



USDA

*A Missouri farmer with rice plants. More CO<sub>2</sub> would increase rice productivity.*

## C4 vs. C3 Photosynthesis: A Response to Low CO<sub>2</sub> Levels

by Christine Craig

About 90 percent of land plants, including both monocots and dicots, are equipped to photosynthesize only through the C3 photosynthetic pathway. Chloroplasts of only one type of plant cell, the mesophyll cell, are primarily involved in photosynthetic light capture and CO<sub>2</sub> assimilation into 3-carbon carbohydrates, which are then used to manufacture plant structural and functional elements.

The problem with this situation, as far as human food production is concerned, is that, “under current atmospheric conditions (0.036% CO<sub>2</sub>, 21% O<sub>2</sub>), up to 50% of the fixed carbon is lost by photo-

respiration”<sup>1</sup> in such plants.

Why? The enzyme which catalyzes the primary CO<sub>2</sub> fixation reaction in mesophyll chloroplasts, Rubisco, is sensitive to CO<sub>2</sub> concentration. Under low CO<sub>2</sub> conditions, it will bind with oxygen instead, essentially, breaking down carbohydrate and releasing CO<sub>2</sub>, in a process known as photorespiration. This is considered very wasteful to plant productivity.

C4-type photosynthesis apparently evolved at various times, in various plant groups, as a mechanism of concentrating CO<sub>2</sub> in the cells where CO<sub>2</sub> fixation is occurring. In monocots such

as maize and sorghum, this is accomplished by a division of labor between two cell types: CO<sub>2</sub> is brought into mesophyll cells, chemically joined to a three-carbon molecule to make a four-carbon molecule, and shunted to the bundle sheath cell, where it is cleaved off and made available to the Rubisco-catalyzed C3 photosynthetic cycle.

The 3-carbon molecule resulting from the CO<sub>2</sub> removal in the bundle sheath cell is shunted back to the mesophyll cell for reuse, and two ATP are used up in the process. Therefore, C4 photosynthetic pathways are reactions in addition to C3 pathways, with a division of labor set up between bundle sheath cells, where photosynthetic carbon assimilation occurs, and mesophyll cells, which house the mechanisms for bringing CO<sub>2</sub> into the cell and temporarily adding it to a 3-carbon molecule for later use by Rubisco. So, both enzymatic and anatomical changes are part of the evolutionary developments which have allowed plants like maize to get around the problem of photorespiration under low CO<sub>2</sub> conditions.

### Higher CO<sub>2</sub> Would Boost Rice

C4 plants function well in high-light, high-heat conditions as in the tropics, whereas C3 plants do best in lower light, more temperate conditions. The problem for crop scientists is, that one of the main food crops in tropical climates is rice, a C3 monocot. Under present atmospheric conditions, rice is not nearly as productive as it would be under higher CO<sub>2</sub> concentrations. Until—or unless—that situation occurs, scientists are in a bind

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## Letters

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(2) that mathematics cannot be separated from a general understanding of nature,

(3) that political action is coexistent with all the rest. . . .

It's not easy for a scientist to crawl against the current. Even if modern science is full of so-called accepted “paradoxes,” it's not a good basis for reflection.

It's necessary, as you do, to return to older conflicts, an idea out-of-fashion, except perhaps recently. (As I must go frequently to an university hospital, I went to the library there, only to find that all books older than 10 years are thrown away!)

We must not accept “technical” truth, reread critically even Cauchy, and accept that morals may be a key of mathematics!

**Jean-Pierre Wallenborn**  
Brussels, Belgium

## Correction

A box titled “Thorium Converter Reactor Ready for Development,” on p. 49 of the Fall 2005 *21st Century* erroneously states that Tak Pui Lou, Ph.D., of Lawrence Berkeley National Laboratory, is a co-owner of the company Thorenco LLC. He is not, and we regret the error.

## C<sub>4</sub> vs. C<sub>3</sub> Photosynthesis

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as far as boosting rice productivity to keep pace with population growth and land loss to non-agricultural uses.

One of the most promising approaches to give a large boost to productivity of rice, would be the successful incorporation of CO<sub>2</sub>-concentrating C<sub>4</sub> photosynthetic pathways into the rice plants by genetic engineering techniques.

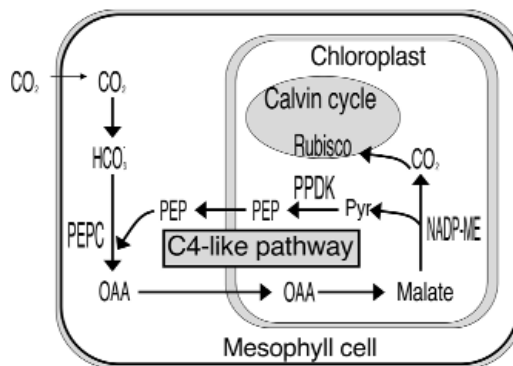
Many scientists are looking at ways to do this, and some progress has occurred with the overexpression of C<sub>4</sub> enzymes in C<sub>3</sub> plants, but the ultimate goal—significantly boosting photosynthetic efficiency—has not yet been reached. The main problem lies in the anatomical arrangement of C<sub>4</sub> plants.

As mentioned earlier, almost all C<sub>4</sub> plants break up photosynthetic activity into two cell types, with CO<sub>2</sub> concentration occurring in a different cell than CO<sub>2</sub> uptake. A few C<sub>4</sub> plants with just one cell type have elongated cells with one end facing outward and the other to the center of the plant, allowing another sort of separation in space. C<sub>3</sub> plants as

### A MODEL FOR INCREASING THE CO<sub>2</sub> AVAILABLE FOR C<sub>3</sub> RICE

Scientists at the National Institute of Agrobiological Sciences (NIAS) of Japan are inserting genes that code for C<sub>4</sub> photosynthetic enzymes (PEPC, PPDK, and NADP-ME) into rice, in an attempt to create a

functional C<sub>4</sub>-like pathway to move CO<sub>2</sub> into the mesophyll cell, and incorporate it into the three-carbon molecule phosphoenolpyruvate (PEP) to make the four-carbon oxaloacetate. That would then be shuttled into the chloroplast, where it would be transformed and ultimately cleaved back into PEP by way of pyruvate, releasing CO<sub>2</sub> to be utilized by Rubisco in the C<sub>3</sub> photosynthetic cycle, the Calvin cycle. This diagram is adapted from a NIAS schematic.



a rule do not have those qualities of structural complexity.

Whether C<sub>4</sub> genes in C<sub>3</sub> rice will successfully boost productivity remains to be seen. Perhaps the easier route would be to tinker with the Rubisco protein to shift its affinity for CO<sub>2</sub> vs. O<sub>2</sub> so the CO<sub>2</sub>

assimilation reaction drives forward more efficiently under present levels of CO<sub>2</sub>, but that also has proved hard to achieve so far.

#### Notes

1. Mitsue Miyao, 2003. *Journal of Experimental Botany*, Vol. 54, No. 381, pp. 179-189.

## 21<sup>st</sup> CENTURY SCIENCE & TECHNOLOGY

- Jerry M. Cuttler, "The Significant Health Benefits of Nuclear Radiation," Fall 2001
- James Muckerheide, "It's Time to Tell the Truth about the Health Benefits of Low-Dose Radiation," Summer 2000
- Dr. Theodore Rockwell, "Radiation Protection Policy: A Primer," Summer 1999
- Zbigniew Jaworowski, "A Realistic Assessment of Chernobyl's Health Effects," Spring 1998
- Jim Muckerheide and Ted Rockwell, "The Hazards of U.S. Policy on

Low-level Radiation," Fall 1997  
*Radiation experts argue that current U.S. policy of a "linear no-threshold" approach to radiation damage has no science behind it and is wasting billions of government dollars in clean-up that could be spent on real health benefits.*

- Sadao Hattori (interview), "Using Low-dose Radiation for Cancer Suppression and Revitalization," Summer 1997  
*A discussion of Japan's wide-ranging program of research into the health effects of low-dose radiation.*
- T.D. Luckey, "The Evidence for

## ARTICLES ON RADIATION and HORMESIS

Radiation Hormesis," Fall 1996  
*A comprehensive review of the evidence of the beneficial effects on health of low-dose radiation.*

- Zbigniew Jaworowski, "Hormesis: The Beneficial Effects of Radiation," Fall 1994  
*In 1994, the United Nations Scientific Committee on the Effects of Atomic Radiation, after 12 years of deliberation, published a report on radiation hormesis, dispelling the notion that even the smallest dose of radiation is harmful.*

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