Effect of Oxygen on Photosynthesis, Photorespiration, and Respiration—Commentary

Forrester ML, Krotkov G, Nelson CD (1966) Effect of oxygen on photosynthesis, photorespiration and respiration in detached leaves. I. Soybean. Plant Physiol **41:** 422–427

This article played a prominent role in establishing the interrelationship between O_2, CO_2, photosynthesis, and photorespiration in C_3 plants. The research was done by Marlene Forrester, a graduate student working with Gleb Krotkov and C.D. Nelson at Queen's University in Kingston, Ontario. Many of their observations had been previously published with other species, but I was drawn to this particular article because I had been hired to improve soybean photosynthesis at the U.S. Department of Agriculture laboratory in Urbana, Illinois, and control of photorespiration offered promising potential in this regard. In the late 1960s, photosynthesis research was experiencing a robust renaissance because of the discovery of C_4 photosynthesis and from work by many people finding novel but perplexing O_2 effects on photosynthesis, CO_2 compensation points, photorespiration, and related physiological parameters. I spent a year reading and trying to understand the observations in this article, writing and rewriting simple equations to describe the data, particularly the inhibition of CO_2 fixation by O_2, the linear relationship between O_2 and the CO_2 compensation point, and the equations that included a term they labeled "carboxylation efficiency." Photosynthesis and photorespiration were considered to be competing processes, and the CO_2 compensation point was that combination of CO_2 and O_2 concentrations where the rates of photosynthesis and photorespiration were equal. In my mind, the most critical fact in this article was the linear dependence of the compensation point on O_2 concentration. Furthermore, from the literature and measurements in my laboratory, I also knew that the compensation point of all C_3 species was the same, about 40 μL L^{-1} at 25°C and 21% O_2. How could two separate processes give these linear and invariable results? After studying this article and related literature, I concluded that the O_2 and compensation point data could be explained only if the same step rate limited both photosynthesis and photorespiration. But what was this step? At the time, George Bowes was a postdoctoral fellow in my laboratory, and we had decided an important rate-limiting enzyme in CO_2 fixation was carboxydismutase, later designated Rubisco, so Bowes was developing techniques and experiments to study this enzyme in soybean. Back then, Rubisco assays routinely included reduced glutathione to protect Rubisco sulfhydryls, but in one experiment Bowes used glutathione that had become oxidized, a propitious happenstance that subsequently led to the discovery that Rubisco CO_2 fixation was competitively inhibited by O_2. From this result, we knew instantly that Rubisco was the common rate-limiting step in photosynthesis and photorespiration, initiating photosynthesis with CO_2 fixation and phosphoglycerate production, and photorespiration with O_2 fixation and phosphoglycolate production. Demonstrating ribulose 1,5-bisphosphate oxygenase activity did not come easily, however, but after three separate attempts over 17 months, bolstered by the insights gleaned from Forrester et al., Bowes successfully demonstrated Rubisco-mediated synthesis of phosphoglycolate from ribulose 1,5-bisphosphate and O_2. An additional key development arising from this article is that carboxylation efficiency was an apt and prescient description of this factor, as subsequent analysis and experimentation determined that it comprises the kinetic constants of Rubisco.

Submitted by William L. Ogren
Hilton Head Island, South Carolina 29928

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