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Estimation of Annual Carbon Sequestration in *Psophocarpus tetragonobulus* used as Biofacade in Tropical Environment

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Abstract**:** *Carbon dioxide was emitted in huge amount from greenhouse gasses. Thus, carbon dioxide emissions are the most important cause of global warming. This research seeks to reduce the amount of carbon emission into the atmosphere. Biofacade has been in the development for about two years in Universiti Sains Malaysia, Penang, Malaysia. Psophocarpus tetragonobulus was a legume climber plants which was grown on a typical brick wall facing the west, oriented towards the afternoon sun. The investigations on annual carbon sequestration of P. tetragonobulus were conducted in two phases, one being carbon sequestration study and the other a leaf area study. The investigation for carbon sequestration study was conducted in April 2011. The leaf area study was done in May 2011. Conclusions were made on an estimation of annual carbon sequestration for P. tetragonobulus in open-tropical environment.*

Keywords: *biofacade, carbon sequestration, leaf area, Psophocarpus tetragonobulus*

1. Introduction

The world system has gone through two cycles of cooling and warming processes. However, recent large scale building development influences have led to the dramatic changes within the system. As a consequence, the warming cycles are proceeding faster than the cooling cycles [1]. The Kyoto Protocol is an international agreement highlighting on limiting emissions of greenhouse gasses [2], [3]. Among the six dominant greenhouse gasses mentioned by United Nation Framework Convention on Climate Change (UNFCCC), carbon dioxide was the strongest gas effect on the climate change [4]. This paper only focuses on the carbon dioxide. Carbon cycles occur within the atmosphere and plants, soil and oceans. The carbon emit from fossil burning were the second largest impact of carbon in the atmosphere [5]. The carbon cycles between atmosphere and plants are the main discussion in this paper. Actions needed to be taken consistently and reliably. Many projects failed to fulfill the objective of reducing carbon dioxide emission because the development planning was not always supported by science. This paper urges the industry to collaborate with science to ensure sustainability of development. The objective of this paper was to estimate the annual carbon sequestration of selected plant in the open environment.

We hardly ignore the importance of development because we need it as part of our lives. To do so, we seldom did land clearing for the sake of new buildings. Land clearing activities release about 1.6 Gt C per year to the atmosphere [5]. It was important to balance between two. Growing plants on buildings was believed helpful in offsetting the carbon emission. We develop buildings without ignoring the important of plants for carbon uptake.

Carbon dioxide emission contributes to the rise of global mean temperature and sea level [6]. Due to the rise of sea level, lands are getting smaller while population increase through decades are getting higher making the land even more pricey. Thus, crop plantation was not seen as a promising high yield investment compared to commercial industry and residential development. In securing an easy food production in urban area, Biofacade was seen as capable of supplying supplementary fruit or herbs but has yet to be a viable full-scale alternative.

Biological façade or Biofacade can be defined as a plant cover which act as a shading device for building façade and a centre for carbon offset which also supply food and medicine. The term Biofacade was also used by Sunakorn [7], while researching several studies relating to the building temperature and carbon dioxide. The term Biofacade is also synonym to Vertical Greenery System [8], Green Wall [9], Green Facades [10], Living Wall [11] and Bioshaders [12].

One of the world's concerns was to fulfill the needs of food security [13]-[16]. The food production on presently used land must be doubled in the next two decades [17]. Cash crop in agriculture was grown for profit. Malaysia is a tropical country and is categorized as one of the highest in biomass production because of its regular and constant sunlight intensity and rainfall, compared with temperate country which has winter as hibernation period [18]. Other than food production, another benefit of Biofacade is that it can also be exploited to produce commercial product such as *P. sativum* or sweet pea can be made into biodegradable thermoplastics [19].

2. Experimental Analysis

2.1. Materials and Methods

A predominant legume species such as *Psophocarpus tetragonobulus* was taken for further investigations in Biofacade study. *P. tetragonobulus* was a legume species with tendril as a climbing method. The height of this plant can go about 3 to 4 meters. The pods are 6 to 9 inches long and an inch broad, whereas the leaf was 3 to 6 inches long. It does well in a variety of soils except sands or high salinity environments with pH soil 4.3 to 8.5 [20], [21]. It was also known as winged bean and was popular with for its fruit and medicinal usage in tropical country.

Ten pots of *P. tetragonobulus* were growth for about eight months on a 2.5 m width x 3.67 m height external building wall (Figure 1). Leaves harvested were done in early four months growth for other interest investigations. After new vigorously leaves came out for about two months, the carbon sequestration of plants were measured with LICOR-6400 (LI-COR, Inc.) along with leaf chamber 2 cm x 3 cm size, named first experiment. The measurement was taken in three consecutive days in April 2011, the transition period of wet and dry season. Every randomly selected leaf was logged three times to get the average of photosynthetic assimilation rate (representing Gross Primary Productivity, GPP in µmol CO2 m^{-2} s^{-1}). The researcher deduct the dark respiration rate from GPP to obtain Net Primary Productivity, NPP as estimation for the amount of CO_2 sequestered by the plant.

Fig.1: *P. tetragonobulus* over two month's growth

Second experiment was to measure the Leaf Area on May 2011, a month after carbon sequestration measurement. To extrapolate the total CO_2 sequestered by all the plant in this study, we used LICOR-3000A, a leaf scanner along with LICOR-3050A, a leaves belt conveyor to estimate the total leaf area of two randomly selected pots of *P. tetrogonobulus*. Two potted plants from pot 3 and pot 10 were randomly selected with random integer generated (www.random.org/integers/). All leaves were ensured to keep moist before harvesting to prevent the leaves wilt while measurements were taken. To do so, the leaves were watered heavily a day before harvesting. The measurement and record of leaf area was undertaken in an hour. The plate sized of 50 cm^2 was used to check on accuracy of instrument LICOR-3000A and LICOR 3050A, by 10 times measurement repeated.

2.2. Results and discussions

The finding of April 22, 2011 was investigated base on the reliability and fine weather condition. The unit used in measuring the carbon sequestration was µmole m^{-2} s^{-1}. The results of averages for 20 leaves were logged as in Table I. The negative values (dark respiration) were not considered in the calculation of the average Gross Primary Productivity (GPP). The average GPP reading of *P. tetrogonobulus* was 5.69 µmole CO_2 m^{-2} s^{-1}.

TABLE I: Environmental parameters average logged during 14 sampling period. The unit of carbon sequester is µmole m^{-2} s^{-1}, Stomatal Conductance (cond) is mole m^{-2} s^{-1}, air temperature and leaf temperature are degree C, Intercelullar CO_2 is mole m^{-2} s^{-1}, Relative Humidity (RH) is percent, and Photosynthetically Active Radiation (PAR) is µmole m^{-2} s^{-1}.

Date 22/04/11	mean carbon sequester	mean cond	mean Tair	mean Tleaf	mean CO_2R	mean RH_R	mean PARi
630am	-3.34 (dark respiration)	0.00	31.50	29.88	457.60	46.30	1.35
7am	-3.11	-0.01	29.43	27.94	445.75	53.10	27.72
8am	0.21	0.06	29.87	28.33	430.22	52.88	172.28
9am	4.43	0.07	31.61	29.99	410.09	43.54	281.00
10am	6.35	0.08	32.41	30.91	427.89	43.79	373.00
11am	6.90	0.10	33.61	31.76	420.15	39.30	447.73
12pm	6.37	0.11	35.56	33.69	410.23	35.62	469.10
1pm	7.86	0.12	35.51	33.33	408.19	36.00	582.55
2pm	7.00	0.14	37.17	34.72	399.52	33.61	498.68
3pm	12.25	0.16	38.65	36.72	399.65	30.08	2148.32
4pm	12.82	0.16	40.20	38.03	397.89	27.68	2084.48
5pm	1.91	0.02	34.16	32.63	412.06	37.96	98.15
6pm	1.62	0.01	31.79	30.39	396.92	37.38	88.45
7pm	0.58	0.00	31.79	30.50	428.48	48.51	41.45
Average	**5.69**	**0.09**	**34.36**	**32.58**	**411.77**	**38.86**	**607.10**

The average relative humidity ranged from 27% to 53% (Figure 2f); air temperature, 29 ^oC to 40.2 ^oC (Figure 2c; leaf temperature, 28 ^oC to 38 ^oC (Figure 2d), and ambient Carbon Dioxide concentration (atmospheric [CO_2]), from 397 mol m^{-2} s^{-1} to 458 mol m^{-2} s^{-1} (Figure 2e) during Carbon sequestration study. The average stomata conductance ranged from 0 mole m^{-2} s^{-1} to 0.16 mole m^{-2} s^{-1} as negative values were ignored (Figure 2b). The leaf stoma conductance dropped very fast when the leaf temperature exceeded 38 ^oC. The sunlight or Photosynthetically Active Radiation (PARi) reached over 2000 µmole m^{-2} s^{-1}, with the highest radiation at the 3 p.m and 4 p.m sampling period (Figure 2g).

Table II shows the correlation coefficients among the variables. It shows that all environmental parameters correlated significantly with each other during 14 sampling periods. The table illustrates the trend of *P. tetragonobulus* in a day period. Carbon sequestration coincided with Stomatal Conductance and Photosynthetically Active Radiation.

For Leaf Area measurement, two out of ten pots were sufficient to represent the case. Destructive method was used in the experiment resulting in 154 leaves with a total leaf area of 5136.82 cm^2 (Pot no. 10), and 123 leaves with a total leaves area of 5398.22 cm^2 (Pot no. 3). The leaf area of *P. tetragonobulus* was derived by the average of the two, which was 5267.52 cm^2. The reliability of instrument accuracy resulted on error +/-0.066.

TABLE II: Correlation Coefficient between all variables for a day sampling period (April 22, 2011). P. tetragonolobus (*correlation is significant at 0.05 level, ** correlation is significant at 0.01 level).

	Conductance	T_{air}	T_{leaf}	CO_2	Relative Humidity	PAR
Carbon Sequester	.937**	.881**	.879**	-.759**	-.846**	.846**
Conductance	-	.846**	.824**	-.655*	-.762**	.794**
T_{air}	-	-	.998**	-.701**	-.933**	.844**
T_{leaf}	-	-	-	-.704**	-.935**	.853**
CO_2	-	-	-	-	.818**	-.547*
Relative Humidity	-	-	-	-	-	-.734**

From carbon sequestration and Leaf Area studies, a prediction of yearly carbon storage was estimated. It is recommended to modify the unit into Ton C or kg C for easy comparison with Kyoto Protocol obligations. Thus, the unit of μmole C was modified into kg C, and the unit for timeline was changed from seconds into year from planting.

Average of carbon sequestration 2.35 μmole CO_2 m^{-2} s^{-1} (NPP-dark respiration) is converted to Ton CO_2 per year per meter square assuming 12 hours daylight hour. 1 μmole of C CO_2 is approximated to 44 x 10^{-9} kg molecular weight. A year with assumption of daylight only, was equal to 15,768,000 second.

Thus, 2.35 μmole CO_2 m^{-2} s^{-1} is equal to:

= (2.35 μmole m^{-2} s^{-1}) x (44 x 10^{-9} kg CO_2) x (15, 768, 000 second)

= 1.63 kg CO_2 / year / m^2

= 0.0016 ton CO_2 / year / m^2 (1)

P. tetragonobulus were grown on a 2.5 meter by 3.67 meter height wall. Thus, the total area of growth was 9.175 meter square or 91,750 centimetre square. During a year of *P. tetragonobulus* growth, assumption was made that the wall was not fully covered by leaves at all times. To do so, a ratio has been made, which is the *Average total leaves in 10 pots to Total area of plant growth.* In conclusion, a year of *P. tetrogonobulus* growth as Biofacade has resulted in 57.41% of wall coverage.

Overall, (0.0016 ton CO_2 $year^{-1}$ m^{-2}) x (0.5741) was equal to sequestration rate of 0.00092 ton CO_2 $year^{-1}$ m^{-2} or 9.2 ton CO_2 $year^{-1}$ $hectar^{-1}$.The ability of plants to store carbon was an important part of this study. However, this sink was only temporary and harvesting the plants should release back the carbon dioxide to the atmosphere. As long as the harvesting parts were not burned, the carbon was still safe from harming the environment.

To fulfil the objective above, a longer period of study was needed. This includes observing and investigating the carbon dioxide sequestration until the end of the plant's life span. Knowing the life span's trend can benefit building development, making it easier to choose plants for the benefits of sequestering the carbon without neglecting the importance of aesthetic. Variance set of plants made excessive choice on plant selection. There are five factors affecting the photosynthesis rate which are light, water, wind and turbulence, temperature and carbon dioxide concentration [22]. Analysis showed the strong positive correlation for all environmental parameters in all sampling period. *P. tetragonobulus* recorded the highest carbon sequestration at sampling period 3pm and 4pm with 12.25 μmole m^{-2} s^{-1} and 12.82 μmole m^{-2} s^{-1} opposed with minor difference with highest Photosynthetically Active Radiation (PAR) at 2148 μmole m^{-2} $s^{-1}$and 2084 μmole m^{-2} s^{-1}, respectively.

Average of carbon sequestration 2.35 μmole CO_2 m^{-2} s^{-1} was converted to kg CO_2 per year per meter square assuming 12 hours daylight hour is equal to 0.935783 kg CO_2 $year^{-1}$ m^{-2} or 9357.83 kg CO_2 $year^{-1}$ $hectar^{-1}$.

Even on extremely hot days, the need for an air conditioner really depends on the design of the building. For example, decreasing the temperature in the building by adding shade plants like Biofacade to the building made the interior cooler, thus reducing the energy usage of air-conditioning. The significance of the decrease of indoor temperature when the Biofacade was applied will be discussed further on the next paper.

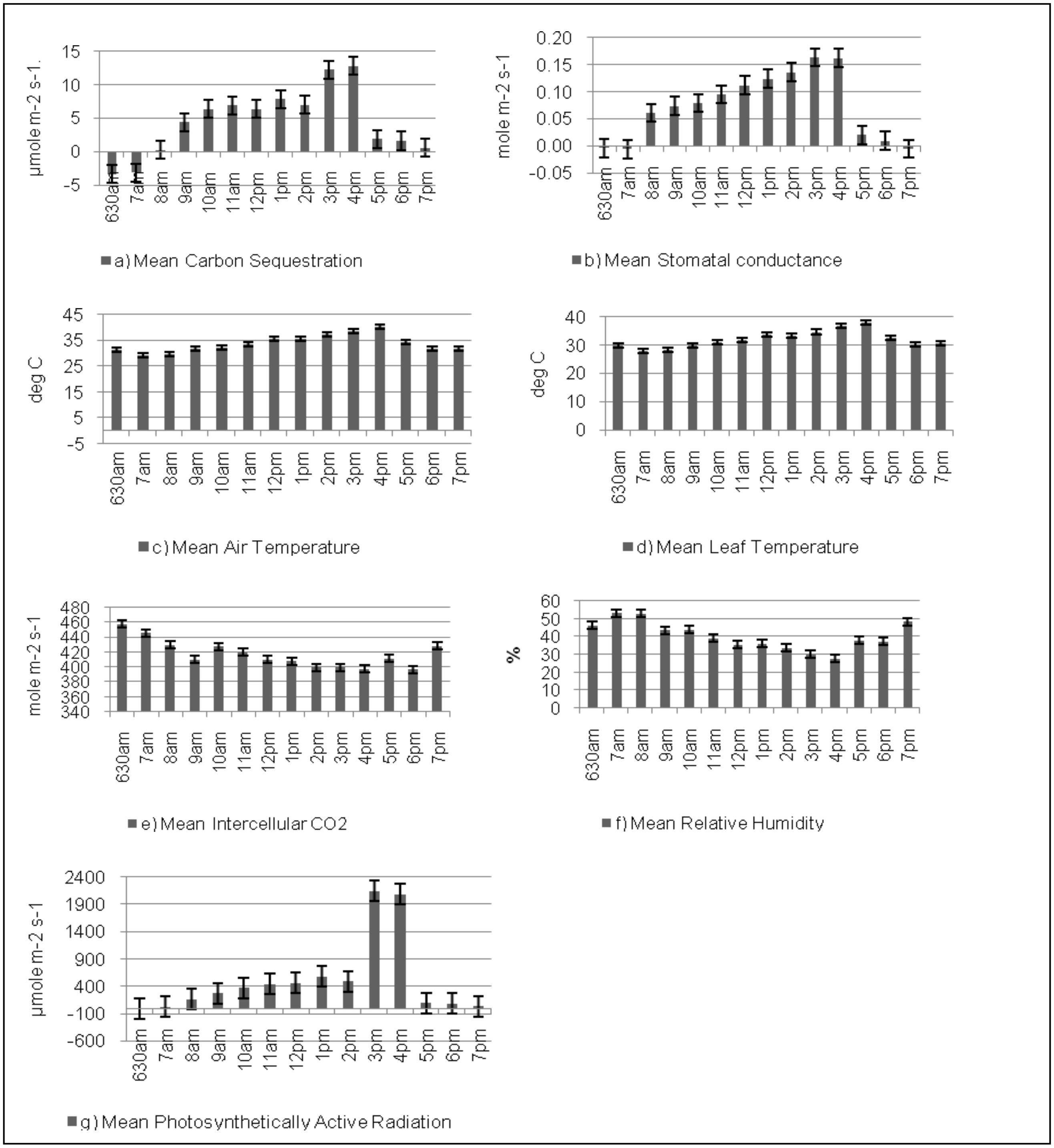

Fig. 2(a) to 2(g): The trend of *P. tetragonobulus* in a day period with 14 sampling periods: (a) Carbon sequestration (μmole m^{-2} s^{-1}); (b) Stomatal Conductance (mole m^{-2} s^{-1}); (c) Air Temperature (°C); (d) Leaf Temperature (°C); (e) Intercellular CO_2 (mole m^{-2} s^{-1}); (f) Relative Humidity (%); (g) Photosynthetically Active Radiation (μmole m^{-2} s^{-1}).

2.3. Conclusion

P. tetragonobulus was a plant that gave moderate impact in reducing carbon emission. More plants should be studied to determine their rate of carbon sequestration. This is to help the construction industry in selecting suitable plant species for different types of building to reduce carbon emission in the atmosphere without neglecting the needs of aesthetic. Studies observing the life longevity of plants should include the consideration of possible maintenance cost. For example, William's report in 1989 on *Piper sp.*, summarized that the leaf longevity of this species correlates with its photosynthesis rate and construction cost. Reference [23] shows, a competitive study between tropical and temperate plants, strengthened Williams' result that leaf life span was short when photosynthesis assimilation rate of the leaf was high, thus the construction cost (production of leaves) was low. This applies to most species for both climates. Therefore, while a higher photosynthesis rate might be good towards reducing emission of greenhouse gases, other factors such as life span of species should be considered to ensure sustainable development.

Last but not least, the different methods in growing plants can yield different result on the plants' durability. The drought tolerance in legumes was parallel with salinity tolerance in soil components [24]. The legume that was deeply rooted may reduce leaf size with thickened cuticles, which can reduce water loss [25]. An experiment on *P. vulagris L.* in Columbia with two different soil location and conditions was conducted to observe the root growth [25]. The result shows that the roots of drought tolerance lines were able to grow as deep as 1.3 meter where as the drought sensitive lines were only able to reach 0.8 meter. As a conclusion, the planned site for growing Biofacade plants which were received the high intensity of sunlight should provide enough soil depth to secure the water loss from the plants.

The longer period of plant observe regarding on life span and durability should continue persistently. The exact or approximate amount that was effectively released was a possible venue for future research.

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