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Model of Energy Generation in Plant by the Cells of The Leafs During the Night (From 18:00 to 6:00).

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Abstract:- It is known fact that plants generates energy using the sunlight and that the intensity of the sun drastically reduced from 18:00 hours to 6:00 hours (over the night). A mathematical model is presented to describe the process and the energy generated by the cells in the leaf of a plant at this period. The model equations are solved with graph showing the production level within the range of periods stated. This study assumed that plants have already generated enough energy both stored and used. The result showed that plant makes use of existing stored energy thus reducing the level of the stored energy until the next day when the energy level begins to increase.

Keywords:- *Energy, Photosynthesis, Equation, Carbon-dioxide, Plant, Sunlight*

I. INTRODUCTION

Growth in plant is as a result of their ability to get light energy and change it into chemical energy, which is used to fix carbon dioxide in order to produce food. The plant adapts and interacts with its environment through the flow of energy and flow of gases and molecules produced between the plant and the environment. However, all plant process including their manufacturing of food (photosynthesis), cell-enlargement, cell-division, translocation, respiration, etc do work and consume energy. Plant generates its energy through the process of photosynthesis with the help of its green pigment called chlorophyll. Chlorophyll when concentrated into structures is known as chloroplast. The chlorophyll is the only structure capable of typing the sun energy or other form of light energy.

Therefore, this study wish to know how the cells of the leaf of a plant generate this energy especially during the night and what quantity generated are actually stored as a source of energy in other parts of the plant for growth and other metabolic processes.

II. RELATED WORKS

Plant is divided into leaf, shoot, and root and according to Weisz (1980) and Guttmann (1983), plant leaf consists of cells, which accommodates chloroplast that contains green pigment called chlorophyll. Plant manufactures its energy in the leaf and stores them in the trunk, stems and roots in the form of carbohydrates, proteins, vitamins, etc as well as those stored in the leafs. Weisz (1980) also states that in addition to the energy subsequently generated by the leaf in the presence of light energy from the sun, the variation in the amount of energy supplied by the plant is as a result of the variation in the energy generated by the cells of the leaf. Photosynthesis occurs in two stages: light dependent and light independent (dark) reactions. Cushman (2001) stated the three phases of the light dependent reaction collectively called Calvin cycle as carbon fixation, reduction reactions, and ribulose-1, 5-bisphosphate (RUBP) regeneration. Light dependent reaction captures the energy of light and uses it to make the energy storage and transport molecule ATP and NADPH (Campbell et al, 2006). The light independent reactions are chemical reactions that convert carbon dioxide and other components into glucose. These reactions occur in the stoma. The fluid filled area of the chloroplast outside the thylakiod membranes. This process takes the light dependent reaction and performs further chemical processes on them. Despite its name, this process occurs only when light is available. Plants do not carry out Calvin cycle by night; instead they release sucrose into the phloem from their starch reserve. This process happens when light is available independent of the kind of photosynthesis (C_3 Carbon fixation, C_4 Carbon fixation, and Crassulacean Acid Metabolism) CAM plants store malic acid in the vacuoles every night and release it by day in order to make this process work (Cushman, 2001).

The key enzymes of the cycle are called RuBisCO. In the following biochemical equations, the chemical species (phosphates and carboxylic acids) exist in equilibria among various ionized states or governed by the pH. The enzymes in the Calvin cycle are equivalent to most enzymes used in other metabolic pathways such as gluconeogenesis and the pentose phosphate pathway, but they are to be found in the chloroplast stoma instead of the sell cytoplasm separating the reactions. They are activated in the light, and also byproduct of the light dependent reaction. These regulatory functions prevent Calvin cycle from being respired to carbon dioxide. Energy (in form of ATP) would be wasted in carry out these reactions that has no net production (Farazdaghi, 2009). The sum of the reaction in the Calvin cycle is the following

$3CO_2 + 6NADPH + 5H_2O + 9ATP \rightarrow$ glyceraldehyde-3-phosphate (G3P) + $2H^+ + 6NADP^+ + 9ADP + 8Pi$ (Pi = Inorganic phosphate)

Hexose (six-carbon) sugars are not a product of Calvin cycle. Although many texts list a product of photosynthesis as

$$6CO_2 + 6H_2O + \frac{Energy}{Energy\ in} \xrightarrow{photosynt\ hesis} C_6H_{12}O_6 + 6O_2 \text{ aerobic respiration}$$

This is mainly a convenience to counter the equation of respiration when six carbon sugars are oxidized in mitochondria.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \frac{Energy}{Energy\ out}$$

The carbon products of the Calvin cycle are three carbon sugar phosphate molecules or “triose phosphates” namely glyceraldehyde-3-phosphate (G3P) (Russell et al, 2010, Leegood, 2007). From the two processes shown in the simplified equations above, photosynthesis absorbs energy (from the sunlight) where as aerobic respiration yields energy (as a result of the oxidation of the glucose the carbohydrate molecule) observe that these are essentially completing processes, one producing glucose (photosynthesis) and the other consuming glucose (respiration). During respiration, plants turn glucose into energy. Inside the cells, plants use energy to turn glucose into energy. They also produce carbon dioxide and water. On sunny days, plant makes lots of glucose which lasts for them through the night and through several cloudy days but they cannot store up lots of glucose. If glucose is not used in respiration and other metabolic processes, they are turned into starch. Starch can be stored in leaf cells and other parts of the plant for later use. Hence, we develop the model equation for the energy generation for storage and usage by the plant during the night.

III. THE MODEL

In our model, the system of enzymes X converts excess carbohydrate to starch and other polysaccharides and is stored in the leaf, stem, branches and roots. Here all the stored energies will be sum up as E^*. Using this therefore, we present the model equation as:

$$\frac{dE^*}{dt} = E^* - a_2XE_0^* - a_3E^* - a_4E^*e^{-\alpha(t-t^*)} \quad (1)$$

$$\frac{dX}{dt} = b_1E^* - b_2X \quad (2)$$

where a_2, a_3, a_4, b_1, b_2 are constants to be determined,

α is the factor associated with sunlight energy,

E_0^* is the quantity of starch/ glucose not used nor converted when the sun goes down by 18:00,

t^* is the time when the sun energy seizes,

t is the time between 18:00 – 6:00,

E^* is enough carbohydrate already stored in the cell, and

X is the system of enzymes involved in the conversion process of the carbohydrate to starch and other polysaccharides.

Solving these two equations (1) and (2) simultaneously by solving for the complementary and particular solutions. The complimentary parts of equations (1) and (2) are:

Whose complimentary solutions are:

$$\frac{dE^*}{dt} = E^* - a_2XE_0^* - a_3E^* - a_4E^*e^{-\alpha(t-t^*)} \quad (1)$$

$$\frac{dX}{dt} = b_1E^* - b_2X \quad (2)$$

$$\begin{pmatrix} E_C^* \\ X_C \end{pmatrix} = \begin{pmatrix} \rho \\ \mu \end{pmatrix} e^{kt} \quad (3)$$

From equation (1) and (2), we have the matrix co-efficient of the complimentary equation as:

$$T = \begin{bmatrix} 1 - a_3 - a_4 e^{-\alpha(t-t^*)} & -a_2 E_0^* \\ b^1 & -b_2 \end{bmatrix}$$

whose eigen-vector is given as:

$$\begin{vmatrix} 1 - a_3 - a_{4^e} e^{-\alpha(t-t*)} - \lambda & -a_2 E_0^* \\ b_1 & -b_2 - \lambda \end{vmatrix} = 0 \qquad (4)$$

which is evaluated as:

$$\left(1 - a_{3-} a_4 e^{-\alpha(t-t^*)} - \lambda\right)(-b_2 - \lambda) - (b_1)(-a_2 E_0^*) = 0$$

$$\lambda^2 + a_3\lambda + b_2\lambda + a_4\lambda e^{-\alpha(t-t^*)} - \lambda + a_3 b_2 + a_2 b_1 E_0^* + a_4 b_2 e^{-\alpha(t-t^*)} - b_2 = 0$$

$$\lambda^2 + (a_3 + b_2 + a_4 e^{-\alpha(t-t^*)} - 1)\lambda + a_3 b_2 + a_2 b_1 E_0^* + a_4 b_2 e^{-\alpha(t-t^*)} - b_2 = 0$$

solving for λ using $\lambda = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

we have:

$$\lambda = \{-(a_3 + b_2 + a_4 e^{-\alpha(t-t*)} - 1)$$
$$\pm\sqrt{(a_3 + b_2 + a_4 e^{-\alpha(t-t*)} - 1)^2 - 4(a_3 b_2 + a_2 b_1 E_0^* + a_4 b_2 e^{-\alpha(t-t^*)} - b_2)}\ \}/2$$

$$\lambda = (a_3 + b_2 + a_4 e^{-\alpha(t-t*)} - 1)^2$$
$$\pm\frac{1}{2}\{-(a_3 + b_2 + a_4 e^{-\alpha(t-t*)} - 1) - 4(a_3 b_2 + a_2 b_1 E_0^* + a_4 b_2 e^{-\alpha(t-t^*)} - b_2\ \}^{\frac{1}{2}} \qquad \textbf{(5)}$$

For the particular solution this does not exist for any of the equations. Since the equations are solved simultaneously, we have the solutions as:

$$\begin{pmatrix} E_p^* \\ X_p \end{pmatrix} = \begin{pmatrix} C \\ D \end{pmatrix} \qquad (6)$$

If we differentiate this equation (6) with respect to "t" and then substitute into equations (1) and (3), we have then that:

$E_p^* = 0$

$X_p = 0$

$$\Rightarrow\ 0 = C - a_2 D E_0^* - a_3 C - a_4 C e^{-\alpha(t-t^*)}$$
$$0 = b_1 C - b_2 D$$

$$a_2 D E_0^* = C - a_3 C - a_4 C e^{-\propto(t-t^*)}$$
$$b_2 D = b_1 C$$

$$(a_2 E_0^*) D = (1 - a_3 C - a_4 e^{-\propto(t-t^*)}) C \qquad (7)$$

$$(b_2) D = (b_1) C \qquad (8)$$

$$Let \qquad C = \frac{b_2 D}{b_1} \qquad (9)$$

Substituting equation (9) into (7), we have:

$$a_2 E_0^* D = (1 - a_3 C - a_4 e^{-\propto(t-t^*)}) \left(\frac{b_2 D}{b_1}\right)$$

$$a_2 E_0^* D b_1 = D(b_2 - a_3 b_2 - a_4 b_2 e^{-\propto(t-t^*)})$$

$$\Rightarrow \quad \{a_2 b_1 E_0^* - (b_2 - a_3 b_2 - a_4 b_2 e^{-\propto(t-t^*)})\} D = 0$$

$$\Rightarrow D = 0$$

Since D = 0, C = 0 (10)

Thus:

$$\begin{pmatrix} E_p^* \\ X_p \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \qquad (11)$$

From equation (3) and (11) we have the general solution to equation (1) and (2) as;

$$\begin{pmatrix} E^* \\ X \end{pmatrix} = \begin{pmatrix} E_C^* \\ X_C \end{pmatrix} + \begin{pmatrix} E_P^* \\ X_P \end{pmatrix}$$

So that more explicitly we have:

$$E^*(t) = \rho e^{-\propto(t-t*)} + 0 \qquad (12)$$

$$X(t) = \mu e^{kt*} + 0 \qquad (13)$$

From these two equations; (12) and (13), we need to find the expression for "ρ" and "μ". Thus using equation (3), we have:

$$\begin{pmatrix} E_C^* \\ X_C \end{pmatrix} = \begin{pmatrix} \rho \\ \mu \end{pmatrix} e^{kt} = \begin{pmatrix} \rho_1 e^{k_1 t} + & \rho_2 e^{k_2 t} \\ \mu_1 e^{k_1 t} + & \mu_2 e^{k_2 t} \end{pmatrix}$$

Where k = λ

This means that:

$$E_C^* = \rho_1 e^{k_1 t} + \rho_2 e^{k_2 t} \qquad (14)$$

$$X_C = \mu_1 e^{k_1 t} + \mu_2 e^{k_2 t} \qquad (15)$$

If we differentiate these and substitute into (1) and (2), we then get:

$$k_1 \rho_1 e^{k_1 t} + k_2 \rho_2 e^{k_2 t} = E^* - a_2 X E_0^* - a_3 E^* - a_4 E^* e^{-\alpha(t-t^*)} \qquad (a)$$

$$k_1 \mu_1 e^{k_1 t} + k_2 \mu_2 e^{k_2 t} = b_1 E^* - b_2 X \qquad (b)$$

Using equation (a) and substituting appropriately for X_C and E_C using equation (14) and (15), we have:

$$\rho_1 k_1 e^{k_1 t} + \rho_2 k_2 e^{k_2 t} = \rho_1 e^{k_1 t} + \rho_2 e^{k_2 t} - a_2(\mu_1 e^{k_1 t} + \mu_2 e^{k_2 t}) E_0^*$$
$$- a_3 (\rho_1 e^{k_1 t} + \rho_2 e^{k_2 t}) - a_4 (\rho_1 e^{k_1 t} + \rho_2 e^{k_2 t}) e^{-\alpha(t-t^*)}$$

$$\rho_1 k_1 e^{k_1 t} - \rho_1 e^{k_1 t} + a_3 \rho_1 e^{k_1 t} + a_4 \rho_1 e^{k_1 t} e^{-\alpha(t-t*)} + \rho_2 k_2 e^{k_2 t} - \rho_2 e^{k_2 t} + a_3 \rho_2 e^{k_2 t} + a_4 \rho_2 e^{k_2 t} e^{-\alpha(t-t^*)}$$
$$= - a_2 E_0^* \mu_1 e^{k_1 t} - a_2 E_0^* \mu_2 e^{k_2 t}$$

Equating terms of corresponding coefficients, we have:

$$(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_1 e^{k1t} = -a_2 E_0^* \mu_1 e^{k1t}$$
$$(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_2 e^{k2t} = -a_2 E_0^* \mu_2 e^{k2t}$$

$$(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) p_1 = -a_2 E_0^* \mu_1$$
$$(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) p_2 = -a_2 E_0^* \mu_2$$

$$\left.\begin{matrix} \dfrac{(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_1}{-a_2 E_0^*} \\ \dfrac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_2}{-a_2 E_0^*} \end{matrix}\right\} \qquad (16)$$

Substituting these values appropriately into equations (12) and (13) gives:

$$E^*(t) = \rho_1 e^{k_1 t} + \rho_2 e^{k_2 t} \qquad (17)$$

$$\text{where } \rho e^{kt} = \rho_1 e^{k_1 t} + \rho_2 e^{k_2 t}$$

$$X(t) = \mu_1 e^{k_1 t} + \mu_2 e^{k_2 t} \qquad (18)$$

$$\text{where } \mu e^{kt} = \mu_1 e^{k_1 t} + \mu_2 e^{k_2 t}$$

Substituting μ_1 and μ_2 we have:

$$X(t) = \left[\frac{-(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_1 e^{k_1 t}}{a_2 E_0^*}\right] - \left[\frac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_2 e^{k_2 t}}{a_2 E_0^*}\right] \qquad (19)$$

From these two equations, we need to find the value of ρ_1 and ρ_2 at a given time "t" and let this time "t" be $t=t^+$ which will be any comfortable time of interest. This, using our t* as our starting time of count such that $t^+ = t^*$, solving equations (38) and (40) simultaneously, we obtain:

$$E^{*+} = \rho_1 e^{k_1 t} + \rho_2 e^{k_2 t} \qquad (17)$$

$$X^+ = \left[\frac{-(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_1 e^{k_1 t}}{a_2 E_0^*}\right] - \left[\frac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}) \rho_2 e^{k_2 t}}{a_2 E_0^*}\right] \qquad (19)$$

From equation (17) we have:

$$E^{*+} = \rho_1 e^{k_1 t} + \rho_2 e^{k_2 t}$$

$$(E^{*+} - \rho_1 e^{k_1 t})e^{-k_2 t} = \rho_2 \qquad (20)$$

Substituting into equation (19) we have;

$$X^+ = \left[\frac{-(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\rho_1 e^{k_1 t}}{a_2 E_0^*}\right] - \left[\frac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\,(E^{*+} - \rho_1 e^{k_1 t})e^{-k_2 t}e^{k_2 t}}{a_2 E_0^*}\right]$$

$$X^+ = \frac{-(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\rho_1 e^{k_1 t}}{a_2 E_0^*} - \frac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\,(E^{*+})}{a_2 E_0^*} + \frac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\,(\rho_1 e^{k_1 t})}{a_2 E_0^*}$$

$$X^+ + \frac{E^{*+}\left(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}\right)}{a_2 E_0^*} = \frac{-(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\rho_1 e^{k_1 t}}{a_2 E_0^*} + \frac{(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)})\,(\rho_1 e^{k_1 t})}{a_2 E_0^*}$$

$$X^+ + \frac{E^{*+}\left(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}\right)}{a_2 E_0^*} = \frac{-(K_1 - 1 + 1 + a_3 - a_3 + a_4 e^{-\propto(t-t^*)} - a_4 e^{-\propto(t-t^*)})\rho_1 e^{k_1 t}}{a_2 E_0^*}$$

$$\rho_1 e^{k_1 t}.\left(\frac{K_2 - K_1}{a_2 E_0^*}\right) = X^+ + \frac{E^{*+}\left(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}\right)}{a_2 E_0^*}$$

$$\rho_1 = \left(\frac{a_2 E_0^*}{K_2 - K_1}\right) e^{-k_1 t} \left\{\mathrm{X}^+ + \mathrm{E}^{*+}\frac{\left(K_2 - 1 + a_3 + a_4 e^{-\propto(t-t^*)}\right)}{a_2 E_0^*}\right\} \qquad (21)$$

But equation (20) may also be written as:

$$\rho_1 = (E^{*+} - \rho_2 e^{-k_1 t}) \qquad (22)$$

Substituting the above equation we have:

$$\rho_2 = \left(\frac{a_2 E_0^*}{K_2 - K_1}\right) e^{-k_2 t} \left\{\mathrm{X}^+ + \mathrm{E}^{*+}\frac{(K_1 - 1 + a_3 + a_4 e^{-\propto(t-t*)})}{a_2 E_0^*}\right\} \qquad (23)$$

IV. DISCUSSION

In this model, we considered many variables as earlier stated and thus we had a fairly good model. Of particular importance to be mentioned among the parameters here are the quantity of starch or glucose not used nor converted when the sun goes down by 18:00 and the system of enzymes involved in the conversion process of the carbohydrate to starch, and other polysaccharides. In showing how well this model predicts what happens in the leaf, we made some assumptions about the values of the constants as well as other parameters in the model. Thus, we assumed that $a_2 = 0.04, a_3 = 0.04, a_4 = 0.03, b_1 = 0.27, b_2 = 0.033, E^* = 120,$ $E_0^* = 20, X = 1.5, t = 18$

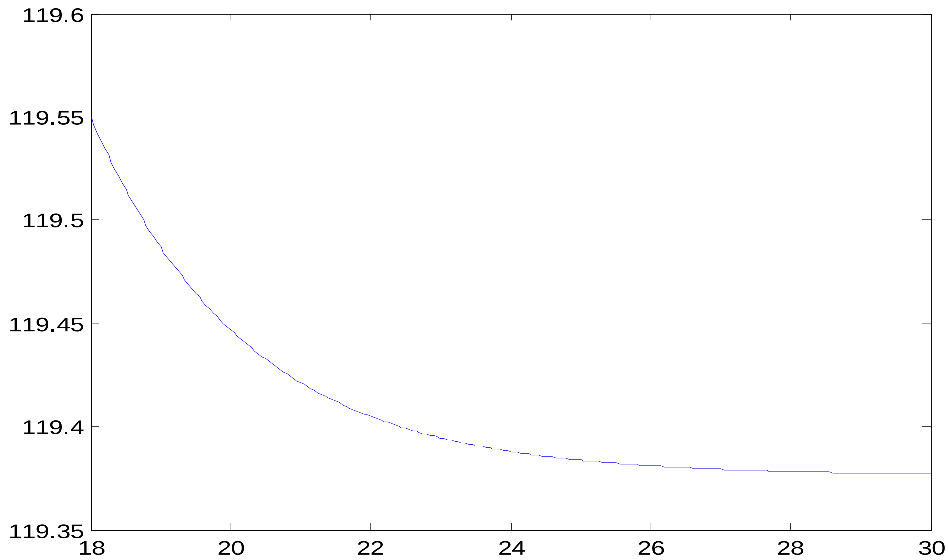

Figure 1: Production of energy at night

Figure1 shows that at 18.00 hour, production of carbohydrate or energy continues to reduce sharply until 24.00 hour where there exists, a slower reduction rate of carbohydrate or energy. This simply indicates that the plant is not generating more energy but rather making use of the already generated/stored ones. From the biological view, it has been proposed that plants do not perform photosynthesis at night because there is no light and they need light energy to do this. And since is not making more food, they shut down (close) their guard cells accommodated in the stomata thereby not allowing the passage of carbon dioxide while oxygen production within the leaf will continue. Farazdaghi (2009) stated that at night, or in the absence of light, photosynthesis essentially cease, and respiration is the dominant process; the plant consumes food (for growth and other metabolic processes). However, if the concentration of carbon dioxide is low, the enzyme that captures them in the light independent reaction will bind oxygen instead of carbon dioxide. This process called photorespiration uses energy but does not produce sugar. This is known as RuBisCO oxygenate activity and is disadvantageous to plants as one of its product is 2-phosphoglycolate (2 carbon) instead of 3-phosphoglycolate (3 carbon) and this represents loss of carbon. Also it drains the sugars that are required to recycle ribose 5-bisphospate and for the continuation of the Calvin-Benson cycle.

V. CONCLUSION

However, by the modeled equation, where E^* representing the quantity of starch/glucose not used nor converted, continues to decrease from 119.55 units at 18.00 hour to 119.38 units at 30.00hour. This can be attributed to the fact that at night, plants cannot make food, but they perform cellular respiration (photorespiration) which is an oxidative process that converts sugar and starch into energy using oxygen. Energy stored as chemical energy is as a result of photosynthesis in the day (i.e. between 6.00 hour – 18.00 hour). Carbohydrate, protein etc. is continually released in living cells during the process of respiration. Basically, photosynthesis creates and stores energy and respiration releases energy, allowing the plant to take up water, building new cells and grow, and basically run all other growth processes. Unlike photosynthesis, respiration does not depend on light, so it occurs at any time, even during the night as well as the day. Stomata (singular stoma) which are microscopic openings on the undersurface of leaves that allow gas exchange and water evaporation from inside the leaf closes when the plant is under water stress and at night. When closed, CO_2 needed for Calvin cycle cannot enter. Since the concentration of CO_2 is low, oxygen will bind to the active site of RuBisCO. When oxygen is bound to RuBisCO, RuBP is broken down and CO_2 is released. This wastes energy and is of no use to the plant. It is called photorespiration because oxygen is taken up and CO_2 is released. Normally, photosynthesis reduces CO_2 to carbohydrate, but because oxygen is taken up and CO_2 is released, further production of energy is not allowed at night. The plant only make use of the already stored energy thereby reducing the level of the stored energy until the next day when the energy level begins to increase, as production of energy through photosynthesis will commence.

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