Modelling The Effects Of Climate Change On Plants

Introduction

In this study, the effects of Carbon Dioxide (CO_2) and light on Eruca sativa growth and photosynthesis have been investigated. E.sativa is a C3 plant, so they undergo carbon assimilation in photosynthesis in a different way to C4 plants (Hall, Jobling and Rogers, 2012; Sharkey et. al, 2007). This is important, as C3 and C4 plants likely respond in different ways to changing concentrations of CO_2. CO_2 influences the rate of photosynthesis in several ways; the main cause is because CO_2 is used in the Calvin Cycle as a substrate by the enzyme Rubisco to make RuBP (Sharkey et. al, 2007). The more CO_2 there is, the more CO_2 assimilation (using the enzyme Rubisco) can occur, which allows more sugars to be made by the Calvin Cycle.

How does this relate to the growth rate of the plants? Rozema (1993) grew C3 plants in ambient (350 l l-1) and elevated CO_2 (750 l l-1), and found that CO_2 increases assimilation in photosynthesis, which causes an initial increase in leaf size and plant biomass, and starch amount in the leaves. This suggests the increase in starch from an increased rate of photosynthesis allows the plants to grow more. Furthermore, a decrease in stomata density in the plant leaves may also have led to an increased leaf surface area in plants grown in elevated CO_2 (Rozema, 1993). Furthermore, Rozema (1993) also investigated the effects of UV-B (280 – 320nm) rays on plant growth, and found that UV-B rays decrease plant growth.

Unlike UV rays, visual light is of critical importance to photosynthesis; it is used in the Light Dependent Stages. Without light, both portions of the Light Dependent Stages (Photosystems I and II) could not occur, as they both require electrons to be promoted to a higher energy level by light (Lopez and Barclay, 2017). Light also increases the assimilation of carbon in the Calvin Cycle (Sharkey et. al, 2007). A study by Lopez-Hoffman et. al (2006) found that light increases the photosynthetic rate of mangrove plants, which caused an increase in plant growth. In general, it appears that leaves of plants which are adapted to live in sunny areas have smaller leaves, as smaller leaves allow heat dissipation to occur (Smith et. al, 1997). However, these findings don't necessarily mean plants grown in high light conditions will have smaller leaves than those grown in low light conditions, as Smith's (1997) findings may be due to genetics, rather than an increase or decrease in growth rate because of the bright light conditions.

Why study the effect of light and CO_2 on plants? Global warming, which has been caused largely by human pollution and infrastructure, will increase the world's temperature and CO_2 (Manuel, 1994). It is possible that plants could sequester excess CO_2 which has been produced, thereby curbing the effects of climate change (Manuel, 1994). However, the effects of increased CO_2 on plants is still unclear, particularly when combined with the variable of light. If increased CO_2 increases plant growth, areas with dense plant growth may experience excess plant growth, such that plants at the bottom level of the canopy get little sunlight, due to the enlarged sizes of plant leaves. Hence, it is important to study both the impacts of increased CO_2 and decreased light on plant growth.

For this experiment, it was hypothesised that increased CO_2 and light will increase plant growth (measured by leaf surface area and plant biomass). This is consistent with Rozema (1993) and

Sharkey et. al (2007), who report that CO2 is necessary for the Light Independent Stage of Photosynthesis to occur. Increasing CO2 increases the amount of carbohydrates available to the plant, which then increases the amount of growth they are capable of undergoing (Rozema, 1993). Sharkey et. al (2007) and Lopez-Hoffman et. al (2006) describe how light is necessary for the Light Dependent stages of photosynthesis to occur. As to the relationship between CO2 and light in increasing photosynthesis, they are both limiting factors. Hence, increasing only light will increase photosynthesis up until a point, but after that, the rate of photosynthesis can no longer increase, as there is not enough CO2 to be used in the Calvin Cycle, and vice versa (Johnston, 1940). This suggests that the High Light, Elevated CO2 plant condition should have the highest growth.

Discussion

In this experiment, it was discovered that High Light and Elevated CO2 both increased the amount of growth of E.sativa (measured by leaf size and plant biomass). For both the leaf size and biomass, the High Light Elevated CO2 condition had the greatest growth, and the Low Light, Ambient CO2 had the least growth. For leaf size, the interaction between the variables of light and CO2 on the plants was significant, but it was not significant for the biomass measurements. Overall, these findings support our hypothesis. The increase in plant growth caused by higher light and CO2 quantities is most likely due to the increased amount of photosynthesis which can occur, which increases the amount of carbohydrates available to the plant to grow (Rozema, 1993). The High Light Elevated CO2 condition likely had more growth than any other condition because both light and CO2 are limiting factors in photosynthesis, so increasing one factor can only increase the rate of photosynthesis up until a certain level (Johnston, 1940). This explains why the High Light Ambient CO2 and Low Light Elevated CO2 conditions both had less growth than the High Light Elevated CO2 condition.

These results agree with findings from Rozema (1993) and Sharkey et. al (2006) that CO2 is a crucial factor in photosynthesis, and higher levels of CO2 will increase photosynthetic and growth rates. Aside from photosynthesis, the decrease in stomatal density of leaves of plants grown in elevated CO2 conditions means that their leaf size and biomass would be higher, as was found in this experiment (Rozema, 1993). CO2 is used in the Calvin Cycle to add a Carbon atom to a 5 Carbon molecule, to form Ribulose Bisphosphate (RuBP), which is a reaction catalyzed by Rubisco. This is the first stage of the Calvin Cycle, and without it, no carbohydrates could be made. These carbohydrates can then be used by the plant to increase the height, stem width and leaf size of the plant.

Akin to CO2’s role in the Calvin Cycle, light is equally necessary for the Light Dependent portion of photosynthesis, as light is needed to promote electrons to a higher energy level (Lopez and Barclay, 2017). These electrons are then moved across the membrane of the Stroma, which causes an electrochemical gradient of protons. These protons are then moved back across the membrane via ATP-synthase, which makes ATP. Furthermore, these excited electrons are also used to make NADPH+, which is needed for the Calvin Cycle. Hence, light also increases the amount of times the Calvin Cycle can occur, as well as carbon assimilation (Sharkey et. al, 2006). The increase in the rate of photosynthesis caused by an increase in light has also been shown to increase the growth rate of Mangrove plants (Lopez-Hoffman et. al, 2006), which supports the findings of this study.

The broad application of this investigation was to model some of the impacts of climate change on plants. These results, coupled with secondary research, suggest that increased light and CO2 will increase photosynthetic rate. Hence, the increased CO2 due to climate change will increase the amount of plant growth; potentially, plants could be crucial in excess absorbing CO2 and decreasing the effects of climate change. However, this increase in plant growth and leaf size could potentially decrease light available to plants which live in a rainforest. Hence, we can look at the Low Light, Elevated CO2 condition to model the effects of climate change. This condition is very similar to the Low Light, Ambient CO2 condition, which suggests that the increase in plant growth caused by CO2 may be counteracted by the Low Light levels, meaning plant growth would still be impeded by climate change. However, E.sativa is a small plant which doesn't naturally occur in rainforests (Hall, 2012). Perhaps, future studies could use a rainforest plant species to investigate the impact of decreased light and increased CO2 on plant growth. The fact that E.sativa growth increases with increased CO2 suggests as a food crop, it would not be severely impacted by climate change. This is an important finding for farmers and food producers looking to prepare for climate change.

Despite this, it is necessary to recognize that climate change could cause many more changes to the Earth's atmosphere, including increased temperatures and extreme weather patterns (Manuel, 1994). Thus, future experiments should investigation the impact of other facets, such as increased heat, on plant growth. Furthermore, it is still unclear how much increase in CO2 and decrease in light will occur with climate change (Manuel, 1994). The fact that the experiment only had two conditions for each variable means that the results do not encompass the different possibilities of CO2 and light changes caused by climate change. Moreover, to fully reveal the impacts of long term climate change on plants, it would be appropriate to do a long-term study (this study grew plants in their conditions for just five weeks).

Thus, in this experiment, it was concluded that CO2 and light both increase the growth of E.sativa plants. This effect was most likely caused by the increased capacity of the plants to undergo photosynthesis, which produced more starch and in turn allowed the plants to grow more. These findings are of great relevance to the future challenges which the environment will face due to climage change. It seems likely that the increase in CO2 caused directly by climate change, and the indirect decrease of light available to plants due to high growth, will counteract each other and keep plant growth fairly consistent with the rate at which it is currently at.

References

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11. Average leaf size (cm2)
12. High Light 0.00367572612251392 0.00411231221995556 0.00367572612251392 0.00411231221995556 Ambient CO2 Elevated CO2 0.15 0.17 Low Light 0.00280029000263058 0.00355744030902036 0.00280029000263058 0.00355744030902036 Ambient CO2 Elevated CO2 0.08 0.09