Sweet Beets: Making Sugar Out of Thin Air

by
Sarah R. Sletten
Division of Science and Mathematics
Mayville State University, Mayville, ND

Part I – First Fall in the Red River Valley

Jack knew that things would be different for him when he made the move from sunny Miami up to North Dakota to play college football. He was anticipating the upcoming long winter, and wondered how cold it would be for morning practices; he was happy that he had insulating football gloves!

On a Sunday night in late September, after a light rain, Jack and a couple of his teammates decided to go out for 25-cent wing night and watch the game. Their college was a little out of the city, and shortly after turning on to the county highway Jack hit a huge mud slick on the road and slid into the ditch! Luckily, there wasn't any snow yet, so he was able to drive right out and they were again on their way to catch the game and the wing special.

One of Jack's teammates, a longtime resident of North Dakota, explained that muddy roads are a big problem during the fall, especially after a rain. He said that beet trucks drag dirt and mud out of the fields and make a huge, slippery mess with every harvest.

"Beets! You're not in Florida any more," Jack thought to himself.

Figure 1. Sugar beet *(Beta vulgaris), Botanische Wandtafeln* (Botanical Wallchart) by Alois Pokorny (1826-1886) *Source:* https://commons.wikimedia.org/wiki/File:Beta_vulgaris_Pokorny.jpg

Part II – Mountains on the Prairie

Located a few states north of Oklahoma, the landscape of eastern North Dakota and western Minnesota runs along the beds of the Red River of the North and provides some of the flattest farm land in the world. The Northern Great Plains' lack of terrain and trees allows a person to see for miles on end. However, each fall, gigantic mounds of sugar beets are stockpiled up and down the valley, creating what appears to be mountains in the distance.

Figure 2. Sugar beet stockpiles, October 2013.

Question

1. Sugar beets *(Beta vulgaris)* are a major crop in the Red River Valley of the North. Why do you think the beets have to be harvested and stockpiled in September?

Part III – Sugar Beet Anatomy

Beta vulgaris is a plant that has a large taproot, or beet, that grows underground. It is white and shaped like a short, fat carrot. The inside of the beet is made up of vascular tissue containing xylem and phloem. The plant also has numerous large, dark-green leaves that grow in a tuft from the center of the beet. These leaves are perforated with stomata on both the upper and underside.

Beta vulgaris is best grown in soil that is level, rich in nutrients, and deep enough for several inches of cultivation. The desired climate is temperate with long periods of moderate intensity sunshine.

Figure 3. Sugar beet intact and (left) and cross-section (right).

Figure 4. Sugar beet field, August 2014.

Questions

1. The anatomy of *Beta vulgaris* has two major parts: (1) the taproot or beet, and (2) the leaves. What functions do these two parts carry out for the plant?
2. What functions do the vascular tissue and stomata carry out for the plant?
3. Why do you think level, nutrient-rich, and deep soils are optimal conditions for *Beta vulgaris?*
4. Why do you think long periods of moderately intense sunlight is ideal for *Beta vulgaris?*

Part IV – Making Sugar

Like all land plants, *Beta vulgaris* is a photoautotroph. This means that it generates its own energy supply by capturing energy from the sun and using it to make carbohydrates. This process is called *photosynthesis* because molecules are being synthesized with light energy. Some of the carbohydrates made during photosynthesis are used directly by the plant for energy to carry out life's processes. Any remaining carbohydrates are stored within plant tissue.

Plant photosynthesis takes place in chloroplasts, which are organelles found mainly in leaf cells. The carbon source for carbohydrate production comes from carbon dioxide (CO_2) taken directly from the air around the plant. Water (H_2O) is also utilized during photosynthetic reactions, which produces oxygen (O_2) as a byproduct. The following equation summarizes the overall general reaction:

$$6CO_2 + 12H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

In the above general reaction, 6 molecules of CO_2 and 12 molecules of H_2O are taken into the plant and, with the energy from the sunlight, 1 molecule of the carbohydrate glucose ($C_6H_{12}O_6$) is made along with 6 molecules of H_2O and 6 molecules of O_2.

These reactions are carried out in a series of enzyme catalyzed reactions that are divided broadly into light-dependent and light-independent reactions. The reactions in the light-dependent phase of photosynthesis require the energy from sunlight to make ATP (cell energy units) and NADPH (electron carriers). The light-independent reactions make up what is known as the Calvin cycle, and are responsible for taking the carbon out of CO_2 and incorporating it into a carbohydrate (e.g., glucose). This processes is called carbon fixation. Carbon fixation requires the ATP and NADPH generated in the light-dependent reactions to make carbohydrates from CO_2.

Photosynthesis in *Beta vulgaris* follows the general equation above and makes glucose for energy and structural growth. Any glucose not used directly by the plant is further modified and stored in the "sink tissue" (the beet) as sucrose ($C_{12}H_{22}O_{11}$). Sucrose is more commonly known as "table sugar" and is made up of a glucose molecule joined to a fructose (another carbohydrate) molecule.

Questions

1. Recall the videos you watched prior to beginning this case. Use that information, along with other resources, to sketch a simple diagram of the process of photosynthesis. Include: CO_2, H_2O, sunlight, ATP, NADPH, carbohydrates, and O_2 and identify the light-dependent and light-independent reactions. If possible, also include the intermediary products during carbon fixation.
2. Photosynthesis requires a supply of CO_2 as well as H_2O and sunlight. How do plants obtain these resources? (*Hint:* refer to plant anatomy.)

Part V — Connecting to the Larger Picture

Global atmospheric CO_2 levels are monitored closely by the National Oceanic and Atmospheric Administration (NOAA). The tables below provide two years of data collected by the NOAA Southern Great Plains station located in Oklahoma.

Year	2012											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CO_2 (ppm)	398	398	395	391	394	396	394	393	396	398	400	403

Year	2013											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CO_2 (ppm)	404	404	403	400	399	397	394	392	394	398	402	404

Data are reported as numbers of molecules of CO_2 per total molecules of air (excluding water vapor) and expressed as parts per million (ppm). Data was retrieved from Dlugokencky, 2015.

Questions

1. Graph the data in the tables above. What trends in CO_2 levels do you notice over the course of a year?
2. What may be some possible contributors to the higher carbon dioxide levels found during the fall and winter months vs. the summer months?
3. How do those trends correspond to the *Beta vulgaris* growing season in the Red River Valley of the North?
4. Provide an explanation of how *Beta vulgaris* plays a role in the movement of carbon atoms between living and non-living systems.

References

Artschwager, E. 1926. Anatomy of the vegitative organs of the sugar beet. *Journal of Agricultural Research* 33(2), 143-176.

Dlugokencky, E.J., P.M. Lang, K.A. Masarie, A.M. Crotwell, and M.J. Crotwell. 2015. Atmospheric carbon dioxide dry air mole fractions from the NOAA ESRL carbon cycle cooperative global air sampling network, 1968–2014, Version: 2015-08-03, path: ftp://aftp.cmdl.noaa.gov/data/trace_gases/co2/flask/surface/co2_sgp_surface-flask_1_ccgg_month.txt. Last accessed September 2, 2015.

Raven, P.H., G.B. Johnson, K.A. Mason, J.B. Losos, and S.R. Singer. 2014. *Biology* (10th ed.). New York: McGraw-Hill.

Rolph, G.M. 1917. *Something about Sugar: Its History, Growth, Manufacture, and Distribution.* San Francisco: John J Newbegin.

Singh, R., and S. Malhotra. 2000. Carbon fixation, sucrose synthesis, and its transprot to storage tissues. In A. K. Gupta and N. Kaur (Eds.), *Carbohydrate Reserves in Plants*. Amsterdam, The Netherlands: Elsevier Sciences B. V.

Warrick, J. 2014. CO_2 levels in atmosphere rising at dramatically faster rate, U.N. report warns. *The Washington Post*, Online, September 9. http://www.washingtonpost.com/national/health-science/co2-levels-in-atmosphere-rising-at-dramatically-faster-rate-un-report-warns/2014/09/08/3e2277d2-378d-11e4-bdfb-de4104544a37_story.html. Last accessed August 28, 2015.