.

In the present study, I am measuring the short-term photosynthesis response of corn to elevated CO_2 levels. I will determine this response by performing a comparison of photosynthesis rates of corn under ambient levels and corn under elevated levels of CO_2. Then I will determine if the rates are significantly different. By using possible future CO_2 levels, I can use my results to predict the changes in photosynthesis of corn in the future. With continued research concerning the effects elevated CO_2 will have on vegetation, we can be prepared for future changes in vegetation associated with change in climate. Preparation for the future is increasingly crucial to accommodate for the rapid population growth the world is experiencing.

MATERIALS AND METHODS

I planted 30 seeds of corn; each seed was planted in a separate pot. The seeds of corn were Country Lane Cleaned whole corn from Orscheln Farm and Home. The corn was planted so that each individual plant was measured around the same time in its growth cycle. This experiment measured only short-term effects of the CO_2 on the rate of photosynthesis, so I waited until the plants matured to a point where the leaves were large enough to fit comfortably in a 1L chamber of the LiCOR 6200 Portable Photosynthesis system. The approximate length of time between planting and measuring was 4.5 months. The average area of leaf measured was approximately 15 cm^2. I started growing the plants with Miracle-Gro seed starting soil mix. Once the seeds germinated, which occurred around 1-2 weeks after planting, I replaced the soil with the general Miracle-Gro potting soil. Along with the using the same type of soil for each plant, they were given a steady water supply, and planting took place in the green house of Melhorn Hall at McPherson College in McPherson, KS.

Once the plants matured to a stage where they could be measured, I began testing the rate of photosynthesis. I place part of the leaf of the plant in the chamber connected to the Li-COR 6200, the surface area of the plant was measured. The surface area was measured in order to determine the net photosynthesis per unit surface area of the plant.

To start the testing process I entered in the appropriate initial setup parameters such as, volume of the chamber and hoses of the machine, atmospheric pressure, stomatal conductance ratio and maximum flow rate for the test. I set up the machine to record an observation every five minutes for a total of thirty observations. After the initial setup was complete, I zeroed the machine using the zero knob after the scrub lever was switched on. Once the machine was zeroed, I turned the scrubber off and the pump off. Once the zeroing was complete, I attached a hose running from a tank of gas with a known concentration of CO_2. For this experiment, I used a tank with a known concentration of 634 ppm. The lid to the photosynthesis chamber was open and the pressure of the gas running into the machine was set approximately the same flow rate the machine will be during testing. Using the span knob, I calibrated the machine to 634 ppm.

Once the initial setup and calibration of the machine was complete I began testing. Testing an individual corn plant took approximately 2.5 hours. I was able to test 3 plants a day. To start, I tested the plants that were planted first and continued in an order from oldest to youngest. Just before clamping a leaf into the chamber I breathed into the chamber to increase the concentration of CO_2 in the system. The concentration of CO_2 in the system was higher that 700ppm at this point. The CO_2 scrubber was used to reduce the concentration of CO_2 in the system to 700 ppm. This was a tricky process and sometimes required starting over by breathing into the system again. Once the system was at 700 ppm, I began to log data. I repeated this test on 26 other plants. I tried to measure the spot on the plant leaf with the largest area. Because 1 plant died and 2 others withered, I was not able to test the anticipated 30 total plants.

Once testing was complete, I found the descriptive statistics for the CO_2 concentration and photosynthesis at each observation point. From all of the data points collected, I plotted a graph of photosynthesis versus CO_2 concentration to find a correlation between the two variables. I had strong reason to believe that increasing CO_2 could cause the photosynthesis to increase. I used a linear regression analysis to determine if the short-term effect of an increase in CO_2 caused an increase of photosynthesis.

RESULTS

I have analyzed 27 corn plants to find the change in photosynthesis over time. In order to do this, each corn plant was hooked up to the LI-COR 6200 portable photosynthesis system; and the change in CO_2 concentration during a span of approximately 2.5 hours was measured. Graph 1 shows the decrease in CO_2 concentration (ppm) as time progresses for the first corn plant measured. If the first corn plant absorbed CO_2 at a constant rate even as CO_2 decreased the graph would show a straight line; however, the line in Figure 1 indicates that the rate was not constant. The line in Figure 1 is similar to the other 27 plants tested.

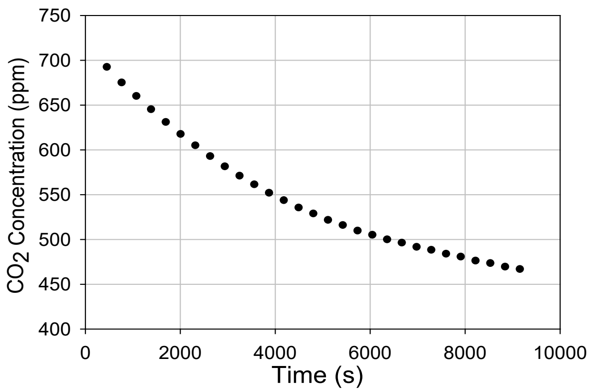

Figure 1 The relationship of CO_2 concentration over time for plant 1. The curved line indicates that at lower concentrations of CO_2 the attached part of the plant didn't assimilate CO_2 at the same rate throughout the experiment with plant 1. This was repeated for 26 other plants and similar results were found.

The rate of the decrease in absorption of CO_2 in each plant is the net rate of photosynthesis as the concentration of CO_2 decreases. The Li-COR-6200 machine makes many measurement of CO_2 and the dots plotted in Figure 1 are the mean concentrations of CO_2 during each 5 minute interval. The slope of all the sample measurements that gave the mean concentration for each individual data point on Figure 1 is the net rate of photosynthesis the plant performed. Figure 2 shows the net rate of photosynthesis of plant 1 as the concentration of CO_2 decreases. The line shows a direct linear relationship. The p value of this relationship was <0.001. This same analysis was performed on each of the 27 corn plants. In all of the other plants a linear regression showed $p < 0.001$. This similar p value for all 27 plants indicates that the relationship between photosynthesis rate and CO_2 concentration is statistically significant. The F-test is used to determine if a factor explains a significant amount of variation in the data, the factor (eg. [CO_2]) explains the variation.

The slope of the net rate of photosynthesis as the CO_2 increased was found for all of the plants and averaged. The average net rate of photosynthesis as CO_2 concentration changed for all 27 plants was 0.0213 ± 0.0021 μmol s^{-1} m^{-2}. This average is shown as the bold black line in Figure 3. The compensation point or x-intercept of this slope is 465.44 ppm of CO_2. This indicates that under the lab conditions with temperature and light intensity the plant would no longer be doing net positive photosynthesis at 465.44 ppm CO_2. The average light intensity used in the lab was approximately 33-40 μmol s^{-1} m^{-2}. Obviously this

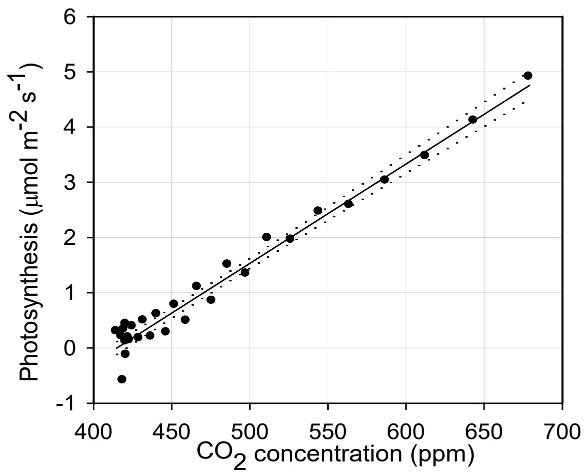

Figure 2 The net rate of photosynthesis of plant 1 at elevating levels of CO_2 concentration. As the concentration of CO_2 increased, the net photosynthesis increased as well. The line indicates the mean rate of photosynthesis of plant 1 as CO_2 increases. This also shows the 95% confidence interval, represented by the small dashes and the large dashes dots are each individual data point. A statistical regression analysis indicates $p < 0.001$

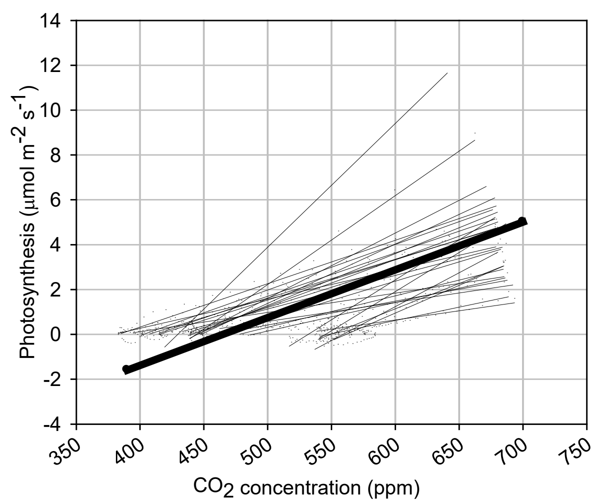

Figure 3 The average net rate of photosynthesis for each individual corn plant as CO_2 concentration levels increase is represented by the skinny lines. The large bold line indicates the average rate of net photosynthesis as CO_2 increases for all 27 plants corn plants. The average slope of this line was found to be 0.0213 μmol s^{-1} m^{-2} ppm and the CO_2 compensation point of 465.44 ppm was found under the lab setting the research was conducted in. The two outlying plant rates of photosynthesis per ppm could possible be explained from leaks in the system during testing.

is not the CO_2 compensation under natural conditions which are in the range of 200-2000 μmol s^{-1} m^{-1} depending on the day (Albright, 2011). Under natural conditions, the light intensity is much greater which allows the CO_2 compensation point of the plant to be much lower and enables the plant to perform photosynthesis at these concentrations.

DISCUSSION

Carbon dioxide is being emitted into the atmosphere in very large quantities everyday. The atmospheric CO_2 concentration is approximately 390 ppm and is expected to increase in the coming century. There has been much speculation about how photosynthesis will be affected by this increase in atmospheric CO_2. The purpose of this experiment was to find how increased CO_2 concentration affected the short-term rate of photosynthesis. This experiment was conducted in a lab setting. The plants were grown in a greenhouse and were only exposed to the high CO_2 concentrations during testing unlike many large-scale FACE, or Free-air CO_2 Enrichment, operations in which corn was grown under the increased levels of CO_2 in it's natural ecosystem. Under lab conditions, I found that the increased levels of CO_2 increased the rate of photosynthesis in corn. This is different than the results I anticipated. Corn photosynthesis uses a C_4 mechanism, with the enzyme PEP carboxylase. This enzyme only takes in CO_2. This eliminates the competition between CO_2 and O_2 assimilation, so I expected photosynthesis to only increase to a certain point and then level off because the plant was absorbing and using as much carbon as it could. My results in the lab setting indicate that the maximum point of carbon intake had not been reached, and the rate of photosynthesis increased as a result of an increase in CO_2.

It's hard to translate this data to field applications because of the differences in some variables due to the indoor lab setting with the main difference being intensity of light. If this could be translated to the field in the coming century corn photosynthesis would expect to increase as the atmospheric CO_2 increased. CO_2 is a greenhouse gas and increasing CO_2 could also lead to increasing global temperature. As the temperature increases plants don't open there stomata as much, thus reducing both transpiration and photosynthesis. This counter balancing affects the increasing rate of photosynthesis and could reduce the future rate of photosynthesis of corn.

ACKNOWLEDGEMENTS

A special thanks goes to Dr. Jonathan Frye for continued help during the course of this experiment. I'd also like to thank the entire Natural Science department staff for direction and funding.

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