It is happening too slowly for the animals to understand. The air they breathe and the grass in their mouths is changing - more subtly than butterflies or bacteria. Farmers and cattlemen, shepherds and gardeners also hardly understand what is happening. They struggle with the larger and more familiar rain and snow, drought or flood, water rights, crop rotation, market prices, cost control, breeding, varieties, weeds, yields, organic or chemical fertilizer choices, and pest control methods – the daily, almost comfortable, almost automatic crush of immediate decisions. The slow variations in climate and flora, invisible in a given year or decade, challenge even the abilities of researchers to understand. But the changes continue, silently and relentlessly.

The grass and foliage looked normal. But what was normal any more? Year by year the cattle and buffalo took longer and longer to digest the grass they foraged. Deer, elk, oxen, antelope and the multitudes of other wild ruminant's diets were slowly declining, almost imperceptibly. Deer or cattle, sheep or buffalo, wild or domestic, they all gained weight more slowly. The grass and browse they grazed appeared thick and green. So why was it taking longer for these most efficient animals - ruminants with four stomachs - to convert grass to flesh? They seemed to be in no hurry, as they spent more time chewing their cuds.

Ruminants are the source of nearly all the milk and half the meat the world eats. Ruminant's efficient digestion enables them to extract nutrition from plants that other animals cannot. Their symbiotic relationship with the microbes living in their four stomachs allows them to digest diverse forages on rangeland throughout the world. Ninety percent of all ruminants graze on grassy rangeland. Wild ruminants get ninety-five percent of their food from grassy rangelands[1]. The grass on these rangelands, as every other plant in every biome, grow in an atmosphere of rising carbon dioxide.

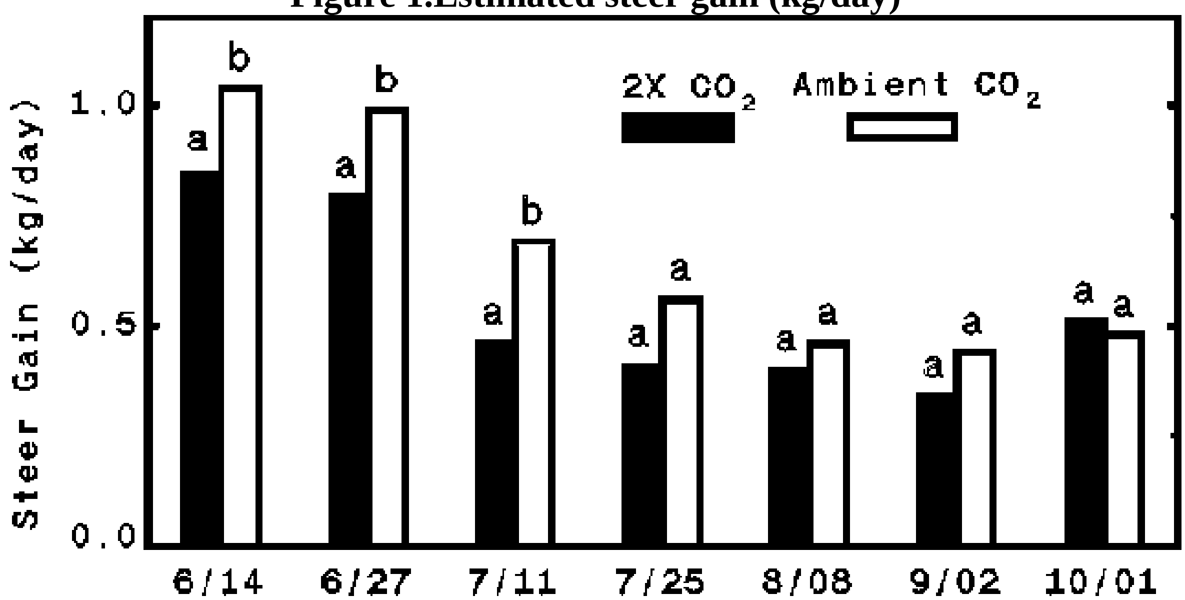
Carbon dioxide (CO_2) in our earth's atmosphere has been increasing, slowly impacting green plants which need carbon dioxide to perform the miracle of photosynthesis. Understanding the slow silent impact of rising CO_2 on biomes such as grassy rangeland, and ruminants' response to those changes, is not only fascinating, but of huge importance. It embraces the food we eat, the fuel we use to power our world and every person and industry, business and government, from Afghanistan to Arizona to Antarctica. This broad and vital story has never been told. We can provide the cleanest, safest and most reliable power known - sun power from space - while decreasing our dependence on foreign oil and increasing harmony between our developing world and this fragile Eden we share. We can also build new businesses on the High Frontier of space, which can lower the cost of construction and open wide the door to the High Frontier. But we are getting ahead of our story...

In the half million years before the industrial revolution, the level of CO_2 in the atmosphere cycled slowly between 182 and 299 parts per million (ppm)[2], averaging about 240 ppm. Then the steam engine, the internal combustion engine and other fossil fuel (coal, oil, and gas) burning engines were introduced. Innumerable labor saving and other marvelous machines were introduced. Agriculture came to depend more on diesel tractors than the plow horse. Production soared as the number of farmers declined. Since the industrial revolution, great population increases, larger markets for yet more amazing machines, and ever more fossil fuel burning engines have raised the CO_2 level in the atmosphere to over 370 ppm. By the middle of this century CO_2 is expected to reach double the "historic level" (approximately 278 ppm).[3,4]. What differences will this make?

Through thousands of studies investigating climatic and atmospheric changes, scientists have begun understanding the wide impact of rising CO_2 levels on photosynthesis,[a] plants and animals. Special outdoor laboratories, known as Free Air CO_2 Enrichment (FACE) areas, have given us a natural way to test elevated CO_2 without bringing the plants into an unnatural greenhouse or laboratory. Instead, a bit of extra CO_2 is released into the air around test plots to match the atmospheric CO_2 test level desired. Many tests have been examining doubled CO_2 levels. Slowly, a clearer picture of the impact of plant and animal response to increasing CO_2 is emerging.

In one important study, Dr. Clenton Owensby and colleagues, studied ruminants grazing in a FACE range with a doubled CO_2 level on Kansas' grassy rangelands. Their studies into the impact of increasing carbon dioxide on those rangelands revealed a surprising effect. The grass these animals foraged from the FACE range had less nitrogen and correspondingly less protein. The protein content and digestibility, even by the four highly efficient stomachs of ruminants, was reduced at increased CO_2 level[5,6].

Figure 1.Estimated steer gain (kg/day)



[a]All the food we eat begins with photosynthesis – the process that converts the energy in sunlight to food energy that can be used by animals. Plants, algae and their relatives in the oceans use photosynthesis to convert water, CO_2 and light to sugar, which plant cellular respiration converts into adenosine triphosphate (ATP), the "fuel" for all living things. Photosynthesis releases both the oxygen we breathe and the food we and other animals need! That is why understanding the impact of rising CO_2 on photosynthesis is crucial.

> "Since nitrogen and fiber concentrations in the diet of ruminants impact forage digestibility and utilization efficiency, the reported reduced nitrogen and increased fiber concentrations in plants grown under elevated CO_2 will likely impact ruminant productivity negatively. Data reporting reduced productivity or increased consumption for insects consuming diets of plants grown under elevated CO_2 support that conclusion. Contrary to the results from insect studies, where intake increased as diet quality decreased, ruminant intake declines as forage quality decreases. Therefore, there cannot be a compensatory intake response to maintain productivity levels comparable to current levels. For domestic livestock, diets can be supplemented to compensate for reduced forage quality, but with wild ruminants, or for ruminants in developing countries, diet supplementation is not an option. "

Fiber content under increased CO_2 increases in many plants. For example, cotton (fiber) seems to prosper[7]. Test cotton crops exposed to FACE[8] increased biomass and harvestable yield by 37 and 48 percent, respectively, in doubled (550 ppm) CO_2. Food may become more expensive and less nutritious, but we'll have plenty of cheap cotton T shirts.

Ruminant forage digestibility is enhanced by thinner cell walls and low fiber and lignin content. So the increased fiber characteristic of elevated CO_2 slows digestion, decreasing intake. The very nature of ruminant digestion makes it impossible for the ruminant to compensate for a lower quality diet by consuming more forage. While the quantity of insect intake *increases* as diet quality decreases, ruminant intake *declines* as forage quality decreases. The reason is that ruminant digestion takes longer with lower nitrogen content. Like composting, the Carbon to Nitrogen ratio[9] is a determining factor in digestion of organic matter, such as grass and leaves.

Ruminants won't be able to spend as much time munching foraging as they did, because their digestion will be busy, working more slowly to digest plant matter with a lower protein and nitrogen content. With all the waiting around for their digestion process to complete its work, animals eating plants grown under increased CO_2 will likely take longer to mature or to reach market weight. Without predictive research studies such as FACE provides to forecast these slow changes, they would not be noticed in year to year comparisons.

Can range fed cattle be given special supplements to aid their digestion? U.S. farmers eventually send about 80 percent of their cattle to feedlots – 30 million head. About 80 percent of all <u>feedlot</u> cattle currently receive steroid hormone supplements. These supplements cost about $2 per animal and increase animal growth by 20 percent. They save about $40 getting an animal to market weight.[10] For some domestic livestock, perhaps special diet supplements could compensate for reduced forage quality, but for ruminants on the open range, wild ruminants, and ruminants in developing countries, diet supplementation would not be an option.

> "The result will be reduced growth and reproduction. Further, changes in climate may impact foraging by ruminants. High daytime air temperatures currently reduce total grazing time for cattle with little or no compensatory nighttime grazing. A future high CO_2 world seems destined to reduce individual animal performance. ...

> Wild ruminant diet quality will be affected, and it is likely that they will have reduced growth and reproduction."

Will every plant experience declining protein, or nitrogen? There will be differences. For example, many C-3 species of grasses from the Serengeti in Africa showed no noticeable nitrogen decline at the elevated CO_2 used in test.[11] Wheat and rice are C3 grains. Corn and sorghum use C4 photosynthesis. (The difference between C3 and C4 plants concerns details of their photosynthetic process.) However, the vast majority of cattle, sheep, and other ruminants will apparently suffer declining growth and reproduction, unless significant changes to reduce CO_2 increases and fossil fuel burning are made.

Farmers and agronomists may be expected to search for and plant improved stocks of grass and other browse for their domestic stock. But it is an unimaginably vast undertaking on a global scale. Especially knowing that increasing CO_2 is only one of the atmospheric and other climate changes taking place[12] in thousands of different microclimates on land *and under the sea* around the globe. Can all the world's ecosystems adapt to rapid increases in carbon dioxide, methane, as well as changing microclimates? It is extremely challenging to anticipate how every wild or farmed grassland, forest, field, orchard or salt marsh will change or can be adapted to cope with those changes.

What about other ecosystems? "Arid ecosystems are predicted to be among the most responsive to elevated carbon dioxide because of projected increases in plant water-use efficiency." While rangelands are the most important ecosystems for meat and milk production by ruminants, declining plant available nitrogen is expected to impact both tropical and arid ecosystems. Recent FACE studies in the Mojave Desert show that "plant-available nitrogen has decreased 40 to 50 % under elevated carbon dioxide"[13].

Should we all become vegetarians to escape this nutritional decline? No, vegetarians will also be impacted by these changes in plants. For example, the world's two favorite grains, rice and wheat, both decline in nutritional value based on testing under elevated CO_2. Growing wheat at elevated CO_2 lowers the protein content of grain and flour by 9-13%[14,15,16]. Grain grown at high CO_2 produces poorer dough of lower extensibility and decreased loaf volume. Hence, for breadmaking, the quality of flour, produced from wheat grain developed at high temperatures and in elevated CO_2, degrades.[17]

"The nutritive value of rice was also changed at high CO_2 due to a reduction in grain nitrogen and, therefore, protein concentration." Rice's amylose content is increased under elevated CO_2[18]. Starch consists of two main fractions, amylose and amylopectin. The starch from high amylose grains is used in adhesives for manufacturing corrugated cardboard, biodegradable packaging materials, chewing gum, and textiles. Starches with high amylose content are resistant to digestion.[19]

While rice may become more important in biodegradable plastic products, due to its rising amylose content, cooked rice grain from plants grown in high-CO_2 environments would be tougher and firmer than that from today's plants. Concentrations of iron and zinc, which are important for human nutrition, would be lower. Moreover, the protein content of rice declines under combined increases of temperature and CO_2[20,21]

Plant's access to nitrogen is crucial to life - being a component of both plant and animal proteins. Elevated CO_2 interferes with plants' ability to use certain forms of nitrogen from soil. Early research into methods to counteract this interference for wheat and tomato plants suggests that increasing ammonium fertilization may overcome some of these nitrogen problems.[22]

At minimum, dramatic alterations in plant life worldwide are forcing significant changes in agricultural fertilizer use. And not only ruminants depend on grass and grain. Chickens, for example, require high protein diets, which is based on wheat germ, alfalfa, bran, soybeans and ultimately other green plant protein sources. We are what we eat - from chicken feed to pig feed, every animal depends on the nutrition in the green plants which initiate the green food chain we all depend on.

Our actions are putting to the test on ever more intensive levels whether our stewardship of wild and natural habitats and the flora and fauna that live there can survive our attempts to farm and fish, mine and manage the earth. We must soon graduate from negligent and irresponsible philosophies, corporate and individual, modern and ancient, from animism to Gaia, that suggest we belong to the earth and "she" will take care of everything.

In over 30 studies, insects known as phloem feeders, such as aphids, increase in population under increased CO_2. Aphids multiply faster and improve their feeding success under increased CO_2[23]. Aphids reproduce 10 to 15 percent faster under conditions of elevated CO_2. Most leaf-chewing insects, however, showed either no change or reductions in abundance under increased atmospheric CO_2[24]

Increases in CO_2, unfortunately, are not the only reason for concern or study. For example, on Alaska's Kenai Peninsula, near Anchorage, beetles have killed a four-million-acre spruce forest, the largest loss of trees to insects ever recorded in North America, according to federal officials. Government scientists tied the event to rising temperatures, which allow the beetles to reproduce at twice their normal rate.[25] The beetles are reproducing faster and in greater numbers than at any time since record keeping began in the late 1800s. Records in Alaska show a seven-degree temperature increase just over the last thirty years.

Like Kenai, real ecological changes are not happening in isolation. The valuable FACE studies of increased CO_2 in test plots generally ignore other variables such as temperature rise which will accompany increases in atmospheric levels of CO_2, methane and other greenhouse gases (GHG). Climate change will fully impact "real" world plants, animals and insects in their ecosystems in all their complexity - whether scientists agree on their precise causality, degree, reason or not.

Most of the world's CO_2 released from fossil fuels since the industrial revolution has been taken up by the oceans, into tiny marine phytoplankton (plants) and zooplankton (animals). These tiny creatures, the foundation of the ocean's food chain, are eaten by small fish and in turn by other, larger, fish and animals, and people. Researchers studying zooplankton off the Pacific coast of California measured an 80% drop in zooplankton biomass or population from 1951 to 1993. They cruised a 130,000 sq km area during 222 cruises off southern California.[26] They ascribe this trend to the increasing ocean temperatures, (1.5 degrees C) which they logged during this time.

How are climate changes and other related human impacts affecting the seas? Like this 80% drop in zooplankton in the California Current they are of concern and apparently a direct result of climate change, but it is more difficult to establish direct cause and effect linkage as can clearly be done with studies such FACE that this chapter has focussed on. We have hardly begun to understand the issues and interactions posed by climate change, and most especially the oceans' role in it. Only recently - during the 1990's - did we discover the existence of vast beds of methane hydrates.

Due to the high pH of ocean water (about 8), CO_2 dissolves readily in earth's vast ocean. The pH of ocean surface water has decreased nearly 0.1 pH-units due to the increase in dissolved atmospheric CO_2 since pre-industrial times.[27] Because CO_2 dissolves so readily into seawater, the ocean absorbs about 2 billion tonnes of carbon per year[28], yet the ocean's ability to remove CO_2, has not kept pace with our CO_2 production from fossil fuel burning. We are producing CO_2 much faster than the plants on land and even the sea can remove and recycle it.[29]

Methane hydrates are an incredible ice like material that have been formed of methane gas locked in a matrix – a cage formed by water pressure and cold temperatures. These ubiquitous sedimentary layers are found in abundance in many deep offshore continental shelves and associated with permafrost in northern environments. The volume of natural gas and carbon reposing in these layers is truly immense, exceeding the total of all other known conventional hydrocarbon sources, according to recent estimates. This is one of many major climate changes slowly impacting the oceans and our earth that researchers can not keep pace with. The ongoing and intensive studies of these developing ocean atmosphere imbalances and other large critical issues impacting our energy environment will be summarized in the next chapter.

This chapter has outlined just a few of the most measurable and predictable of the multitude of changes to our environment which are expected to most directly impact human nutrition and wellbeing. These problems, however, are minor annoyances in comparison with the controversial and knotty issues we will enjoy touring in chapter 2.

The anticipated and yet dimly understood new vagaries creeping into global ecosystems, the increased environmental uncertainty, exaggerated, and in many ways unprecedented, climate and ecosystem change are far more complex than scientists have been able to document or accurately model. Nevertheless, salient features are emerging through important and expanding studies. But can we cope with such massive environmental, social, and resultant political displacement? The road to solving problems begins with understanding and communication.[a]

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If there is righteousness in the heart there will be beauty in the character. If there is beauty in the character, there will be harmony in the home. If there is harmony in the home, there will be order in the nation. When there is order in the nation, there will be peace in the world.

--- Chinese Proverb

[a] The Endnotes of this book provide further references to both peer reviewed studies and Internet resources available for further study.
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End Notes

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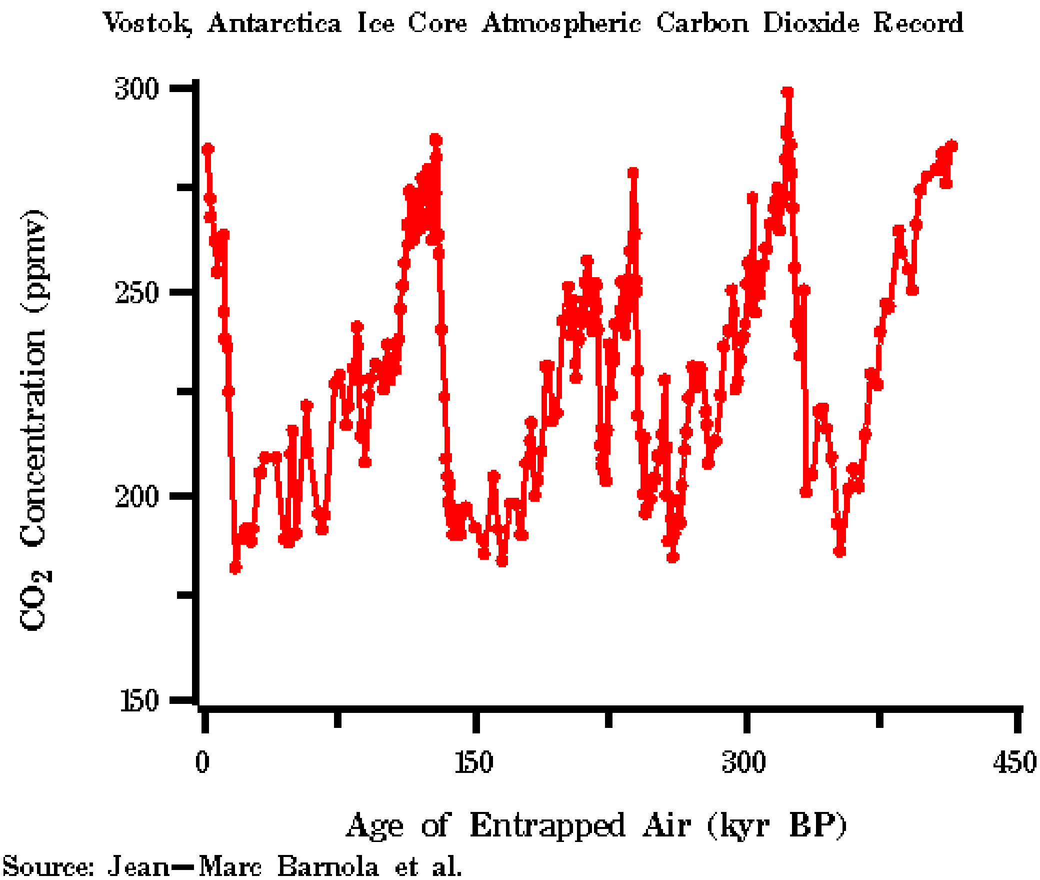

Source: Barnola, J.M., D. Raynaud, C. Lorius, and N.I. Barkov. 1999. Historical CO2 record from the Vostok ice core. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.
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[4] You can monitor CO_2 , methane and other greenhouse gas levels yourself at online sites such as http://cdiac.esd.ornl.gov/trends/trends.htm or the EPA's Greenhouse Gases and Global Warming Potential Values - Table 1 sites a typical pre industrial CO_2 estimated concentration of 278 ppm - http://www.epa.gov/globalwarming/publications/emissions/ghg_gwp.pdf]
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Estimated steer gain (kg/day) is derived from acid detergent fiber and crude protein of diet samples collected on the indicated dates in 1989 by esophageally fistulated sheep from tallgrass prairie exposed to 2X ambient and ambient atmospheric CO_2. Means within a date with a common letter do not differ [LSD, $P< 0.10$]

"Since N and fiber concentrations in the diet of ruminants impact forage digestibility and utilization efficiency, the reported reduced N and increased fiber concentrations in plants grown under elevated CO_2 will likely impact ruminant productivity negatively. Data reporting reduced productivity or increased consumption for insects consuming diets of plants grown under elevated CO_2 support that conclusion. Contrary to the results from insect studies, where intake increased as diet quality decreased, ruminant intake declines as forage quality decreases. Therefore, there cannot be a compensatory intake response to maintain productivity levels comparable to current levels. For domestic livestock, diets can be supplemented to compensate for reduced forage quality, but with wild ruminants, or for ruminants in developing countries, diet supplementation is not an option. The result will be reduced growth and reproduction. Further, changes in climate may impact foraging by ruminants. High daytime air temperatures currently reduce total grazing time for cattle with little or no compensatory nighttime grazing.

"A future high CO_2 world seems destined to reduce individual animal performance. For domestic livestock enterprises, increased stocking rates can occur because of the reduced intake of lower quality forage, and dietary supplementation may be used to maintain current production levels, but that will increase cost of production. Wild ruminant diet quality will be affected, and it is likely that they will have reduced growth and reproduction."

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"Summary: Atmospheric CO_2 concentrations have been increasing since the industrial revolution, and are projected to double within this century over today's concentration of approximately 360 parts per million. We installed six large, plastic-covered chambers over shortgrass prairie vegetation in northeastern Colorado and elevated CO_2 concentration in three of these chambers to 720 parts per million to determine how rising atmospheric CO_2 will affect the ecology of these important grasslands. In comparisons between the three CO_2-enriched chambers and the remaining chambers maintained at present-day CO_2 concentrations, we found that elevated CO_2 enhanced production of grasses by up to 47% over grasses grown under present ambient CO_2 concentrations, although the concentration of N in CO_2-enriched plant tissues was reduced, indicating a decline in forage quality. These results suggest that while rising atmospheric CO_2 concentrations will enhance productivity of Great Plains grasslands, the quality of the forage may decline which could impair cattle production." http://www.nal.usda.gov/ttic/tektran/data/000011/77/0000117762.html

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II. Impacts, Adaptation & Vulnerability ISSN: 0 521 80768 9 (hb) 0 521 01500 6 (pb)
III. Mitigation ISSN: 0 521 80769 7 (hb) 0 521 01502 2 (pb)

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"Arid ecosystems are predicted to be among the most responsive to elevated carbon dioxide because of projected increases in plant water-use efficiency. Increases in net primary production will also be regulated by available nitrogen because nitrogen is the primary resource limiting net production once water is available. Plant-available nitrogen has decreased 40 to 50 % under elevated carbon dioxide. We hypothesize this is due to an increase in microbial activity caused by increased carbon input into the soil, because the decrease in inorganic nitrogen is accompanied by significant increases in soil respiration and plant nitrogen isotope composition. The increase in plant nitrogen isotope composition is likely the result of increased microbial fractionation of inorganic nitrogen during immobilization.
Experimental manipulation of soil labile carbon also increased soil respiration and decreased gaseous nitrogen loss and plant-available nitrogen. This study suggests that while elevated carbon dioxide may increase available water in arid ecosystems, it might also decrease available nitrogen."
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http://www-personal.umich.edu/~rstey/Site%20files/consequences.html
Iron is the limiting factor to the ocean's phytoplankton growth. That is, if more soluble iron were available to the phytoplankton production would increase. A suggestion was made to seed the oceans with iron to artificially

increase the ocean's CO_2 removal rate. A study of an actual iron "seeding" to artificially speed up CO_2 removal took place in the productive cold Southern Ocean, an area iron-limited. The results to date have shown this not to be a feasible solution, though. It is generally much more successful and far less costly to prevent a problem than cleaning it up later. Preventing the generation of undesirable excessive CO_2, methane, and other GHG emissions is far easier and cheaper than cleaning them up later.