Plants Show Us the Light

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In a recent article published in *Science,* Arp et al. propose a new theory as to why plants are green: plants prioritize the management of light fluctuations over maximal efficiency. Beyond plant science, this conclusion may inspire our sustainability strategies, to shift our societal goals from performance to resilience.

Life on our planet largely depends on the ability of plants to harvest light and convert it into metabolites and energy sources. However, it may come as a surprise to many that photosynthesis is in fact very inefficient. In theory only up to 2% of the energy of the incident solar radiation is captured, and this number drops to 0.3 to 0.85% when measured in real ecosystems [1]. This is reflected in part by the color of plants: they are green, because they absorb much less green light than red and blue light (Figure 1). What could be the evolutionary advantage of such a wasteful strategy? A recent study goes one step further to explore the biophysical mechanism behind such apparent inefficiency. Plants are exposed to dynamic light properties and fluctuating molecular structures. Dealing with such noise has a cost, and this implies wasting a lot of energy [2].

Some of the plant strategies that deal with light intensity fluctuations were already known. For instance, a sudden burst of light can lead to photo-oxidative stress in the photosynthetic light harvesting complexes. One of the functions of carotenoid pigments is precisely to convert this excess of light energy into heat, i.e. to dissipate the excess of energy input. What is new here is that the authors dealt with the systemic response of light harvesting complexes to noisy light fluctuations and internal cell dynamics.

In short, the quantum conversion of photons into energy is a physical process that works best when the input is steady. In theory, to reduce the fluctuations in the rate of energy flow, one would need to have absorbing peaks in very close light wavelengths (e.g. red and red-orange).

However this is not observed in real living systems, simply because both light and protein properties fluctuate: a light harvesting system cannot be tuned like one fixes a radio [3]. What the authors find instead is that spread-out absorption peaks, i.e. red and blue, can effectively reduce noise, allowing steady input of energy, while being robust to fluctuations. This theory is strongly supported by the fact that the well-known absorption spectra of photosynthetic systems peak in red and in blue, also explaining why plants appear green [2][4].

This is a remarkable example illustrating how living organisms have selected robustness over performance during evolution. Efficiency is indeed not the common denominator of life. At the molecular scale, living systems are very random, redundant, heterogeneous, inconsistent... in short, not very efficient. This is in line with an ongoing revolution in molecular biology, where the many roles of stochasticity are beginning to be understood through quantitative approaches [5][6]. The recent work by Arp et al. [2] illustrates the need to take into account much longer time scales, within which local inefficiencies can balance each other to generate robustness. In other words, this analysis of photosynthesis illustrates the trade-offs between efficiency and resilience in biology.

Back to societal questions, the current Covid-19 crisis illustrates how such a trade-off may also be relevant to other sectors [7]. Seeing the Anthropocene as the era of man-made uncertainties, taking inspiration from such a viewpoint might be very timely. The environmental crisis is indeed largely caused by the blind compass of humans towards efficiency increments, a bit like the light harvesting complex going into photo-oxidative stress. This is a trivial observation when considering the green revolution and the associated negative externalities on desertification, pollutions and biodiversity collapse. The same applies to strategies supporting over-fishing, over-mining or over-consumption. Gains in efficiency can be counterproductive, and this has already been theorized [8]. It is even the basis of the rebound effect, or the so-called "curse of efficiency": gains of efficiency usually make a technology more attractive, meaning that resource consumption is not reduced, but does increase globally [9][10]. Many reports, and most notably the Meadows reports on the limits to growth, have implicitly warned humanity against such excesses for the long-term viability of our civilization [11][12].

The lesson from plant light harvesting complexes does not only shed light on our past, it could also question our future sustainable development strategies. Dealing with noisy environments is a well-known challenge in engineering, e.g. when designing energy grid architecture [13]. More broadly, such suboptimal strategy can be observed in many contexts, from technological to cultural spheres [14]. How could this translate into our future sustainable strategies? For instance, should we first consider the stochastic nature of supplies (e.g. rare earth availability) and environmental conditions (e.g. increasing wind variance following the climate crisis), instead of prioritizing the gains in efficiency in energy conversion when developing renewable energy solutions? With geo-engineering, are we not trying to optimize our climate, i.e. to make it more efficient for our needs in a reductionist framework, instead of embracing uncertainty.

During Earth's history, living organisms have demonstrated their ability to adapt to unthinkable conditions. Organisms do not build such resilience on increased efficiency, but instead on their intrinsic inefficiencies [15]. How can this work? As shown in the photosynthetic light harvesting complexes, robustness is an emerging property of the interactions between apparent weaknesses. This can be illustrated in other biological contexts too. For instance, most of the molecular factors in our cells occur in very small numbers, which partly explains the unpredictability of living beings, even at that scale. However, there is great redundancy in these families of molecules and in biological processes, which partly compensates for randomness. Finally, two "weaknesses", randomness and redundancy, balance each other out. It is a bit like a car, where acceleration and braking allows a stable speed regardless of the slope of the road. For living beings, the maintenance of such autonomy allows resilience in the face of environmental fluctuations. This also applies to biomechanics: most living systems are experiencing a balance between tension and compression. This balance provides them with a mechanical resistance to external noise, a bit like a suspension bridge (with its threads under tension and its deck under compression) when it is exposed to wind.

Such suboptimality may very well be a source of inspiration for our future sustainability. Three key principles could be put forward:

1- Based on how inefficient biological systems are intrinsically (see e.g. the 2% maximal yield of photosynthesis), we might vastly underestimate the "slack" needed for true resilience in our societies;
2- Biological systems can afford many internal weaknesses, because those are also often antagonistic (e.g. randomness vs. redundancy); conversely, this generates a form of

autonomy and thus a built-in shield against environmental fluctuations (a component of resilience)

3- Efficiency is more easily understood when referring to the individual scale, whereas resilience usually always applies to the population and thus implies systems thinking.

Although suboptimality is likely to be a key element of our sustainable future, we could be blinded by the attractive and shiny prospect of short-term efficiency. In that respect, our green world is not only harvesting the light, it may very well show us the path to resilience.

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References

1. Smil, V. (2013). Harvesting the biosphere: what we have taken from nature (Cambridge, USA: MIT Press).

2. Arp, T.B., Kistner-Morris, J., Aji, V., Cogdell, R.J., van Grondelle, R., and Gabor, N.M. (2020). Quieting a noisy antenna reproduces photosynthetic light-harvesting spectra. Science *368*, 1490–1495.

3. Lazebnik, Y. (2002). Can a biologist fix a radio?—Or, what I learned while studying apoptosis. Cancer Cell *2*, 179–182.

4. Ortega, R.P. (2020). Why Are Plants Green? To Reduce the Noise in Photosynthesis. Quanta Mag. Available at: https://www.quantamagazine.org/why-are-plants-green-to-reduce-the-noise-in-photosynthesis-20200730/ [Accessed July 30, 2020].

5. Tsimring, L.S. (2014). Noise in biology. Rep. Prog. Phys. Phys. Soc. G. B. *77*, 026601.

6. Nicholson, D.J. (2019). Is the cell really a machine? J. Theor. Biol. *477*, 108–126.

7. Meadows, D.L. (2020). Limits to Growth and the COVID-19 epidemic. Chelsea Green Publ. Available at: https://www.chelseagreen.com/2020/limits-to-growth-covid-epidemic/ [Accessed August 9, 2020].

8. Illich, I. (2009). Energy and equity (London; New York: Marion Boyars).

9. Jevons, W.S. (1865). The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines (London & Cambridge, UK: Macmillan & Co).

10. Foster, J.B., Clark, B., and York, R. (2010). Capitalism and the Curse of Energy Efficiency: The Return of the Jevons Paradox. Mon. Rev. *62*, 1.

11. Meadows, D.H., Randers, J., Meadows, D.L., and Behrens, W.W. (1972). The Limits to growth: a report for the Club of Rome's project on the predicament of mankind (New York: Universe Books).

12. Meadows, D.H., Randers, J., and Meadows, D.L. (2009). The limits to growth: the 30-year update (London: Earthscan).

13. Schmietendorf, K., Peinke, J., and Kamps, O. (2017). The impact of turbulent renewable energy production on power grid stability and quality. Eur. Phys. J. B *90*, 222.

14. Grumbach, S., and Hamant, O. (2020). How humans may co-exist with Earth? The case for suboptimal systems. Anthropocene *30*, 100245.

15. Hamant, O. (in press). Suboptimality (Paris, France: Odile Jacob).

Figure legend

Figure 1. Plants reflect green light, dissipating and wasting a lot of solar energy. Designing future sustainable bio-inspired strategies will depend on our ability to avoid the trap of over-optimization, i.e. on our ability to understand what resilience entails. Credit photo: Technology photo created by jannoon028 - www.freepik.com https://www.freepik.com/free-photo/plant-growing-bulb_969640.htm