Chapter 5

Photosynthetic Light Response at Different Light Levels in *Curcuma alismatifolia Gagnep.*

5.1 Introduction

Photosynthesis in plants is composed of interconnected biological processes. Biophysical processes, which include CO_2 transport through the leaf and stomata, and biochemical processes locate in the chloroplast thylakoid membranes, stroma, mitochondria and the cytosol of the cell, determine the net rate of CO_2 assimilation (Thomas *et al.,* 2007). The major chemical pathway in photosynthesis is the conversion of carbon dioxide and water to carbohydrates and oxygen. As the same suggests, photosynthesis is a process by which light is converted to chemical energy and is used to synthesize compounds within the organism. The green pigment chlorophyll is the central light-absorbing pigment that makes this energy capture possible. Chlorophyll, along with various other accessory pigments, is located in chloroplasts within the cells of the green portions of a plant (Raven *et al.,* 2005).

In general, the photosynthetic and transpiration response to light and temperature have been studied in single factor experiments (Nobel, 1991). The curve of photosynthetic response to light is well known in its biologically meaningful parameters, such as maximum rate of net photosynthesis and photon flux compensation point, when the temperature is optimal for species but not in different

sub-critical temperatures (Neri *et al.,* 2003). Conversely, there is a well described photosynthetic response to temperature at optimal light levels, with net photosynthesis becoming positive starting from a minimum temperature, then reaching the maximum at about 28 ^{o}C and decreasing at different low light levels (Neri *et al.,* 2003).

C. alismatifolia is herbaceous perennial with short fleshy rhizome and storage roots or tuberous roots (Burch *et al.,* 1987). The rhizome is a major source of water and carbohydrates (Wannagrairoj, 1997). *C. alismatifolia* has developed swollen roots to store water and reserve food for plant growth (Phongpreecha, 1997). Therefore, the knowledge of factors affecting these mechanisms would be useful for the efficiency of photosynthesis of this plant, that control shoot emergence, vegetative growth and flowering in order to guarantee a good quality of storage organs.

There is little information on the photosynthesis rates in this plant species. Among environmental parameters, light is one of the limiting factors that affects growth and morphogenetic mechanism of plants. Light quality has been shown to play an important role in morphogenesis and photosynthesis (Kim *et al.,* 2003). Additionally, the optimum light levels for producing flower in *Curcuma* have not yet been determined (Paz, 2003).

The purpose of this experiment was to establish photosynthetic light response curve for *C. alismatifolia* under different light intensity levels.

5.2 Materials and methods

5.2.1 Plant materials

The experiment was carried out by planting rhizomes of *Curcuma alismatifolia* cv. Chiang Mai Pink, having an average diameter of 2.0 cm with 4-5 storage roots, in

plastic bags (containing sand: rice husk: rice hull: soil at the ratio of 1:1:1:1 by volume; Fig. 5.1). The pots were watered daily. After the shoots emerged having the 3rd fully expanded leaf (about 9 weeks after planting: WAP), leaf photosynthetic capacity of *C. alismatifolia* Gagnep. was examined at Lampang Agricultural Research and Training Center, Rajamangala University of Technology Lanna, Thailand.

The study of photosynthetic light response of *C. alismatifolia* was divided into two experiments;

Experiment 5.1: Photosynthetic rate response to light intensity in field condition.

Measurements of leaf gas exchange were taken in the field, when sun-exposed on a clear day at 0-2000 $\mu molm^{-2}s^{-1}$PPFD, with average temperatures from 26.6 to 34.7°C, %RH 32.1 to 75.9 and CO_2 concentration was set constant at 350 $\mu molCO_2mol^{-1}$ under natural light during 08.00 am to 02.00 pm. The light intensity, CO_2 response and the quantum yield were obtained with the gas exchange measurement system (LCA4-ADC, UK) (Fig. 5.2 b). A portable photosynthetic meter was used to measure the difference between incoming and outgoing CO_2 in leaf chamber, containing a part, sized 6.25 cm^2, of the illuminated leaf. This value was assumed to depend on the photosynthetic process (CO_2 uptake) and respiration process (CO_2 release) and to be shortly called "assimilation" (net assimilation, ADC software). The experiment was conducted during April 2009.

Experiment 5.2: Photosynthetic rate response to light intensity under controlled condition in laboratory.

Measurements of leaf gas exchange were recorded, net assimilation rate of CO_2 or photosynthetic rate (*Pn*) and photosynthetically active radiation (*PAR*) of leaf were measured by ADC LCpro+ (ADC BioScientific Ltd., Great Amwell, Herforshire

England) in laboratory under controlled condition, inside the leaf chamber, the carbon dioxide concentration was set constant at 350 µmolCO_2 mol^{-1} air, leaf temperature at 25 ^{o}C and RH at 70-80 %. The net photosynthesis rate was measured under photosynthetic photon flux 10, 50, 300, 500, 700, 900, 1000, 1200, 1700 and 2000 µmol$m^{-2}s^{-1}$PPFD by light box within leaf chamber during mid-morning at 10.00 am to 12.00 pm (Fig. 5.2 a). The experiment was conducted during May 2010.

Figure 5.1 *Curcuma alismatifolia* Gagnep. at 3 rd fully expanded leaf.

Figure 5.2 Measurement of photosynthetic efficiency using leaf chamber analyzer Model LCpro^{+}, ADC BioScientific Ltd., Great Amwell, Herforshire England (a) and LCA4, ADC, Hoddessdon, Herts, England (b).

5.2.2 Data collection

The collected data was the photosynthetic efficiency and the process of collecting was similar to that had been previously described in Chapter 4.

5.3 Results

Experiment 5.1 Photosynthetic rate response to light intensity in the field condition.

Photosynthetic rate (*Pn*) and stomatal resistance (*Rs*)

The photosynthetic rate (*Pn*) and stomatal resistance (*Rs*) of *C. alismatifolia* were shown in Figure 5.3. The result suggested that the photosynthetic rate was at the highest when light intensity (PPFD) increased in range from 400 to 500 $\mu molm^{-2}s^{-1}$PPFD in the morning time and then it decreased when the light intensity was over than 600 $\mu molm^{-2}s^{-1}$PPFD. The maximum value of *Pn* was about 7 – 8 $\mu molCO_2m^{-2}s^{-1}$.

The stomatal resistance continuously decreased when the light intensity increased from 200 to 500 $\mu molm^{-2}s^{-1}$PPFD (Fig. 5.3). Then, it was constant as the light intensity was ranged about 500 - 800 $\mu molm^{-2}s^{-1}$PPFD and slightly increased thereafter.

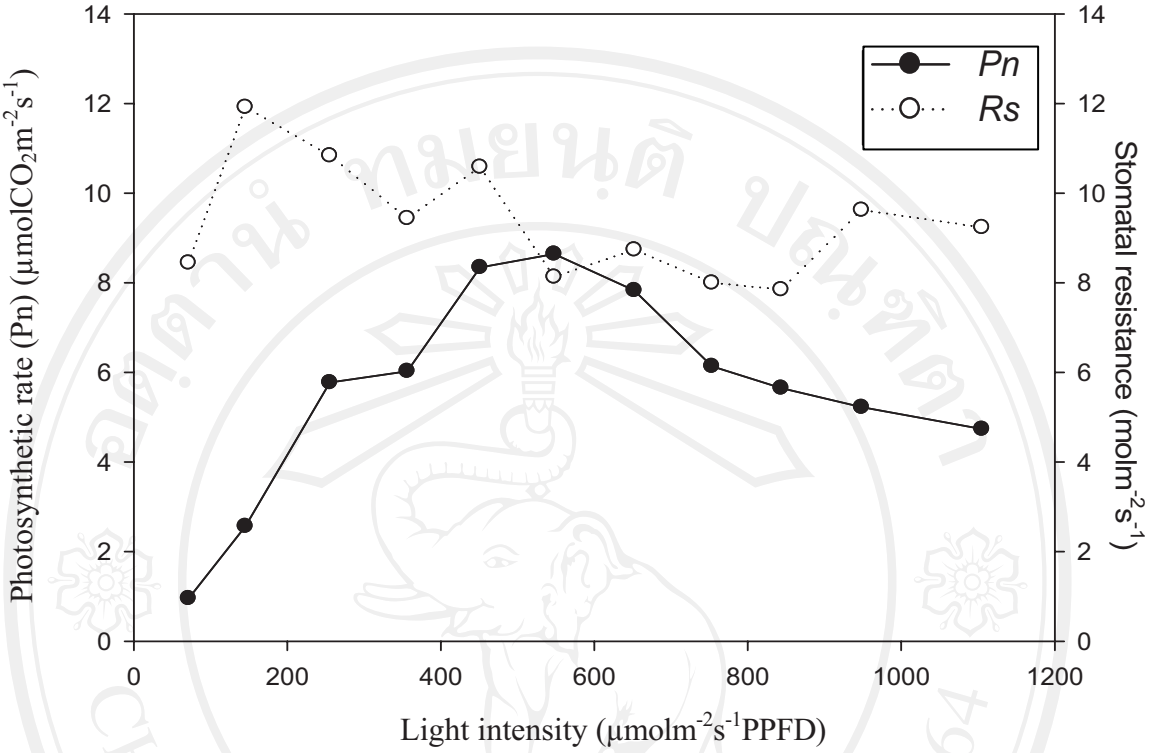

Figure 5.3 Photosynthetic rate (*Pn*) and stomatal resistance (*Rs*) of *C. alismatifolia* Gagnep. as determined in the field condition over a range of light intensity.

Experiment 5.2 Photosynthetic rate response to light intensity in laboratory under controlled condition.

The photosynthetic rate of *C. alismatifolia* leaves was measured under different photosynthetic photon flux densities ranging from 0 - 2000 µmolm^{-2}s^{-1} PPFD. The result showed that increasing light intensity from 10 - 200 µmolm^{-2}s^{-1} PPFD rapidly increased the photosynthetic rate (Fig 5.4). Then, *Pn* gradually increased a long with the increasing of photosynthetically active radiation (*PAR*) values up to 2000 µmolm^{-2}s^{-1}PPFD.

Figure 5.4 showed that the *Pn* reached the maximum of 3.26 - 3.60 µmolCO_2m^{-2}s^{-1} during 600 to 1000 µmolm^{-2}s^{-1}PPFD, equivalent to 30 – 50 % of full sunlight. Consequently, high light intensities over 1000 µmol m^{-2}s^{-1} PPFD seemed to have little effect on the increase of *Pn*.

The dark respiration, the *Pn* value will be minus, but when light intensity increased in it was value, *Pn* gradually increased the value to 0, which was so-called the light compensation point. The light compensation point for *C. alismatifolia* had average values between 2 to 44 µmolm^{-2}s^{-1}PPFD. The apparent photosynthetic rate was shown to be in a range of -0.62 to 1.48 µmolCO_2m^{-2}s^{-1}. A plot of measured values in Figure 5.4, indicated the relationship that y = 0.6799Ln(x) - 1.0925 with the R^2 = 0.8298.

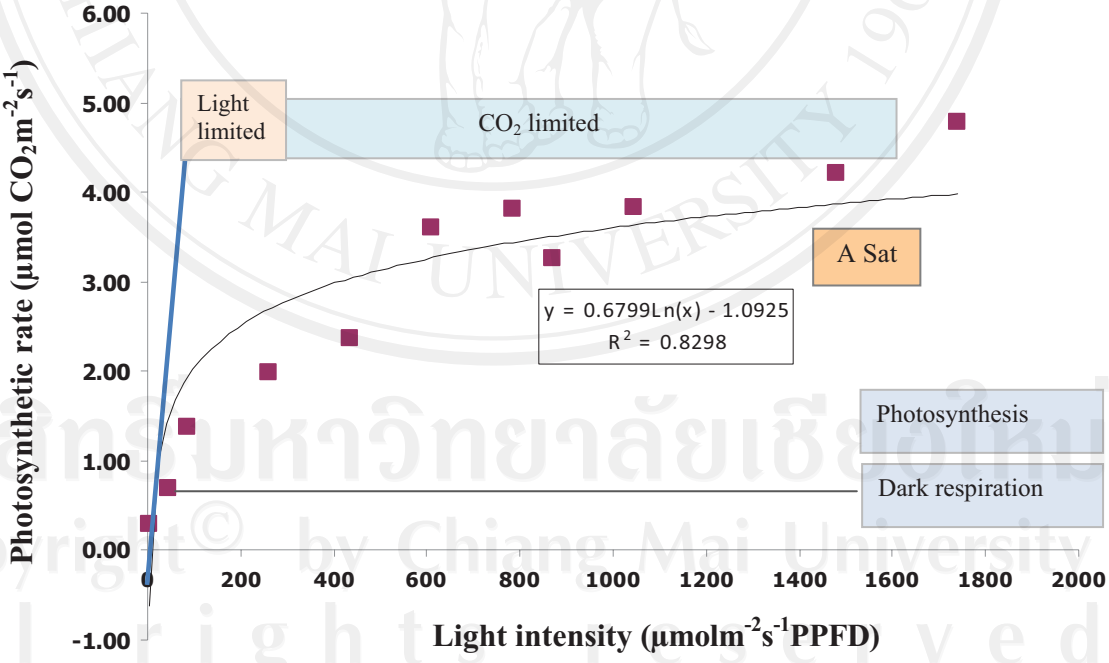

Figure 5.4 Light response function of *C. alismatifolia* Gagnep., net photosynthesis as a function of photosynthetic proton flux (µmolm^{-2}s^{-1}PPFD) as determined in the laboratory.

5.4 Discussion

Experiment 5.1 Photosynthetic rate response to light intensity in field condition

Photosynthetic rates of *C. alismatifolia* Gagnep. increased with increasing of PPFD up to 500 $\mu molm^{-2}s^{-1}$. The peak of photosynthetic rate was maximum at the values about 7 - 8 $\mu molCO_2m^{-2}s^{-1}$ in the range of light intensity values of 400 - 500 $\mu molm^{-2}s^{-1}$PPFD and stomatal resistance values of about 8- 10 $mmolm^{-2}s^{-1}$.

The high PPFD radiation occurred in the afternoon which was in the range above 600 $\mu molm^{-2}s^{-1}$, as shown in Figure 5.3. According to the data in Chapter 4, the temperature in the afternoon was higher than that in the morning. Therefore, the decrease of *Pn* in the afternoon might have been due to the too high temperature caused by the high light intensity, and that brought about by the change of stomatal resistance. High PPFD was probably the cause of high leaf temperature, the threshold of 35 ^oC seemed to lead to partial closure of stomata (Yingjajaval *et al.,* 2005).

Experiment 5.2 Photosynthetic rate response to light intensity under controlled condition in laboratory.

The photosynthetic light response and the movement of stomata of a particular plant is influenced by many factors, i.e. PPFD, leaf temperature, leaf-air VPD, leaf intercellular CO_2 concentrations and leaf water potential (Yingjajaval *et al.,* 2005; Hall *et al.,* 1993). The curve of photosynthetic response to light is well known in its biologically meaningful parameters, i.e. maximum rate of net photosynthesis and photon flux compensation point, when the temperature is optimal for species (Neri *et al.,* 2003). Due in part to the fact that *C. alismatifolia* is a mono cotyledonous

perennial, a member of ginger family (Zingiberaceae) (Khuankaew *et al.,* 2010; Wichailak, 2006; Hagiladi *et al.,* 1997). It is very responsive to environmental conditions. Changes in its surroundings, such as fluctuations in day length, light intensity, temperature, humidity, and soil moisture, may result in allocation of energy (photosynthate) to sink (Neri *et al.,* 2003).

Light intensity caused a pronounced effect on the rate of net photosynthesis as a function of PPFD (Fig. 5.4). *Curcuma* had maximum *Pn* value at 3.60 μmolCO_2 $m^{-2}s^{-1}$ with saturation at 1000 μmol$m^{-2}s^{-1}$ PPFD, but as shade increased net photosynthesis decreased. Therefore, high light intensities might cause photoinhibition reducing photosynthetic rate (Bolhàr-Nordenkampf and Öquist 1993). As *PAR* values increased from 10 to 1000 μmol$m^{-2}s^{-1}$PPFD, the *Pn* values also increased from -0.32 to 3.60 μmol$CO_2m^{-2}s^{-1}$ its maximum of 3.60 μmol$CO_2m^{-2}s^{-1}$. In addition, the observed maximum *Pn* values of *C. alismatifolia* were slightly increased. These maximum values of *Pn* for plant could result from a higher Rubisco amount and therefore, a higher *Pn* activity (Reich *et al.* 1995).

The minimum value of light compensation point for *Curcuma* was in the range of 2 - 44 μmol$m^{-2}s^{-1}$PPFD. The apparent photosynthetic rates showed being -0.62 to 1.48 μmol$CO_2m^{-2}s^{-1}$. In *Curcuma*, increasing the light intensity from 10 to 200 μmol$m^{-2}s^{-1}$PPFD prompted rapidly higher in the photosynthetic rate, in which under low-light levels, the rate of photosynthesis increased as the irradiance level was raised, so-called the light-dependent reaction. Thereafter, *Pn* increased slowly depending on the increase in PPFD values up to 2,000 μmol$m^{-2}s^{-1}$ PPFD, which suggested that the *Pn* did not response with the increasing light intensity, but it

responded with CO_2 concentrations, and it was said to be the 'CO_2 controlled or light-independent reaction'(Hall *et al.,* 1993).

5.5 Conclusion

The light response was measured at mature leaves stage. Photosynthetic rates of *C. alismatifolia* were increased when PPFD levels were intensified, which the optimum light saturated values were approximately 600 - 1000 $\mu molm^{-2}s^{-1}$. Photosynthetic rates at saturating light intensities ranging from about 3.26 to 3.60 $\mu molCO_2m^{-2}s^{-1}$ in this experiment. The minimum values of light compensation point for *Curcuma* were 2 - 44 $\mu molm^{-2}s^{-1}$PPFD. The apparent photosynthetic rates were -0.62 to 1.48 $\mu molCO_2m^{-2}s^{-1}$.

Measurement for the diurnal changes of gas exchange was also followed. The peak of photosynthetic rates had the maximum values about 7 - 8 $\mu molCO_2m^{-2}s^{-1}$ in the range of light intensity values of 400 - 500 $\mu molm^{-2}s^{-1}$PPFD and stomatal resistance values of approximately 8 - 10 $mmolm^{-2}s^{-1}$.