INTRODUCTION

A range of changes, such as increasing atmospheric temperatures, melting ice caps in the Northern Hemisphere and unsustainably changing air and soil moisture levels, is caused by worldwide climate change [IPCC 2013a]. The growth of plants and crops can be affected by changes in soil moisture. The increased \( \text{CO}_2 \) concentration in the atmosphere is among the factors that affect global warming and climate change and cause greenhouse effect; the increase in \( \text{CO}_2 \) concentration stems from refinery industry activity and vehicles emissions [Fathurrahman et al. 2016]. The increase in \( \text{CO}_2 \) started in the Industrial Revolution; it resulted from increased activity from energy derived from coal, gas and crude oil [Keay 2007; Wright, Boorse 2011]. The primary cause of climate change is the increase in \( \text{CO}_2 \) concentrations in the atmosphere, which can have a negative impact on plant growth or production. Recent research has shown that higher \( \text{CO}_2 \) levels in a controlled environment, like greenhouses, can increase yields for \( \text{C}_3 \) plants by 17–29% and \( \text{C}_4 \) plants by 6%–10% [Kimball 1983; Baker, Allen 1993]. In the case of a field where canopy size, structure and climatic conditions also affect water use, low \( \text{CO}_2 \) concentrations would not be enough to ensure that this area used less water [Meinzer et al. 1997].

The addition of \( \text{CO}_2 \) causes a negligible increase in growth and production in some experiments, i.e \( \text{C}_3 \) soybean (Glycine max), rice (Oryza sativa) and wheat (Triticum aestivum) under the free-air \( \text{CO}_2 \) enrichment system [Ainsworth, Long 2005]. In order to increase the growth of many
crops, it has been reported that the photosynthesis process has been improved with an increase in the concentration of CO₂ [Thongbai et al. 2010].

The Albizia saman is also referred to as a rain tree, given its canopy’s ease of draining water from the soil. Either by increasing atmospheric CO₂ or reducing carbon supplies, such as forests, human activities have a direct influence on the carbon cycle. A strategy like forest management or non-agriculture land protection that enables it to absorb CO₂ should be pursued in order to reduce greenhouse gas emissions, such as forest management and non-agricultural land protection that act as a net absorber of CO₂ as such, much CO₂ will be absorbed from the atmosphere and stored in plants, rather than being released. Investigations were carried out to understand its development and physiological correlation with the ambient CO₂ and elevated CO₂ condition. In this study, rain tree was planted with two models, namely, ambient CO₂ model and elevated CO₂ model in a greenhouse. Phenotypical morphological traits, such as leaf area and biomass of roots, were studied. The purpose of this research was also to study the physiological characteristics of rain tree by determining its photosynthesis, stomata conductance, internal CO₂, respiration and water use efficiency (WUE).

MATERIALS AND METHODS

Seedling preparation and growth measurement

Sixty 1-week old rain tree seedlings were grown in polybags (25 cm × 30 cm) with a growth medium of topsoil podzolic type mixed with organic fertiliser at a ratio of 4:1. The NPK fertiliser (15:15:15) was applied at a low dose of 5 g/polybag/month, and the seedlings were sufficiently watered. In the automated CO₂ greenhouse system, thirty seedlings were exposed to an increased level of 800 μmol mol⁻¹. These seedlings have been exposed daily for two hours from 9:00 am to 11:00 am o’clock, when photosynthesis is expected to be optimum in a controlled trial. Outside the glasshouse with ambient CO₂ concentrations of 400 mol mol⁻¹, similar number of seedlings aged between 1 and 2 years were exposed. After 14 days of treatment, the plants were first observed and weekly observations were made for 16 weeks. The plant growth parameters that were measured and counted included leaf area and root biomass. Leaf area was measured by collecting the fresh leaves of A. saman. These leaves were subjected to the principal sample maintainability of CO₂ (800 ppm) and principal escort CO₂ (400 ppm). A total of 30 leaves were obtained at random from each treatment. Leaf sampling was done on the basis of leaf age. The number of whole leaves was 630 strands, whereas that of the sample treatment and control was 630. The leaf area was observed for seven times and used as a data retrieval end. Image-J software was used for digital image processing by investigators at the Research Services Branch, National Institute of Mental Health, Bethesda, Maryland, USA. Image-J is extensively used in digital image analysis in the field of health and biology. ImageJ has been also used for a variety of specific purposes, such as measuring the leaf area and height of a subject in agricultural studies.

Photosynthesis, stomata conductance, internal CO₂, respiration and WUE were analysed using Licor 6400 XT. For each data, a statistical analysis using SAS version 9.1 and min separation has been carried out in order to test the different parameters with T-Test at p < 0.05.

RESULTS AND DISCUSSION

Effects of increase in carbon dioxide concentration to leaf area

The increased carbon dioxide concentrations had a positive effect on leaf area as shown in Figure 1. The leaf of the treated samples (800 ppm) was 13.94% higher than that of the control samples (400 ppm). Thus, high CO₂ concentrations result in a large leaf area at 2, 4, 6, 8, 10, 12 and 14 weeks after treatment.

The tree reaction to the outside CO₂ can be controlled by a steady increase of carbon dioxide concentration from the environment [Farquhar, Caemmerer, 1982; Franks 2013]. Refund of excess nitrogen in the Rubisco enzyme can improve the efficiency of N use at high CO₂ concentrations [Parry et al. 2003; Ainsworth, Rogers 2007]. The increase in N content can affect plant photosynthesis through chlorophyll content and photosynthetic enzymes. As the N content of leaves increases, photosynthates will rise, and vice versa. The increase in N compounds increase the green colour of the leaves and promote stem and leaf
growth [Fathurrahman et al. 2015]. N plays a role in protein and enzyme synthesis. Rubisco acts as a catalyst in setting the CO$_2$ needed for photosynthesis [Schaffer et al. 1999].

Global warming and climate change are mainly caused by an increase in concentrations of CO$_2$ in the atmosphere. This increase could inhibit or stimulate growth and tree production. CO$_2$ concentration increases in a controlled environment, such as in the greenhouse, and increases the yield of C3 and C4 plants by 17–29% and 6–10%, respectively [(Kimball 1983; Baker, Allen 1993]. The rapid growth of $A. saman$ can have a positive effect on the environment, as it can reduce the temperature by 3–4 °C [Dahlan 2013]. In addition to micro temperature changes, it also has positive effects on microorganisms, which produce biomass. $A. saman$ produces humus through decomposition and is used as media for the growth of soil microorganisms [Staples, Elevitch 2006]. Microorganisms in the soil have a good ability to absorb CO$_2$ and other harmful gases in the air. The tree is also reported to have a high ability to grow on barren land and poor soil. Through the symbiosis with rhizobium bacteria that play a role in absorbing nitrogen, $A. saman$ can help bind N from the air and supply plants with nutrients.

**Ratio of canopy and root on wet and dry samples**

The data on the ratio of canopy and roots on wet and dry samples are shown in Figure 2. The ratio of the canopy and root in the wet sample of $A. saman$ control sample (400 ppm of CO$_2$) was 9.06. The canopy and root ratio on the dried control sample (400 ppm of CO$_2$) was 9.7. The proportion of the canopy and root on wet and dry samples was significant (p<0.05). The ratio of the canopy and root samples of in the wet treatment (800 ppm of CO$_2$) was 10:12. The ratio of the canopy and root dry sample treatment (800 ppm of CO$_2$) was 16:06, and the proportion of the canopy and root on wet and dry samples was significant (p <0.05). The ratio of the canopy and root wet and dry samples in the treatment (800 ppm of CO$_2$) is higher than the ratio of the canopy and root wet and dry samples in the control sample (400 ppm of CO$_2$).

The low root biomass from the canopy in the control and sample may be due to good root development that affects the root and canopy growth. Suitable root growth and nutrient absorption positively affect $A. saman$ nutrition and stimulate the fast growth and development of the canopy. Bolinder et al. [2002] showed that the ratio of the canopy and roots can be affected by environmental and climatic conditions. Plants generally

![Figure 1. Leaf area index (cm$^2$) $A. saman$ control (400 ppm) and treatment (800 ppm). The lowercase a and b are significant (t-test p <0.05)](image)

![Figure 2. Ratio of canopy and root samples of wet and dry $A. saman$ sample of the control (400 ppm of CO$_2$) and (800 ppm of CO$_2$). Lower case a and b indicate significance level (t-test, p <0.05)](image)
store more food reserves in the trunk than in the roots. But in some plants, however, it is unlikely that an increase of CO₂ will have a significant effect on plant biomass, such as *Quercus acutissima* and *Rynchophylla fraxinus*; instead, it can even decrease specific leaf area [Cha et al. 2017]. Other studies showed that elevated CO₂ concentration stimulates photosynthesis, increases plant production and increases the amount of carbon stored in the canopy and roots [Reverchon, 2012].

The increase of CO₂ in plants, such as *Pubescentia betula*, *Fraxinus excelsior* and *Platanoides acer*, results in low nitrogen levels in the tissues, resulting in the increase in leaf structural and non-structural carbon [Cotrufo et al. 1994]. Changes in plant tissues affect decomposition and mineral formation [Cornwell et al. 2008] by changing the parameters of quality compost, such as C/N ratio and lignin/N ratio [Taylor et al. 1989]. Changes in plant growth responses due to higher concentration of CO₂ depend on the variety’s growth or ability to grow, as well as the development strategy of the species, such as the creation of sink current for additional carbon [Reich et al. 2014; Lopes et al. 2015]. In the long term, the growth of trees under high CO₂ conditions can help improve nitrogen content, carbohydrate transport and canopy or root alteration. However, whether the mechanism of the relationship between roots and canopy grown under low CO₂ conditions can optimise coordination and stimulate root growth after long-term exposure to high CO₂ remains unknown.

**Photosynthesis rate**

Photosynthetically active radiation flux density was in accordance with the method of Haniff [2006] and 1000 umol was used to measure the rate of photosynthesis in the leaves. The photosynthesis rates were analysed six times. Increasing CO₂ concentration led to different results for all ages between treatment (800 ppm of CO₂) and control (400 ppm CO₂) as shown in Figure 3. The average reading initial observations of the leaf photosynthetic rate for 15 days was 3.03 and 1.77 µM CO₂ m⁻²s⁻¹ for the treatment and control, respectively. The increased photosynthesis rate is in line with the ageing of the leaves on either treatment or control samples. The maximum reading value increase was obtained in the 45-day-old leaves with a reading of 9.78–6.30 µM CO₂ m⁻²s⁻¹. The highest rate of leaf photosynthesis was obtained in the 45-day-old leaves because of the physiology, quality and quantity of the cells that are directly related to the maximum photosynthetic activity. The reading decreased with increasing leaf age (60, 75 and 90 days). The leaf photosynthesis reading was higher at 90 days than at 15 days. Thus, the photosynthesis rate is expected to be a special feature of *A. saman* tree.

Photosynthetically active radiation flux density, such as 1000 umol, was used to measure the rate of photosynthesis in the leaves. The photosynthesis rates were analysed for six times, and increasing CO₂ concentration was different between treatment (800 ppm of CO₂) and control (400 ppm of CO₂) for all ages as shown in Figure 3. The average reading initial observations of leaf photosynthetic rate in 15 days was 3.03 and 1.77 µM CO₂ m⁻²s⁻¹ for treatment and control, respectively. The rates of photosynthesis increased with the ageing of the leaves on the control (400 ppm of CO₂) and treatment (800 ppm of CO₂). The photosynthesis rate decreased after the optimum

![Figure 3](image-url)  
*Figure 3. Relative effect on the rate of photosynthesis of A. saman control samples (400 ppm of CO₂) and treated samples (800 ppm of CO₂). Lower case a and b on the same day indicate significance level (t-test p <0.05)*
level with continuous increase in tree age. Photosynthetic activity may vary between plant species. However, the accumulation of carbon in plants, such as lettuce and spinach, does not increase at high CO$_2$ concentrations.

High CO$_2$ concentrations have adverse effects on the nutritional quality of vegetables (e.g. nitrogen, phosphorus, potassium, sulphur, magnesium, copper and zinc in lettuce) that are lower compared with ambient CO$_2$ [Giri, Rajasheka 2016]. Biomass and yield are expected to be increased due to higher levels of CO$_2$ [Prior et al. 2011; Azam et al. 2013], as it increases the photosynthetic rate in plants [Ainsworth, Long, 2005]. However, an increase in photosynthetic activity occurs within a short period and is not maintained under CO2 exposure. Plants have adapted to high levels of CO$_2$ and are less exposed to ambient concentrations. Being subjected to elevated CO2 for a long time leads to the accumulation of starch grains in the chloroplast thylakoid, leading to changes in the plant. A high rate of photosynthesis in plants grown under elevated CO2 conditions is accompanied by an increase in the number of mitochondria to meet the cellular energy demand [Sharma, Bhatnagar 2014].

Increased CO$_2$ concentrations can significantly increase the cross sectional area of the mesophyll in leaves to increase photosynthesis [Pritchard et al. 1999]. In trees species, a marked increase of the thickness of fence parenchyma has been observed, such as birch and aspen, which grow and thrive in environments with high CO$_2$ concentrations [Wustman et al. 2001].

The results of other studies on C4 plants showed that their growth is impaired by elevated CO$_2$ levels, which may lead to changes in Rubisco enzyme, thereby interfering with photosynthesis efficiency. Mesophyll, which is a surface-active photosynthesis layer, is the most affected by high CO$_2$ concentrations. However, the magnitude of the reaction may vary depending on the species of plants; several reasons for these phenomenon, including the factors involved, have been put forward by scientists [Sharma, Bhatnagar 2014].

**Stomatal conductance**

Increasing CO$_2$ concentration varies at all leaf ages in the control (400 ppm of CO$_2$) and treatment (800 ppm of CO$_2$) as shown in Figure 4. The average readings of the stomatal conductance of leaves aged 15 days during the initial observation were 68.21 and 90.25 mM m$^{-2}$s$^{-1}$, respectively, for the control and treatment groups.

The increase in stomatal conductance is in line with the ageing of the leaves in the treatment and control samples. The maximum stomatal conductance value was on day 60 with a reading of 244.55 mM m$^{-2}$s$^{-1}$ in the treatment sample and 207.60 mM CO$_2$ m$^{-2}$s$^{-1}$ in the control sample. The maximum stomatal conductance reading was recorded on leaves aged 60 days. The stomatal conductance reading decreased at 75 and 90 days of observation. The decline in stomatal conductance between the two samples was the same.

The increase in stomatal conductance is directly proportional to the increase in the age of leaves on the treatment (800 ppm of CO$_2$) and control sample (400 ppm of CO$_2$). The control and patterns at the point of maximum image contrast with the pattern of photosynthesis rates. Monda et al. (2016) found that CO$_2$ enrichment increases stomatal activities. However, few studies have

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**Figure 4.** Effect of stomatal conductance on the control (400 ppm of CO$_2$) and treatment (800 ppm of CO$_2$). Lowercase a and b on the same day indicate significance levels (t-test, p<0.05)
reported the reduction in stomatal density [Lin et al. 2001; Teng et al. 2009] and stomatal conductance [Medlyn et al. 2001; Gao et al. 2015] when the CO₂ concentration is increased.

Increasing the size of the stomata can change the ability and structure of the stomata. Because of the low ratio between the surface area and the amount needed for solute transport to move CO₂ and O₂, the large stomata will open or close more slowly than the smaller ones. [Hetherington, Woodward 2003; Drake et al. 2013].

The size of the stomata in many Leguminosae species (e.g. *Canavalia ensiformis* or broad beans and *Arabidopsis thaliana*) is often not effective in achieving a significant change due to the slow solute transport. The movement of the solute is slow due to the low ratio of the membrane surface area and the amount of solute [Lawson, Blatt, 2014]. This type of cell stomata is large, and the cell wall thickness increases the size of the cell [John et al. 2013]. If the stomata’s large cell walls are thick, the opening of stomatal aperture was smaller under the same turgor pressure.

**Internal CO₂ content**

The increasing internal CO₂ concentration between the treatment (800 ppm of CO₂) and the control (400 ppm of CO₂) varies in terms of leaf age (Figure 5). The reading of the sample treatment for all observations is lower. The average initial observations of the internal CO₂ content of leaves aged 15 days are 253 and 310 ppm. The internal CO₂ content increased with increasing leaf age in the treatment and control. The maximum reading value showed increased internal CO₂ content in leaves older 45 days (404 and 479 ppm).

The reading decreased at 60, 75 and 90 days. The increase in the internal CO₂ content was amended in accordance with the age of the leaf. The readings between the maximum internal CO₂ content between the treatment and control differed. The reduction of the internal CO₂ in leaf shall be reduced due to its use as an essential ingredient for photosynthesis. Concentrations of CO₂ in rice plants with Trichoderma spp. significantly decreases and the treatment shows higher growth than the control sample. Stomata are complex. Their opening and closing depend on light intensity and internal CO₂ concentration in the leaves [Ainsworth, Rogers 2007]. The time of maximal plant development when vegetation absorbed the most carbon dioxide, but this was already noticeable [Czubaszek 2019]. Plant growth was not only influenced by climatic factors, including CO₂ concentrations. Mutagens can also have an effect because there are changes in genotypic characteristics in plants early in the formation of vegetation [Fathurrahman 2023].

**Transpiration rate**

The increase in the rate of transpiration in CO₂ concentrations in the sample (800 ppm of CO₂) and control (400 ppm of CO₂) was different unless the leaf age was 30 days (Figure 6). The average initial reading of leaf transpiration rate at 15 days was 0.37 and 0.1 mM H₂O m⁻² s⁻¹.

The further decline in the rate of transpiration occurred after 30 days in the treatment and control, and this reading is the minimum age compared with other leaves. Transpiration rate began

![Graph](image)

**Figure 5.** Effects of internal CO₂ concentration on the control (400 ppm of CO₂) and treatment (800 ppm of CO₂) based on the age of the leaf. Lowercase a and b on the same day indicate significant levels (t-test p <0.05)
to increase on days 45, 60, 75 and 90 for the two samples of leaves. The highest transpiration rate was 1.66 and 3.36 mM H$_2$O m$^{-2}$ s$^{-1}$, and the reading was expected to increase with increasing leaf age. The high transpiration reading showed that water evaporation was high and water wastage occurred. Growth of cells is the reason for increased and reduced transpiration rates in leaves. If the reading is high, the transpiration process of catabolism in leaf mesophyll cells increases the amount of water used in the plant. The increased concentration of CO$_2$ is having a negative impact on the growth and development of *A. thaliana*, decreasing its transpiration rate.

Given that high CO$_2$ concentrations can reduce transpiration, the situation may be beneficial in mitigating the effects of drought, and photosynthesis may continue. The transpiration rate discouraged the partial closure of the leaf stomata guard cells. Dugas et al. [1997] found that stem flow gauge use on the blade reduces the whole plant’s transpiration when the CO$_2$ concentration increases for soybean crop C3 (and C4 millet). The decrease in transpiration, coupled with the increase in photosynthesis, can improve WUE [Baker et al. 1990a].

**WUE**

The analysis of WUE suggests that increased CO2 concentration varies between the treatment sample (800 ppm) and the control sample (400 ppm) (Fig. 7). After initial observation, the average readings of the WUE of leaf samples aged 15 days were 8.02 and 1.72 mol/mmol respectively. Further increase in WUE occurred on leaves aged 30 days, in which the reading of the treatment sample CO2 was 35.96 mol/mmol compared
with the CO$_2$ reading of 8.04 mol/mmol in the control sample. Reading on the 30-day-old leaves is the highest. The WUE in the treatment after 45 days is more likely to decrease than in the control. The decline slowed down in the sample treatment from day 60 to day 90. In the sample CO$_2$ treatment, WUE decreased relatively slowly from 30 days to 90 days.

WUE in growing plants should be considered to prevent growth disorders. The WUE of treatment (800 ppm of CO$_2$) and control (400 ppm of CO2) varied. WUE increases at elevated CO$_2$ [Wu et al. 2004]. Various experiments have demonstrated through C3 species that increased CO$_2$ increased the rate of photosynthesis, plant growth and WUE [Pleijel et al. 2000; Loladze 2002]. The study of Wu et al. [2004] showed that higher CO$_2$ contributes to plant growth, yields and WUE whereas grain quality has decreased with high CO$_2$, as shown by an increase in the crude starch content along with nutrient reduction and a decrease in lysine and protein concentrations. The WUE was increased by elevated CO$_2$ in the study with a view to increasing plant growth and reducing water consumption. This phenomenon will be beneficial in case of a long-term need for food production, especially in areas with limited water supply.

CO$_2$ results in increased root length and surface area. Water intake in the root becomes easy. High CO$_2$ levels in bentgrass increases leaf photosynthesis and stomatal conductance but reduces the rate of transpiration, contributing to the efficient use of water. Efficient use of water is especially important for the survival of plants, such as turfgrass and rice, when irrigation is limited [Burgess, Huang 2014; Doni et al. 2014].

CONCLUSION

Increasing CO$_2$ in the treatment sample changed the plant’s leaf area index. The ratio of root wet and dry samples within the treatment sample was higher than in control, as far as canopy profile is concerned. On dry samples, the ratio of canopy to roots was greater than it was on dried specimens. Compared to the control, the ratio of the canopy and root samples treated with CO$_2$ was higher. Increased CO$_2$ concentrations affected the physiology of A. saman and increased the flow rate of photosynthesis and stomatal conductance in the treatment sample compared with the control. WUE of treated samples, which had low levels of CO$_2$ in the leaves and underwent low respiratory treatments, was higher than in the control plants.

Acknowledgements

This research was funded by Universitas Islam Riau.

REFERENCES


