# How did Africa's grasslands get started?

July 23 2019, by Kevin Krajick

Savannah grasslands in southern Kenya, where remains of many early humans have been found. Credit: Kevin Krajick/Earth Institute

Between 10 million and 6 million years ago, vegetation across much of the world underwent a transformation, as warmth-adapted grasses displaced previously dominant plants, shrubs and trees. The new grasses carried out the chemical reactions required for photosynthesis in a distinct new way. Scientists have labeled this new process the C4 pathway. In East Africa, the changeover coincided with the evolution of mammal lineages that we recognize today, including early human ancestors. Today, C4 plants comprise about one-quarter of the Earth's vegetation, from the Great Plains of North America to western China, Australia and much of sub-Saharan Africa.

What is the origin of these plants, and why did they spread so far and wide? A new study in the journal *Nature Geoscience* tries to get at this question by looking at deep-sea sediments off east and west Africa, which contain traces of past plant life and the conditions under which it existed. It shows that both northwestern and eastern Africa experienced a spread in C4 plants starting around 10 million years ago, at a time when carbon dioxide in the atmosphere was dipping, but there were no apparent changes in rainfall or dust deposition.

We spoke with co-author Cassaundra Rose, who did the research as a Ph.D. student at Columbia University's Lamont-Doherty Earth Observatory. The study was carried out also by Lamont-Doherty scientists Pratigya Polissar (who is the lead author), Kevin Uno, Samuel Phelps and Peter deMenocal.

## What are C4 plants, and what makes them important?

Plants need sunlight, water and carbon dioxide to perform photosynthesis, but there are differences in the very first step of photosynthesis, when the plant converts $CO_2$ into useable molecules. About 85 percent of all plants use what we call C3 photosynthesis. C4 plants use a slightly different kind that produces a 4-carbon compound in that first step. Hence the "C4" moniker. C4 plants lose less $CO_2$ and water back to the atmosphere during photosynthesis than C3 plants, so they're able to outcompete C3 plants in hot, dry places. C4 photosynthesis has brought humans some very important food crops like corn, sugar cane, sorghum and millet. C4 plants also dominate subtropical and tropical grasslands like the African savannah today. We might not have those iconic grasslands, and zebra, gazelles and other mammals without them. There are also hypotheses that link the evolution of C4 grasslands in Africa to the evolution of our own line, the hominins, including humans.

## What do we know about when they first came along, and spread?

Scientists think that C4 photosynthesis evolved somewhere around 35 million years ago, but C4 plants didn't really become widespread until much more recently, between 10 million and 6 million years ago. When and why they spread, particularly in Africa, is still a very active area of research, and the major focus of our study. The story of why C4 photosynthesis came about is pretty interesting and has to do with the earth's climate history over the last 30 to 40 million years. C4 photosynthesis requires more energy than the traditional C3 style, but it fixes carbon more efficiently. That's a really important adaptation if you are a plant growing in a low-$CO_2$, high temperature, high-light environment. This is where climate history comes in. Over the last 50 million years, the earth was transitioning from high levels of atmospheric $CO_2$ to lower ones. C3 plants in hotter, high-light environments would have found it increasingly difficult to grow because one of their major foods, carbon dioxide, was becoming more scarce. That made an opening for C4 plants.

## Did C4 plants have any impact on human evolution?

We think they're connected, but we're still working on understanding exactly when and how. We now know that C4 grassy ecosystems were already present when the earliest hominins appeared, around 7 million years ago. We also know that human evolution occurred during a period when many areas were transitioning from C3-dominated forests and woodlands to more open C4-dominated grasslands. And we know that by the time hominins first appeared, many other large mammals, like horses, elephants and rhinos, already had diets comprised of C4 plants. Most but not all of our hominin ancestors included some amount of C4 plants or C4 plant-based foods, such as meat from grazers, in their diets. But as to the exact connection to human evolution, we still don't have a clear answer yet.

## What have been the dominant ideas about how these plants took over in many places?

A leading hypothesis is that aridity and declining rainfall are major drivers. An important consequence of aridity and changing rainfall patterns is fire, which promotes the spread of grasslands. Thus, fire, aridity and rainfall are interconnected. We know from several recent studies that C4 plants become more common during dry periods across northern and eastern Africa, and less common during wetter periods. This is exactly what you would expect, given their evolutionary advantages over C3 plants. However, the exact cause for their initial large spread during the Miocene between 10 and 6 million years ago has been elusive, in part because there are few long-term climate, vegetation and $CO_2$ records that reach back that far. Developing long-term records of fire would be a big step toward understanding the role of biomass burning in the spread of C4 grasslands.

## How did your study approach this question?

We went to the only place that has continuous sediment records that reach back over 25 million years: the ocean floor. We analyzed geochemical fossils—plant leaf waxes that were preserved in ocean sediment cores offshore from the western Sahel, and equatorial West Africa and East Africa over the last 25 million years. Using published sea-surface temperature records and our new analysis of dust-flux records, we found that the rise in C4 plants in northern Africa coincides with dramatic high-latitude cooling and increasing pole-equator temperature gradients. We suggest that atmospheric $CO_2$ declined across a critical threshold 10 million years ago, allowing C4 plants to finally gain the competitive edge that they needed to spread at the expense of C3 plants. This means that rainfall and temperature patterns in Africa were already close to that critical threshold when $CO_2$ crossed it. This is helpful and relevant information for understanding the climate context of human evolution.

Right now, carbon dioxide in the air is skyrocketing, due to human emissions. What are the implications for C4 vegetation, other plant life, and us?

The rise in carbon dioxide is much more rapid than anything scientists have observed in the geologic record, including the Paleocene-Eocene Thermal Maximum of about 56 million years ago. So we aren't sure yet how this is going to affect vegetation and ecosystems. But theoretically, increasing atmospheric $CO_2$ levels will diminish the biochemical advantages of C4 photosynthesis over C3 photosynthesis, and that would result in a decrease of C4 biomass. The Intergovernmental Panel on Climate Change's last report suggests that increasing $CO_2$ concentrations up to about 600 parts per million—which may be exceeded by the end of this century–will enhance photosynthesis, particularly in favor of C3 plants. It would also increase plants' water-use efficiency. But these improvements will become less as $CO_2$ rises higher over time. Other important factors that affect all plants are temperature, disturbances like human land use, fire and invasive species, and the availability of water.

Even though plants may photosynthesize more quickly with increasing $CO_2$, many of our important foods, like wheat, rice and maize, may have lower nutrient quality with higher $CO_2$ and higher temperatures. That would impact human health and global food security.

**More information:** Pratigya J. Polissar et al. Synchronous rise of African C4 ecosystems 10 million years ago in the absence of aridification, *Nature Geoscience* (2019). DOI: 10.1038/s41561-019-0399-2

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