Elton Koroly

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Senior Seminar

Light Intensity and Duration on Plant Growth Rates

Introduction:

A recent issue of National Geographic contained a very interesting story on Light. The cover of the issue cites "The End of Night: Why We Need Darkness". The story centered on artificial light created all across the globe. Scientists are just beginning to study this phenomenon, called Light Pollution. "Its benefits come with consequences" (Klinkenborg, 107). The article states that "Wherever human light spills into the natural world, some aspect of life – migration, reproduction, feeding – is affected" (Klinkenborg, 108). The article generally concentrated on these areas. However, the effect of Light pollution is an interesting topic and the author failed to mention the plant ecology angle of the story. What is the effect of light pollution on plants, and has the author missed the larger point? What is the potential effects light intensity and duration can have on plant growth?

Another concept this may effect is the "Green roof". Green roofs are roofs covered in vegetation and usually consist of a thin layer of substrate and a drainage layer. Green roof plants are commonly short perennials, grasses and succulents including varieties of Sedum. These plants will cover the roof and delay storm water runoff, provide insulation and regulate temperatures as well provide a habitat for animals and much more (http://www.greenroofs.org). They are truly important in urban design and landscape as an efficient and effective eco-friendly design feature. Does "The End of Night" have an effect on green roofs?

The topic is so broad; it is hard to begin to address the entire issue. In an attempt to begin to examine this, some facts can be stated. Light is everything to a plant. Light regulates many different processes within a plant. Photoperiodism, the plants ability to flower at a specific time of year is one example of such process. Photosynthesis, the plants ability to convert sunlight, carbon dioxide and water into simple sugars is the most important process affected by light. Photosynthesis is the conversion of light energy into chemical energy by photosynthetic pigments using water and carbon dioxide to produce carbohydrates (Raven, Evert, and Susan Eichhorn pg.116). Photosynthesis can be broken down into two stages:

a. Light reactions, in which chlorophyll capture sunlight and threw several reactions convert sunlight into chemical energy. ATP is synthesized and NADPH supplies the electron used to split water. The chemical energy is then used in the second stage (Taiz & Zeiger pg.132-33).
b. Light Independent reactions, which use the energy molecules formed in the light reactions to reduce carbon dioxide and form inorganic compounds which the plant uses for biosynthesis (Taiz &Zeiger pg.160-61).

The mechanisms by which plants transform carbon dioxide into organic compounds are known as metabolic pathways or carbon fixation pathways. They can be split into three categories based on how they process carbon dioxide:

c. C3 Cycle, or Calvin Cycle, called C3 because the carbon dioxide is first incorporated into a 3-carbon compound, 3 Phosphoglycerate.
 The Stomata are open during the day. Rubisco is the enzyme involved in the reduction of carbon dioxide. C3 plants are more efficient than C4 and CAM plants under cool and moist conditions because it requires less energy. Most plants are C3 and all plants use C3 (http://wc.pima.edu/~bfiero/tucsonecology/plants/plants_photosynthesis.htm).
d. C4 Cycle, called C4 because the carbon dioxide is first incorporated into a 4-carbon compound malate. C4 cycle uses PEP Carboxylase for the enzyme involved in the reduction of carbon dioxide. Involves two different types of cells, the mesophyll and bundle sheath cells. This is termed Kranz anatomy. The stomata are open during the day. C4 plants

photosynthesize better than C3 plants under high light intensity and high temperatures because the carbon dioxide is delivered directly to rubisco. C4 plants use water more efficiently because PEP Carboxylase assimilates carbon dioxide faster and does not need to keep the stomata open as much. C4 plants include several thousand species in at least 19 plant families. (http://wc.pima.edu/~bfiero/tucsonecology/plants/plants_photosynthesis.htm).

e. CAM – Crassulacean Acid Metabolism

Called CAM after the plant family in which it was first found (Crassulaceae) and because the carbon dioxide is stored in the form of an acid either malate or aspartate. This unique adaptation allows the stomata to open at night and close during the day which prevent excess water loss. The carbon dioxide is assimilated at night where it is converted into oxaloacetate which is then converted into acid (malate or aspartate) and stored in the vacuoles. Upon daybreak the acid is transported to the chloroplast and will be decarboxylated and the carbon dioxide is released to the Calvin cycle (Taiz & Zeiger pg.180). CAM plants use of water is the most efficient and therefore CAM plants photosynthesize at higher rates than C3 or C4 plants in hot arid conditions due to opening of the stomata at night when transpiration rates are lower. When conditions are extremely arid, CAM plants can leave their stomata closed all night and day. Oxygen given off in photosynthesis is used for respiration and carbon dioxide given off in respiration is used for photosynthesis. This is called CAM-idling and does allow the plant to survive dry spells, and it allows the plant to recover very quickly when water is available again CAM plants include many succulents such as cacti, agaves and also some orchids and bromeliads (http://wc.pima.edu/~bfiero/tucsonecology/plants/plants_photosynthesis.htm).

This paper and experiment will look at growth rates based on light intensity and duration for a few select species of succulent plants from the Crassulaceae family. The Crassulaceae family is commonly known as the stonecrop family. Sedum is one of the 38 genera found in the family. The family has over 1200 species of succulent plants (http://nt.arsgrin.gov/sbmlweb/OnlineResources/SeedsFruits/rptSeedsFruitsFamData.cfm?thisFamily=Crassulaceae).

These succulents are found in arid regions around the world. These succulent plants have a unique adaptation to deal with these extreme environments; a photosynthetic metabolism know as CAM (Crassulacen Acid Metabolism) which allows them the ability to exchange gases at night rather than during the day in turn reducing water loss. These plants are the choice for green roofs for there ability to withstand intense light, extreme temperatures and severe drought conditions (http://nt.arsgrin.gov/sbmlweb/OnlineResources/SeedsFruits/rptSeedsFruitsFamData.cfm?thisFamily=Crassulaceae).

Experiment Overview:

The experiment will look at growth rates based on the light intensity and durations across four different species of the Crassulaceae family. The four to be looked at are:

1) *Sedum sexangulare*
2) *Sedum album*
3) *Sedum montanum*
4) *Phedimus takesimensis*

The experiment will look at whether a variation in light intensity and duration will have an effect on growth rates. In theory the CAM plants under 24 hours of light will not fix the carbon Dioxide necessary for overall growth. Once these findings are discovered, one could make assumptions on “The End of Night” and its effect on CAM plants.

Experiment Details:

The experiment measured the growth rates of a few select Crassulaceae species under different light conditions and compared the results. The experiment involved 3 boxes. Each box was built with the dimensions of 3 feet by 3 feet by 2 feet and was fitted with an aluminum lid, 200 watt light bulb, an exhaust fan, and a temperature gauge.

Each box contained 12 plants from the Crassulaceae family, 3 of each species.

- *3 Sedum montanum*
- *3 Sedum sexangulare*
- *3 Sedum album*
- *3 Phedimus takeinesis*

Each box contained different light characteristics:

- Box #1 contained a 200 watt bulb and the timer was set for 12 hours of light and 12 hours of dark. (This box serves as a Control)
- Box #2 contained a 200 watt bulb and the timer was set for 15 hours of light and 9 hours of dark.
- Box #3 contained a 200 watt bulb and a 25 watt bulb. The 200 watt was set for 12 hours of light, turns off, and then the 25 watt bulb comes on for 12 hours providing the plants in box #3 with 24 hours of light exposure; under two different intensities.

At the beginning of the experiment, 3 plants of each species were dried for 48 hours, weighed to the nearest tenth of a gram. The weights were then recorded. 3 plants of each species were then planted in a 3 to 1 substrate, consisting of 3 parts expanding slate (a common ingredient in substrate for green roofs) to 1 part pasteurized soil from the school's green house. Each plant was then watered to field capacity.

Expectations and Results:

"For most plants, maximum growth and photosynthetic rates occur in full light and rates decrease as the light is reduced" (Holt).

Based on this quote the box under 24 hours of light should have had the most growth followed by the box with 15 hours of light and finally the control box with 12 hours of light. That was not the case. The control box with 12 hours of light had the most growth, followed by the box under 24 hours of light. The box under 15 hours of light showed little to no growth. Sabotage? unlikely.

A journal article stated that "under conditions of continual irrigation, seasonal and temperature changes affected the degree of dark carbon dioxide fixation and acid metabolism, but these cacti did not change from CAM to carbon dioxide fixation in the continuous light"(Hanscom, III and Irwin P. Ting). Then how does the plant fix the carbon dioxide necessary for growth in the absence of dark?

A journal article discussed "Photoinhibition of the CAM succulent Opuntia basilaris growing in Death Valley" (Adams III, S. D. Smith and C. B. Osmond). This article states that most photoinhibition occurs in situations where external factors have been manipulated. Under intense light photoinhibition would have slowed the growth rates of plants growing under 24hours of light. That was not the case. At the end of the experiment, each plant was removed and dried for 48 hours. It was then weighed to the nearest tenth of a gram, and compared to the initial samples as well as the other plants. Below are the measurements:

Species	**Start Dry Weight**	**End Dry Weight**		
		Box#1	**Box#2**	**Box#3**
Sedum montanum	10.9g	14g	12g	14g
Sedum sexangulare	11.0g	30g	11g	22g
Sedum album	12.0g	15g	13g	15g
Phedimus takeinesis	10.3g	15g	14g	15g

Box#1, which contained a 200 watt bulb and the timer, is set for 12 hours of light and 12 hours of darkness, the following was observed:

Strongest growth across all species

Best overall performance among species was *Sedum sexangulare*

Individual species performed as follows:

Sedum montanum – 3 gram increase, moderate uniform growth.

Sedum sexangulare – 20 gram increase, strong uniform growth.

Sedum album – 3 gram increase, moderate uniform growth.

Phedimus takeinesis – 5 gram increase, moderate uniform growth.

Box#2, which contained a 200 watt bulb and the timer, is set for 15 hours of light and 9 hours of darkness, the following was observed:

If any, slow, poor growth across all species

Best overall performance among species was *Phedimus takeinesis*

Individual species performed as follows:

Sedum montanum - 1 gram increase, poor growth and random death.

Sedum sexangulare - no growth, dried up and died.

Sedum album – 1gram increase, poor uniform growth.

Phedimus takeinesis – 3 gram increase, moderate uniform growth.

Box #3 contained a 200 watt bulb and a 25 watt bulb. The 200 watt is set for 12 hours turns off and the 25 watt bulb comes on for 12 hours providing the plants in box#3with 24 hours of light exposure and two different intensities. The following occurred:

Moderate to strong growth across all species

Best overall performance among species was *Sedum sexangulare*

Individual species performed as follows:

Sedum montanum - 3 gram increase, moderate uniform growth.

Sedum sexangulare – 11 gram increase, strong uniform growth.

Sedum album – 3 gram increase, moderate uniform growth.

Phedimus takeinesis – 5 gram increase, moderate uniform growth.

Conclusion:

From the results of the experiment, broad conclusions can be made.

- Light definitely effects growth rates of the Crassulaceae family.
- Different durations of light effect the Crassulaceae family of plants.
- Light intensity did not have as much of an effect as light duration.
- Biomass measurements showed that light intensity and duration impacted strong growth.

The findings also support that low variations of light will not have significant effect on growth rates of Crassulaceae family plants. That would then also indicate that green roofs, in urban environments where light pollution is present, remain a great alternative for eco-friendly and efficient landscape design.

Citations:

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