Plant growth rates in response to light and CO_2 concentrations

Introduction

Industrialisation and increased human activity have significantly spurred changes in the abiotic environment, particularly elevated CO_2 levels, which influences the photosynthetic pathway and thus alters vegetative yield in the agriculture industry (Vitousek et al. 1997; Ward & Strain 1999; White et al. 2015). It is therefore necessary to recognise the effects of atmospheric CO_2 levels on plant growth to understand the responses of plants to current atmospheric environments and predict future growth in elevated CO_2 levels, which is projected to increase by more than two-fold in the next 80 years (Long et al. 2004; Ward & Strain, 1999). However, prior studies suggest that although elevated CO_2 levels have differing effects on growth depending on the indicator of growth measured, increases in leaf area are generally observed with elevated CO_2 (Ainsworth et al. 2002; Kirschbaum 2011). This is due to elevated CO_2 increasing the source of carbon available to be fixed during photosynthesis, which promotes growth (Dennison 1987; White et al. 2015). As this study will focus on the leaf area as an indicator of growth rate due to its important role in agricultural yield, based on patterns found in prior research, it is expected that if the plant is grown in elevated CO_2 concentrations, then the growth rate will be higher than if the plant is grown in ambient CO_2 concentrations.

Despite the fact that elevated CO_2 levels are widely expected to boost growth, it is essential to study the continuing effect of CO_2 on growth rates at expected future concentrations and in coordination with other factors such as light intensity which this study aims to do (Ainsworth et al. 2002). Continued observation of the effects of CO_2 concentrations on plant health are also necessary to track and predict the negative impact of large-scale changes in environmental conditions caused by human activity on the natural biodiversity of ecosystems (Vitousek et al. 1997).

Light is another factor that influences the photosynthetic pathway of plants, either limiting or encouraging growth depending on its intensity (Dennison 1987; Fan et al. 2013). The relationship between light and plant growth is widely accepted, with higher light intensity associated with higher rates of growth through increased net photosynthesis; however, this increasing relationship has been found to plateau past a certain threshold (Fan et al. 2013). Therefore, it is expected that if plants are grown in high light, the growth rate of the plant will be higher than in low light, which is in line with prior research linking light and growth.

A greater understanding of the effects of light and CO_2 on plant growth will allow for optimal conditions to be applied to agricultural settings in order to increase crop yield, which is particularly important as future climates are expected to disadvantage ecosystems through changes in other environmental factors (Ainsworth. 2008; Long et al. 2004; Ward & Strain 1999). Further, it is necessary to understand the interactions between changing environmental factors such as CO_2 and light in order to mimic natural environments and more accurately predict growth outcomes, and thus this study is a 2×2 study which examines the mean leaf area of *Eruca sativa* plants treated in varying light and CO_2 conditions in order to investigate the interrelated effect of these conditions (Ward & Strain 1999).

Results

Plants grown in elevated CO_2, high light had a significantly greater mean leaf surface area (M=49.34) than those grown in ambient CO_2, high light (M=41.15, t=5.50, d.f. =198, $p=1.14 \times 10^{-7}$) (Figure 1). Additionally, significant differences were observed in plants grown in ambient CO_2 and varying light conditions, with those treated with low light (M=32.46) obtaining a lower mean leaf surface area than those treated with high light (M=41.15, t=6.35, d.f. =198, $p=1.48 \times 10^{-9}$) (Figure 2).

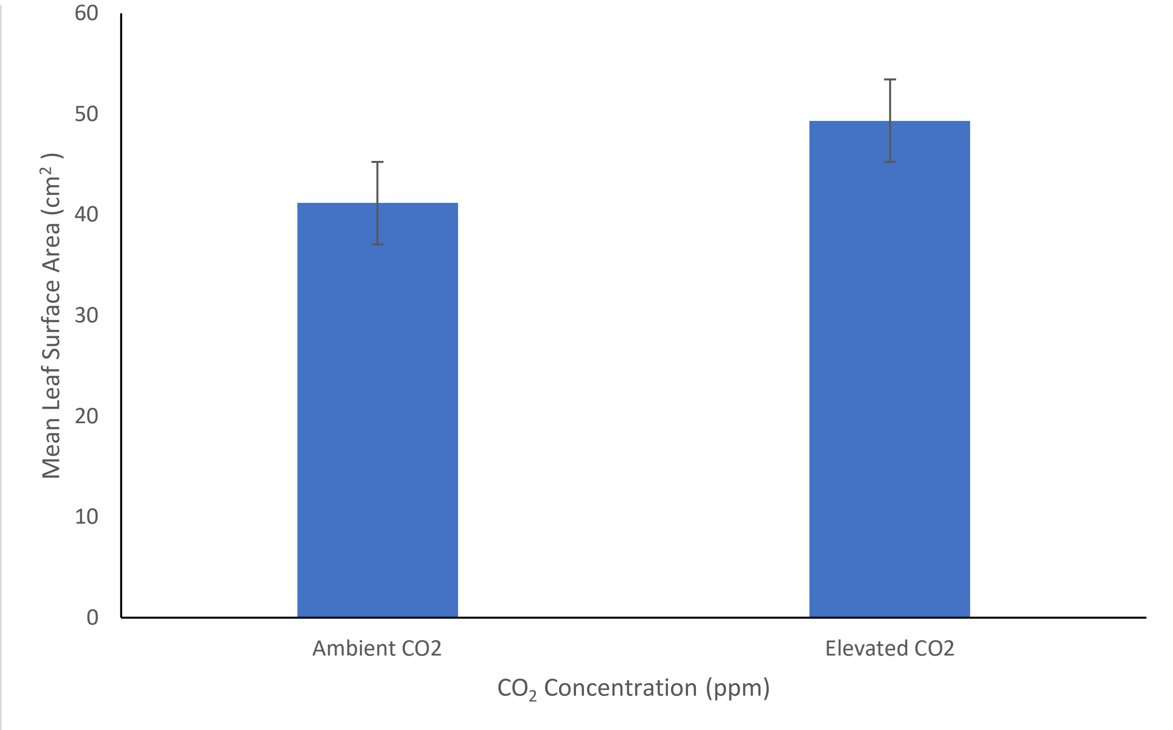

Figure 1. Mean leaf surface area of plants in cm^2 grown in high light (800μmol m^{-2} s^{-1}) and either ambient CO_2 concentration (400ppm; n=100) or elevated CO_2 concentration (1000ppm; n=100).

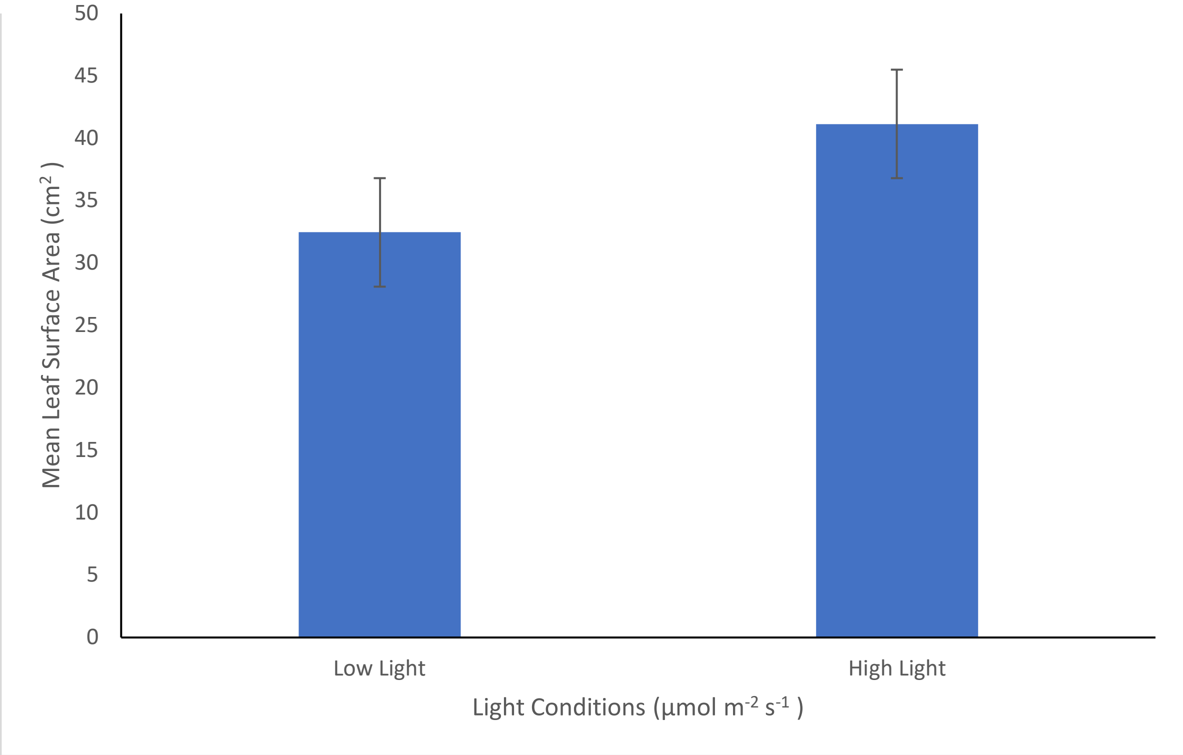

Figure 2. Mean leaf surface area of plants in cm_2 grown in ambient CO_2 concentration (400ppm) and either low light (200µmol m_{-2} s_{-1}; n=100) or high light (800µmol m_{-2} s_{-1}; n=100).

Discussion

The current study sought to examine the interrelated effects of both light and CO_2 on the growth rates of *E. sativa*. As predicted, the findings supported the hypothesis, with increasing CO_2 concentration resulting in significantly higher rates of growth than ambient levels. In terms of light intensity, the hypothesis was also supported, with trends suggesting significantly greater yield and growth in plants grown higher levels of light.

These suggested optimal CO_2 conditions align with previous studies that demonstrated higher crop yield and photosynthetic rate in soybeans treated in progressively higher CO_2 concentrations and in high light conditions (Ainsworth et al. 2002; Cure 1986). This is suggested to be attributed to increased CO_2 uptake combined with greater leaf areas, which increases the potential for greater photosynthetic capacity and thus increased growth rates (Ainsworth et al. 2002; Dennison 1987). Additionally, the behaviour of plants to balance nutrient and carbon acquisition means that beneficial CO_2 conditions allow internal changes that maximise CO_2 assimilation and thus potential for growth through source-sink relationships (White et al. 2015). The findings of this study therefore have significant implications on predicting future photosynthetic and growth responses of plants to expected increases in atmospheric CO_2 as well as increasing understanding of biological responses and processes (Long et al. 2004; Ward & Strain 1999). However, this study cannot predict responses to climate change as a whole as the effect of other environmental factors that are influenced by climate change and alter plant responses, such as temperature and tropospheric ozone concentrations, have not been examined in this study (Ainsworth 2008; Cure 1986).

The results, which show significantly higher leaf area observed in plants grown in ambient CO_2 and high light conditions compared to low light conditions, also support findings from Fan et al (2013) that demonstrate greater photosynthetic rates in young tomato plants grown in progressively higher light conditions up to a certain point (Fan et al. 2013). This is due to the changes in gas exchange which influences the development of photosynthetic structures (Fan et al. 2013). An integrated examination of the combined effects of light and CO_2 allows for optimisation of conditions in agricultural settings to promote crop yield and productivity (White et al. 2015).

A major limitation of this study is the restricted root growth brought on by the limited pot size the plants were permitted to grow in (Ainsworth et al. 2002; Long et al. 2004). Significant differences in growth were observed between plants grown in large pots compared to those grown in fields with unrestricted root growth, with restricted root growth suppressing the plants increased photosynthetic response (Ainsworth et al. 2002). Thus, the findings of this study cannot accurately reflect and predict growth in natural environments (Ainsworth et al. 2002). This is due to the shared influence of both leaf and root growth on co-limiting the overall growth rate of the plant (White et al. 2015).

Further, conclusions from the findings are unable to be drawn to sustain prior findings on the finer effects of progressive increases in light on plant growth, which suggest medium light produces greater yield than both high and low light conditions (Fan et al. 2013; Mohr 1962). The lower growth rates in high light conditions is suggested to be a result of lower rates of increase in photosynthetic capacity above a certain threshold as well as reduced stem growth from photomorphogenesis (Fan et al. 2013; Mohr 1962). However, studies suggest that photomorphogenesis results in greater leaf area (Kim et al. 2005). An extension of the current study to include more conditions which allow incremental increases in light irradiance will therefore be able to investigate the effects of light directly on leaf growth rather than plant growth and uncover a more accurate trend between light and growth as well as the most optimal condition, which is important for agricultural purposes.

Another limitation is the exclusion of process modifications and developmental stage as possible influencing factors on light and CO_2 responses. Alternative findings suggest that modifications in internal processes due to acclimation occur, influencing the effect of light and CO_2 levels on photosynthetic CO_2 assimilation with time, with the rates of photosynthesis reducing over time despite elevated concentrations of CO_2 (Cure 1986; Ward & Strain 1999; Yamori, Evans & Caemmerer 2010). Further, the stage of development that the plant is in, such as harvest or reproduction, effects the stimulation of CO_2 assimilation from elevated CO_2 levels due to internal changes in Rubisco content (Ainsworth et al. 2002; Long et al. 2004). Future studies could therefore investigate the effect of light and CO_2 over the lifetime of a plant to increase biological knowledge and predict changes in internal processes of existing plants to changing external environments, or involve developmental stages as a variable to observe differences in effect of elevated light or CO_2 conditions at different stages (Ainsworth et al. 2002).

Although the current study is limited in its ability to reflect the natural environment and thus predict accurate responses in plant growth, it plays an important role in understanding general responses to the changing environment in terms of crop yield and suggesting general optimal conditions in which to expose crops to. With our rapidly changing environment which is exposed to the possibly detrimental effects of human activity, it is essential that we continue to monitor our effect and examine optimal conditions in which to grow crops in order to sustain our growing population.

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