Aug 11, 2022

Script (english)

Slide 1

Good afternoon, I am Scott Oswald, and today, I'd like to share a bit of insight into the regulation of non-structural carbohydrate dynamics from studying how to model their dynamics.

Slide 2: fatichi figure

First, what are non-structural carbohydrates (that is NSCs)? Simply put, NSCs are sugars and starch. These chemical compounds act as energy and carbon reserves in plants.

Plants make sugars in their leaves during photosynthesis. These sugars are then used for respiration, growth, and other parts of metabolism; however, these sugars can also be converted to starch and saved for later use. This starch can be remobilized to support sugar metabolism when photosynthesis cannot.

So, in this manner, NSCs decouple photosynthesis and the rest of metabolism. For ease of exposition, I'll just be talking about NSCs, but the different roles of sugars and starch do mean different dynamics.

We know that there's several factors that affect the rate of photosynthesis—such as light, CO2, and temperature—and thus the rate of NSC supply.

There's also many factors that affect the rate of respiration and growth—such as temperature, water, and nutrient availability—and thus the rate of NSC demand.

Slide 3: from here to there

So we have this basic paradigm of NSCs as storage but how do we determine the dynamics that we observe?

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Here's an example. Here, you see temporal variation in starch from an actual experiment on Loblolly pine saplings. The smooth fit is from a generalized additive model; it tells us how the measurements varied but not how photosynthesis or respiration and growth drove that variation, nor what we might see in a different experiment.

So the basic question is how to go from processes to dynamics and what do dynamics tell us about the processes. A bit of math helps us go between the two.

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Slide 4: water bucket

So here's an analogy to make talking about the regulation of NSC dynamics more intuitive and to make the math visual. Imagine that the amount of NSC is a bit like the amount of water in a bucket.

The change in the amount of NSC stored is the supply minus demand—that is the amount that flows in minus the amount that flows out.

Of course, the rates of supply and demand depend on the environment. For instance, changing light changes photosynthesis, and so the rate of supply; it's like opening or closing the upper valve. And likewise for the lower valve and demand.

However, as the analogy suggests, the rates of supply and demand can vary as a function of the amount of NSC stored.

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To use the analogy, imagine that the rate of outflow depends on the water pressure, which depends on how much water there is. In this case, more NSC means more demand. We allow the same possibility for the inflow.

Slide 5: supply-demand = torricelli's law

This plot shows how supply and demand could vary as the amount of NSC stored changes.

This dependence is at the core of NSC regulation, because this dependence greatly affects how NSC responds to a changing environment.

Slide 6: supply and demand and bucket dynamics

To see why, let's suppose a constant environment for the moment, so that the valves aren't changing, and the NSC dynamics are only determined by the feedback between supply and demand. What happens?

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Here, the intersection of the supply and demand curves corresponds to the amount of NSC at which supply equals demand and a balance is achieved.

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So, if the amount of NSC is below this balance point, it will increase because supply exceeds demand.

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Inversely, if the amount is above this balance point, it will decrease, because the demand exceeds supply. But once the amount of NSC reaches the balance point, it stops changing.

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Here's a geometric picture of these dynamics. Each blue line in this streamplot indicates a possible time-series of NSC amount. If the amount of NSC starts here, it follows the blue curve; if it starts here, it follows the blue curve.

Notice how the balance point attracts the trajectories. In this case, the balance point is an attractor, and the attractor is the long-term response. All starting positions approach this attractor. Because the environment is constant in this case, the attractor is unchanging in time.

Slide 7: attractor and flow

Now as the environment changes, supply and demand changes, and the balance changes. So the balance point—in orange—changes constantly.

As before, trajectories below the balance point are increasing as supply exceeds demand. Trajectories above are decreasing as demand exceeds supply.

As before, the trajectories are attracted to an attractor, shown in black. If NSC starts here it follows the blue line until it hits the attractor. Because all starting conditions approach it, the attractor is what is mostly likely to be observed in experiment.

Unlike before, the balance point is not equal to the attractor when the environment is changing; in fact, the attractor lags changes in the balance point because it takes time for NSC to respond. The existence of a balance point implies an attractor through time—and many of their properties correspond.

Now that we have this setup, how do we use it to interpret what we observe in experiments?

Slide 8-9: supply vs demand driven dynamics

I have time for a short example. First, we suppose the environment only affects NSC supply through time; i.e., we only change the valve up top, say to simulate how photosynthesis varies seasonally. The other valve is held constant.

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Here we have a streamplot showing two years of the resulting seasonal NSC dynamics; the blue lines of the streamplot are trajectories from all starting values.

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The balance point is shown in orange; it's high in summer, low in winter, reflecting high and low photosynthesis.

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and the resulting attractor is shown in black. Notice the lagging response to changes in the balance point.

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We have a maximum balance point here in mid-summer.

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But the maximum NSC concentration of the attractor is here, up to a couple of months later in summer or early fall.

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And same thing here, minimum balance point in winter, but the minimum NSC in early spring.

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but the minimum NSC in early spring

This is the prototypical dynamics for when the environment only affects supply.

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So now, let's suppose instead we only vary the bottom valve so the environment only affects NSC demand.

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Here again is the streamplot for two years. The timing of maxima and minima are flipped.

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Now the minimum balance point is in summer because higher demand in summer decreases the balance point.

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And now, the minimum NSC occurs almost at the same time, because the lag is much less.

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However, while the maximum balance point is in mid-winter

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The maximum NSC occurs later in spring, well after the maximum balance point.

In all cases, features like the amount of lag, the amplitude, and so on, depend on how quickly the blue lines converge the attractor. This convergence depends on how the amount of NSC stored affects supply and demand more so than the external environment.

So comparing the top scenario to the bottom identifies several qualitative differences.

Even without more detailed, quantitative analysis, a prototypical comparison of supply and demand driven dynamics yields interesting interpretations.

Slide 10: Data comparison

Going back to the data from before,

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Notice that the starch concentrations reach a minimum in late summer.

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Here's some root starch data from two more species. And you can see they also appear to have a seasonal minimum in fall.

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Although not exactly, this roughly matches the prototypical dynamics for when the environment only affects demand.

Furthermore, other measurements indicate that these trees continue to photosynthesize throughout winter, suggesting that seasonal NSC supply does not vary much seasonally.

Together, these observations suggest that growth and respiration drives starch dynamics in these trees; and further simulation would help us understand how starch dynamics might change in experimental manipulation.

Slide 11: Summary

So the main takeaway are that

- simple NSC regulation can yield complex NSC dynamics because the environment varies in complicated ways
- but the balance point and attractor depend on the feedback between the amount of NSC stored and its supply and demand, that is, it depends on the NSC regulation

There is much more to say. We have an up-coming publication on this work; but that’s all the time I have for now.