Insights from Experimentation

Plants form the base of ecosystems and the impact of climate change on them is of paramount importance.

We know that CO_2 is increasing and that as a consequence the climate is warming.

For plants, CO_2 increases have a dual effect.

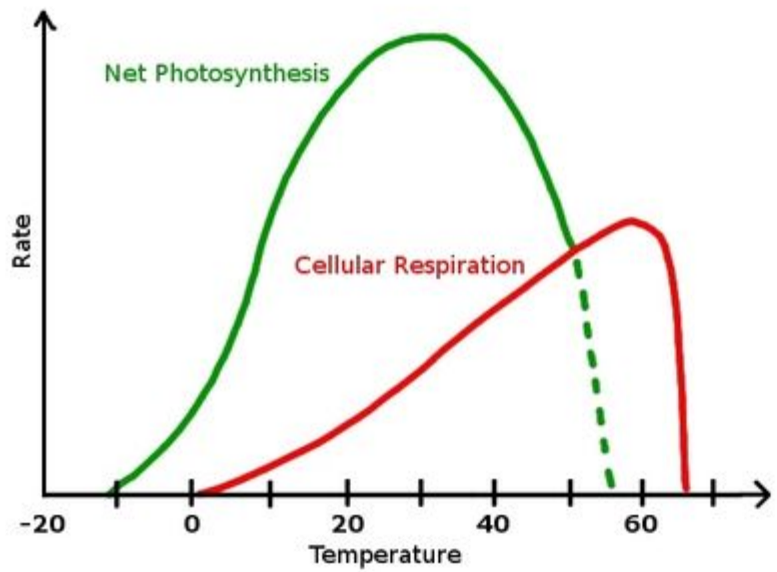
Within limits and for most species, increasing temperature increases physiological processes.

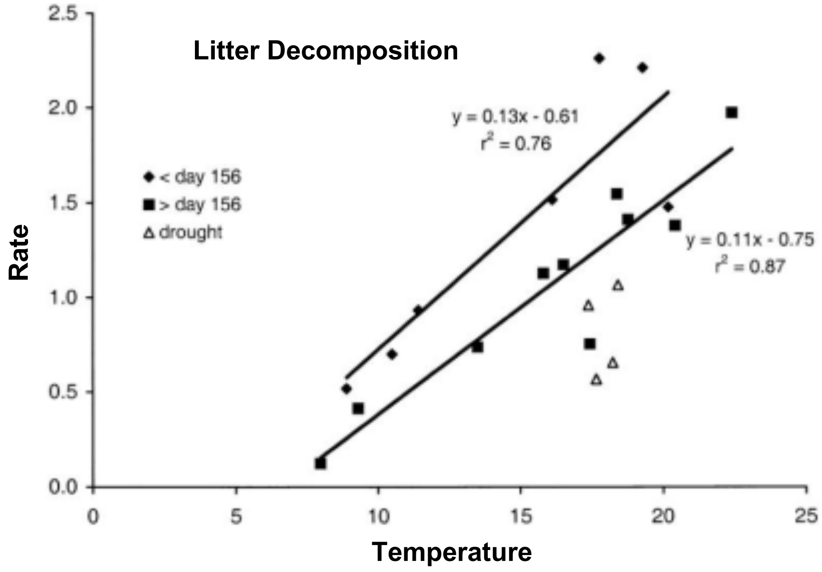
Because plants fix CO_2 through photosynthesis (and drive ecosystem processes), increases in CO_2 directly increase the rate of fixation.

We will examine the predicted responses of plants and then see whether these are borne out in both laboratory and field experiments.

This will give us some idea as to how global ecosystems may change.

Warming





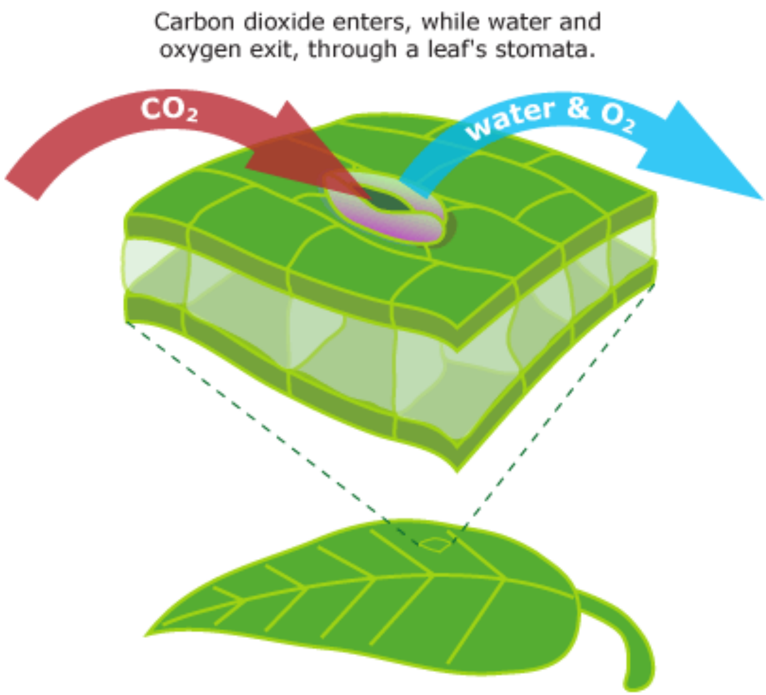
Up to the point it destroys metabolic machinery, increasing temperature raises rates of photosynthesis, respiration and litter decomposition.

All of these will result in increased plant growth with increasing temperature.

Litter decomposition is especially important since plant growth depletes the soil of nutrients which can only be replenished through recycling of nutrients from leaf drop.

The Q_{10} of most plant processes is ~2 – for a 10° increase in temperature the rate doubles.

Elevated CO_2



A key feature of plants that plays a central role in the effects of CO_2 is the system of stomata.

These “pores” are usually more numerous on the underside of leaves.

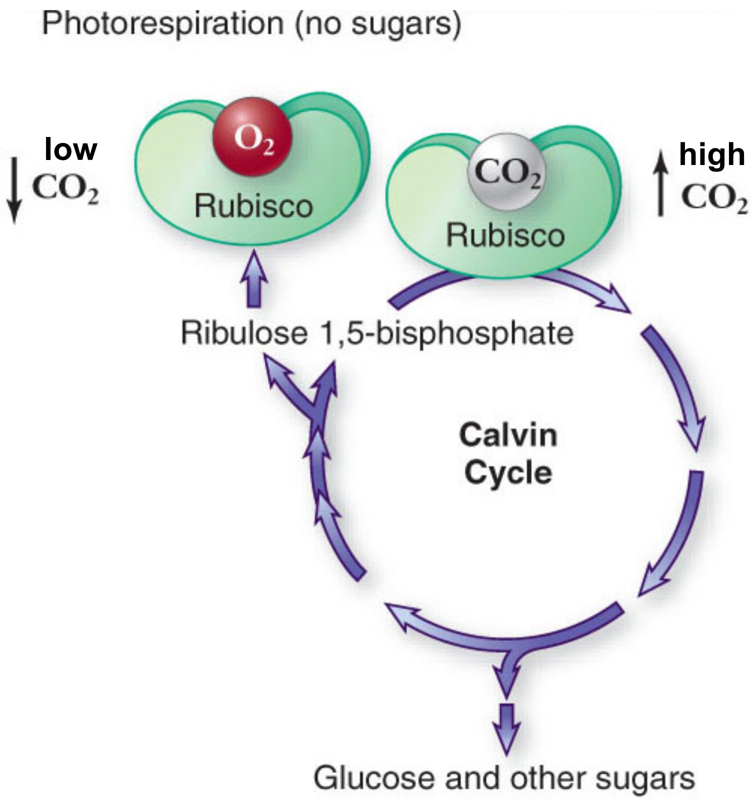
When the guard cells open, CO_2 goes in and water and oxygen (a waste product of photosynthesis) exit.

This can lead to a problem for the plant as loosing too much water can damage the plant.

Interestingly, as CO_2 concentration increases, the stomata need to be open for a shorter time to acquire the carbon dioxide for photosynthesis.

This suggests that increasing CO_2 help plants maintain a positive water balance

Elevated CO_2



Photosynthetic production of glucose relies on the Calvin Cycle.

RUBISCO (Ribulose 1,5-bisphosphate carboxylase/oxygenase) catalyzes the first step of the Calvin Cycle.

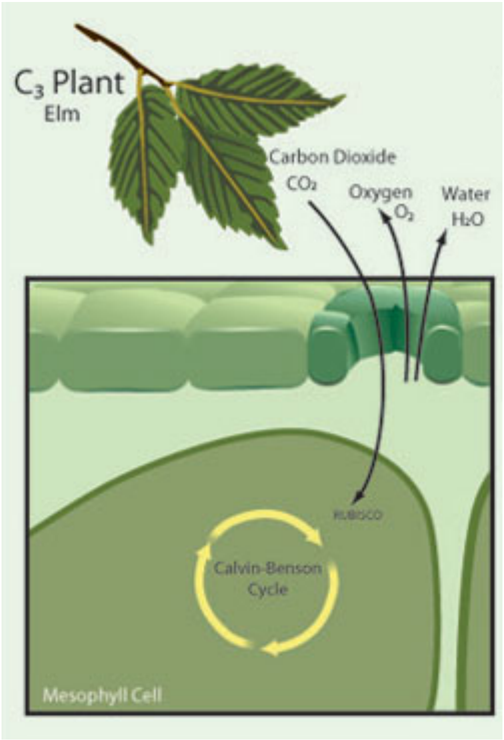
Can bind CO_2 or O_2.

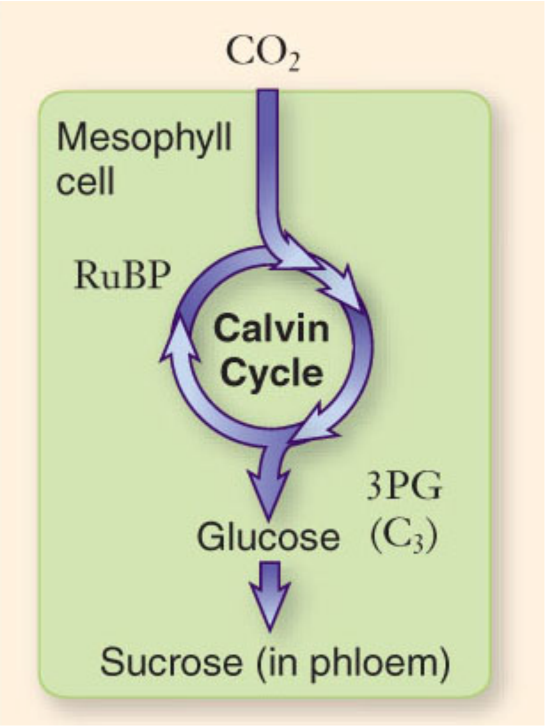
If CO_2 binds, a 3-C sugar is made, that can be used to make glucose and sucrose.

If O_2 binds, photorespiration occurs and there is no nutrient or energy storage.

This leads to a possible inefficiency in plants if CO_2 levels are low, a circumstance that has occurred more than once since plants initially evolved.

Elevated CO_2

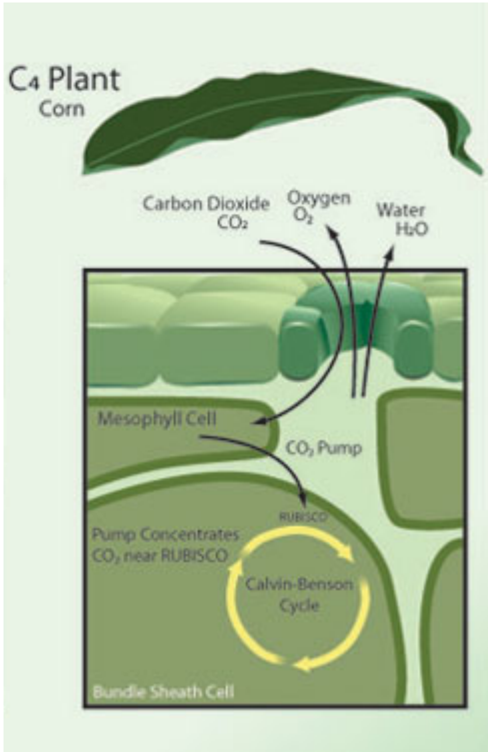


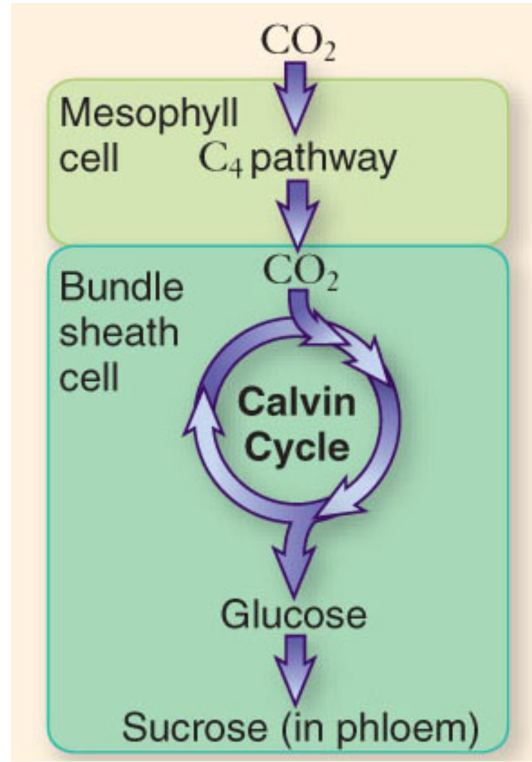


That inefficiency is a real possibility for what are known as C3 plants.

C3 plants include rice, soybean, wheat, rye, oats, millet, barley, potato and most shrubs and trees.

Elevated CO_2

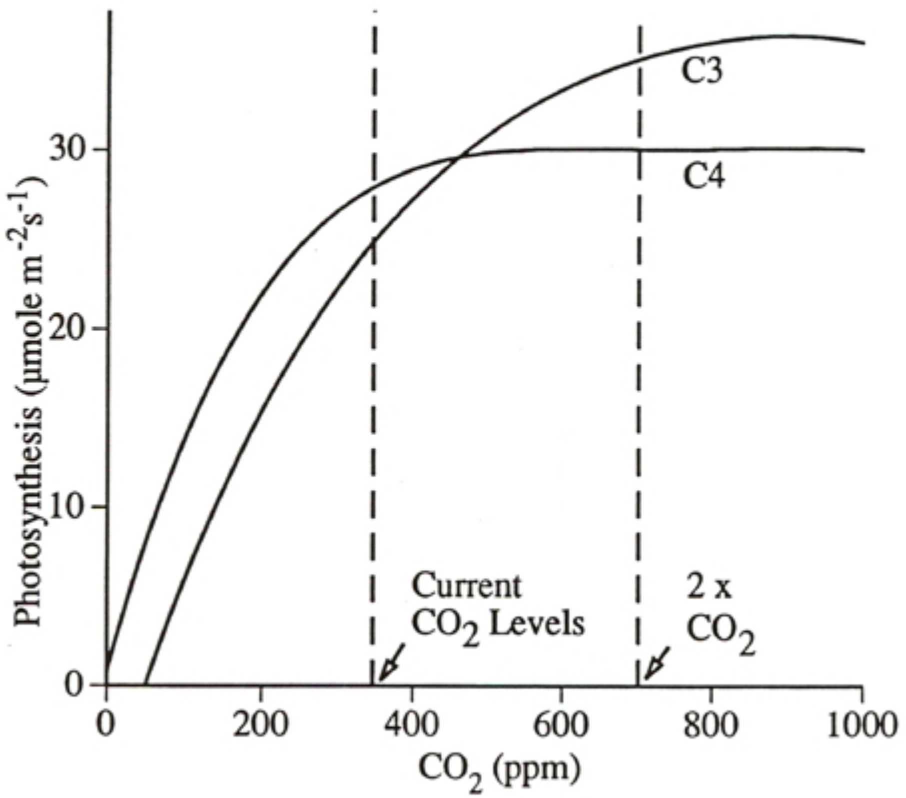




C4 plants (including corn, sorghum and sugarcane) have developed a more complex system that moves the CO_2 deeper into the leaf so that photosynthetic rates remain high even when CO_2 concentrations decline.

It is thought that C4 plants evolved from C3 plants under conditions of lower CO_2 when C3 plants would have lost water while keeping stomata open.

Elevated CO_2



At current CO_2 levels C4 plants are more productive than C3 plants and the proliferation of C4 versus C3 monocots likely reflects this.

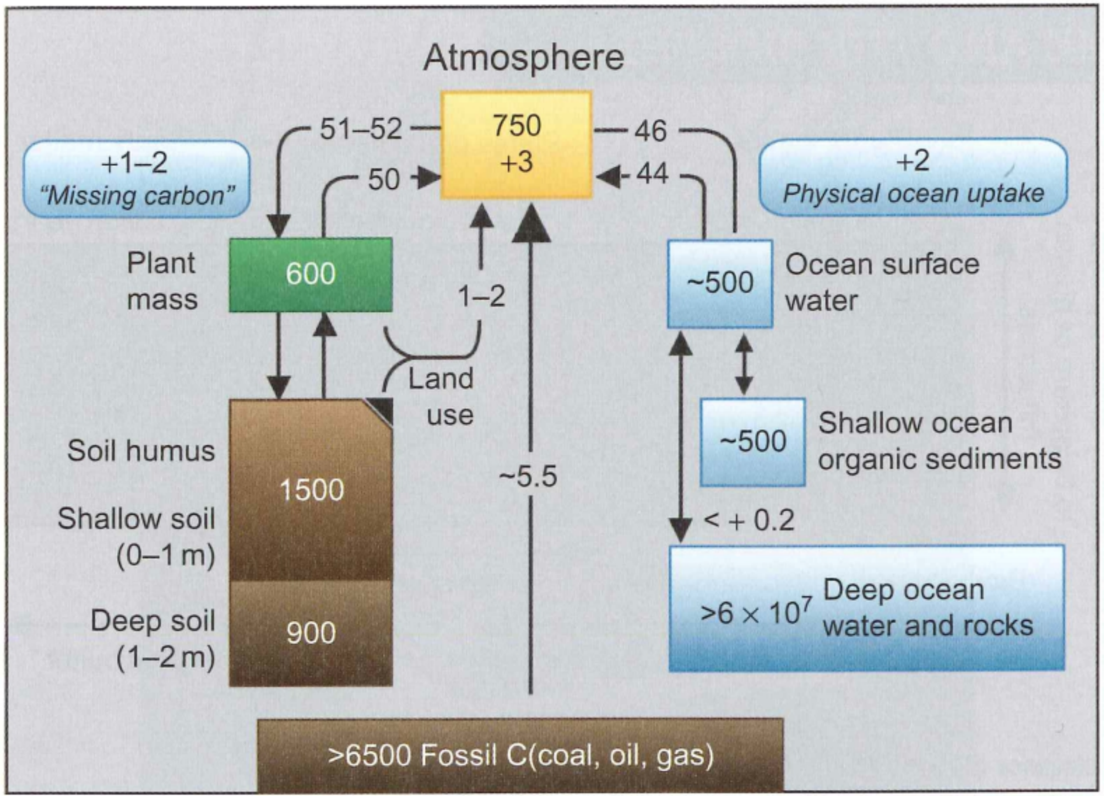
However, increases in CO_2 will lead to a reversal of fortunes and the species composition of ecosystems will likely change.

Elevated CO_2

There is a complication to increased productivity of C3 plants under increasing CO_2.

Soils are often poor in nitrogen and phosphorus and although higher CO_2 may lead to more primary productivity, it will be of lower quality.

Carbon Reservoir

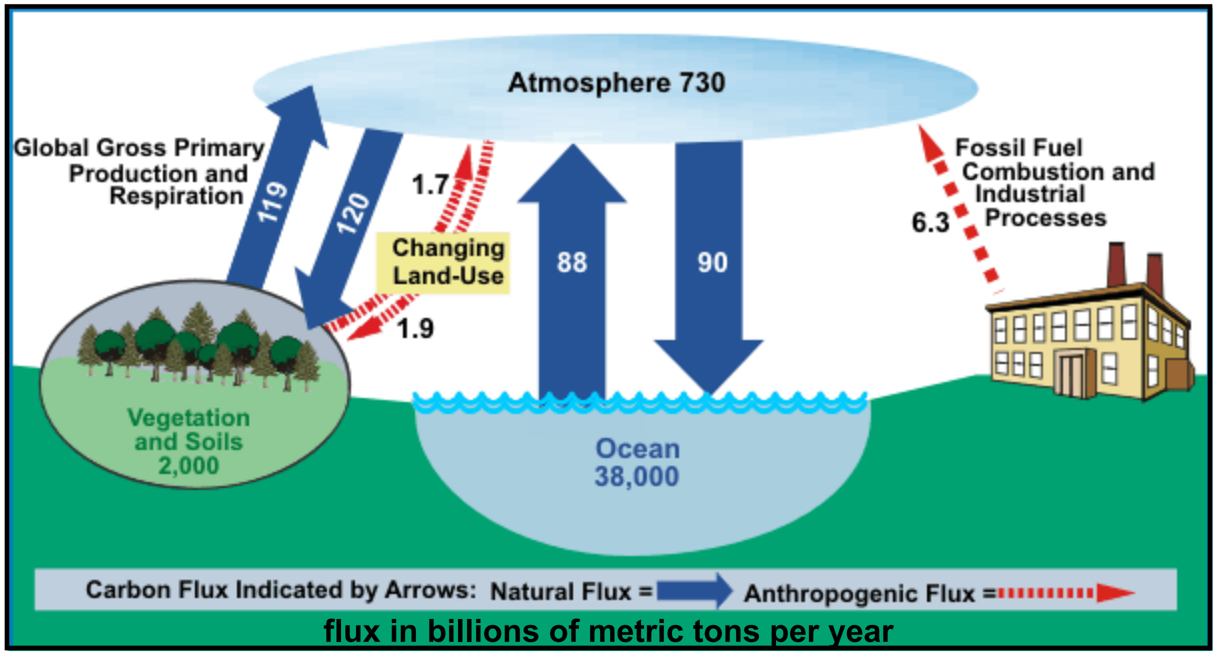


Plant biomass is 0.1 fossil fuel. It has the potential to sequester much of our emissions.

Soil holds much of our carbon and if soil respiration increases with temperature it will add much to greenhouse gases. Frozen soil is a special problem releasing methane.

The oceans sequester most of our carbon and turnover is high since the plants (phytoplankton) do not have non-productive parts (like trunks).

Carbon Flux



Flux shows us that the atmosphere and the natural reservoirs are close to being in balance.

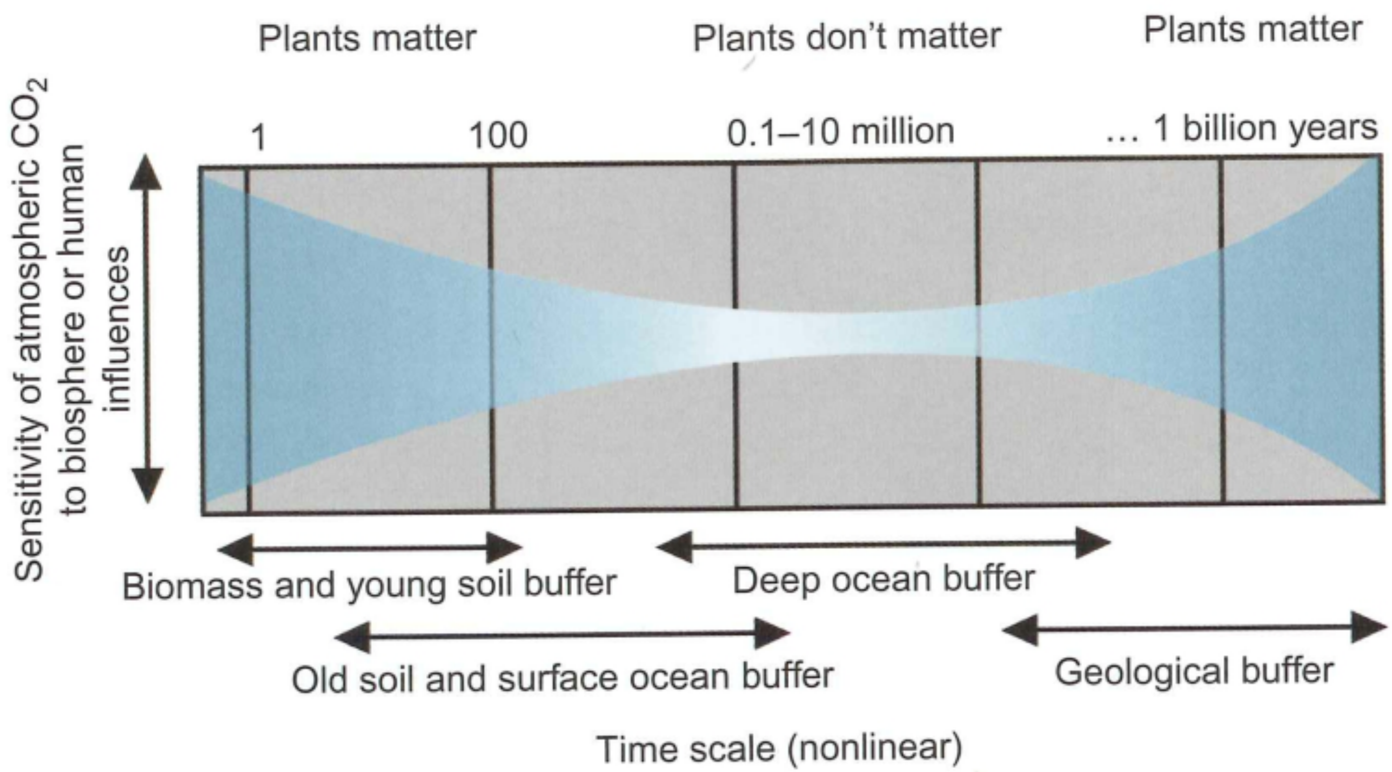
Anthropogenic flux (6.3 Bt/year) is adding to the Atmospheric CO_2 level.

We need to reduce this effect by lowering emissions and increasing sequestration in natural pools.

Increasing forested land is a good option since it provides wildlife habitat as well.

Increasing ocean primary productivity and harvesting fish higher up the food chain is another.

A Matter of Time



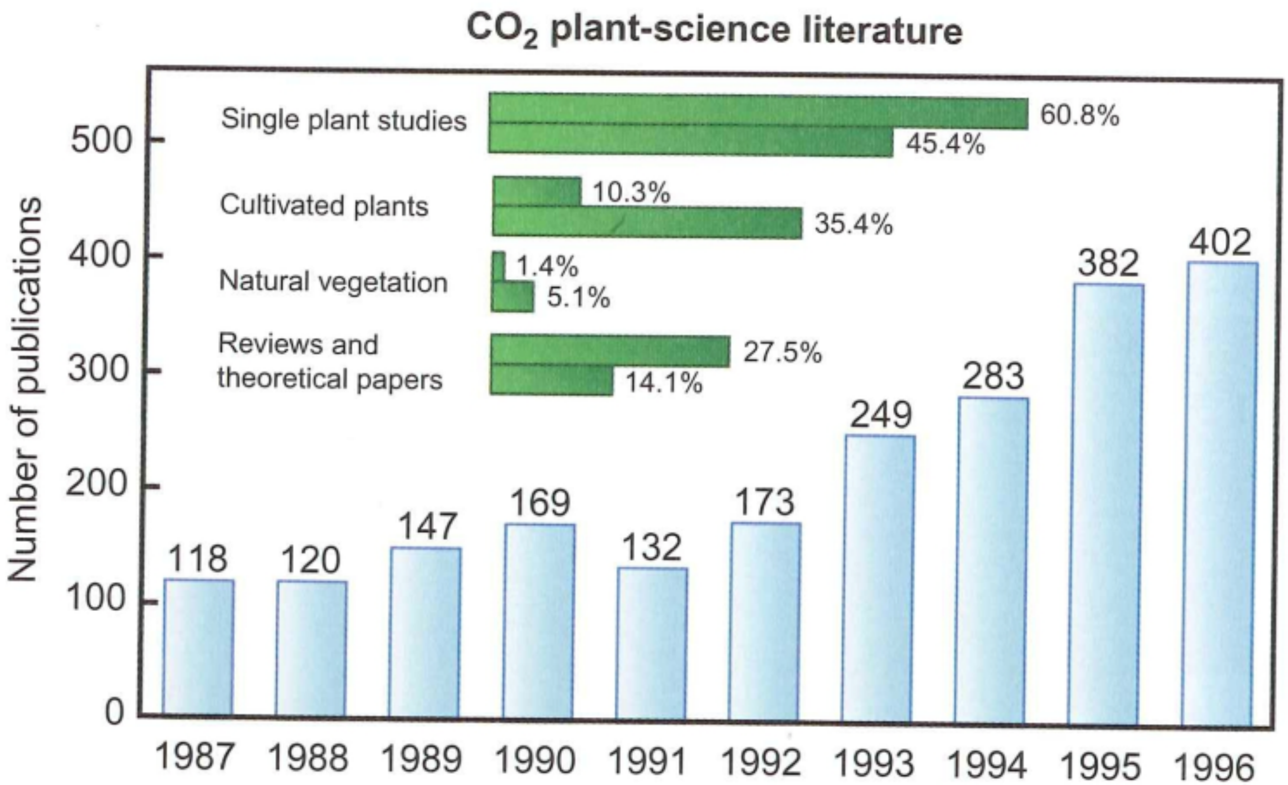
Relevance of Living Plants to Atmospheric CO_2 Concentrations.

Experiments

Experiments can be done in both greenhouses and the field to examine the veracity of predictions regarding the effects of climate change.

While the former allow for finer control, the latter are likely more realistic.

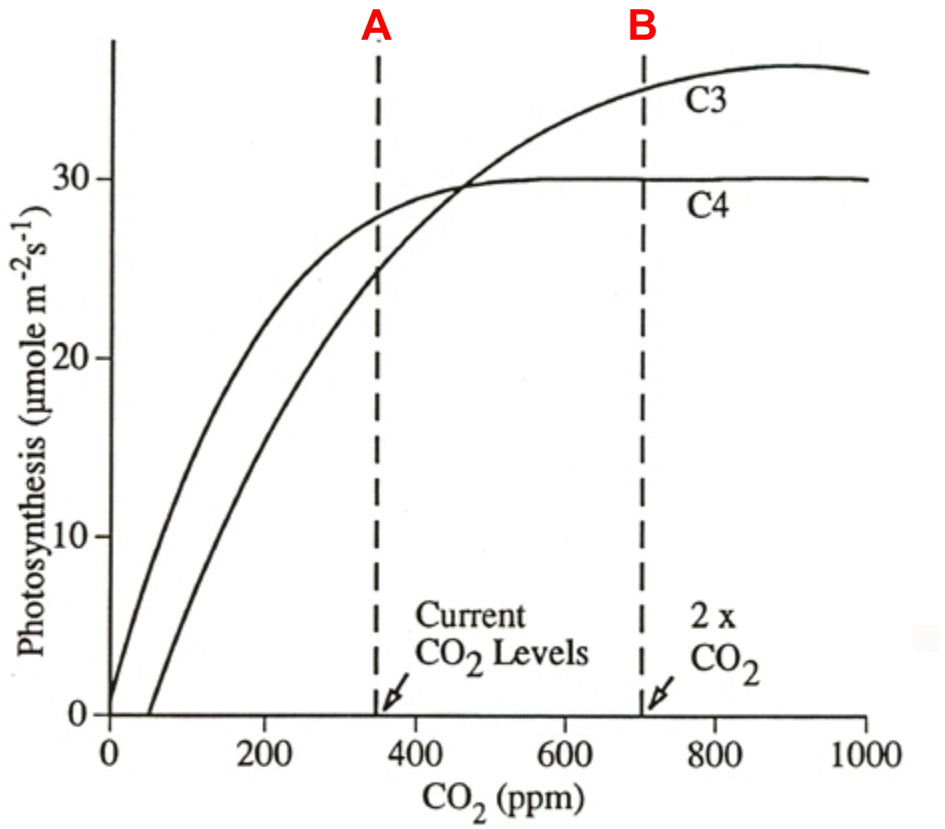
Research Output



The overall output of research in this area has nearly quadrupled in 10 years.

Importantly, there has been a shift in focus with upper green bars of each pair giving percentage of papers during the first 5 years and the lower during the second 5 years.

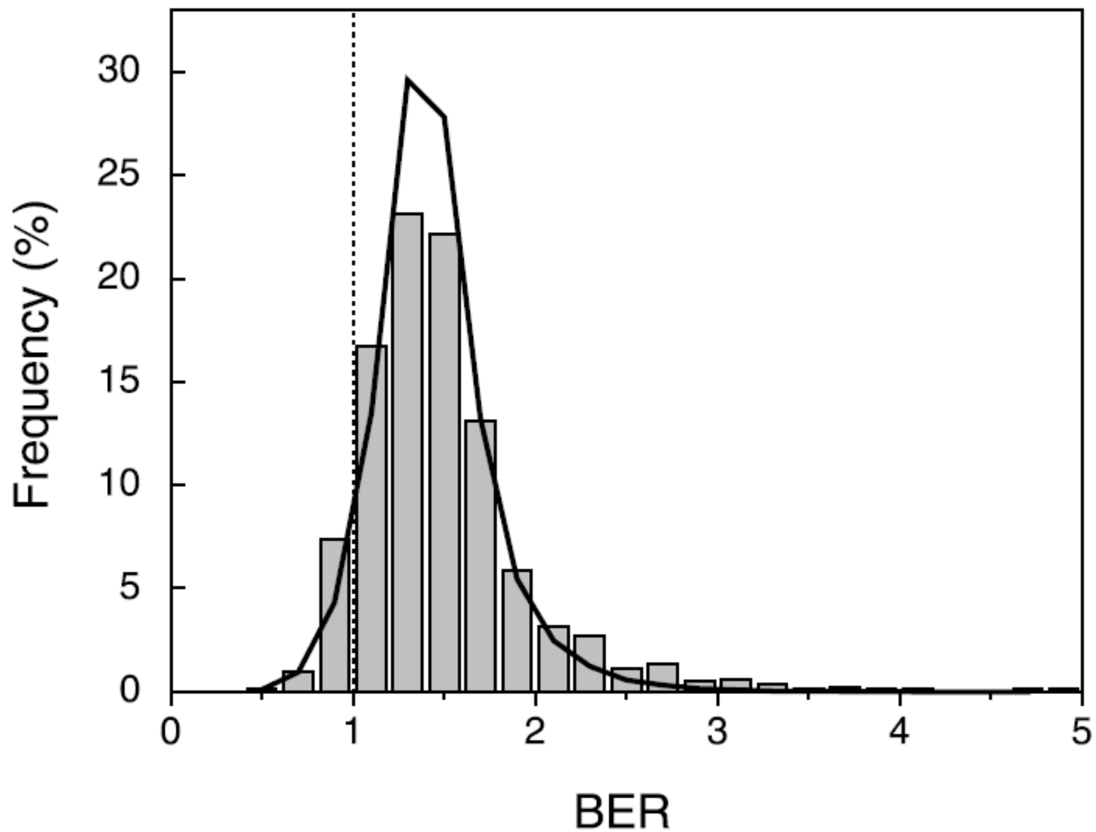
Biomass Enhancement Ratio - BER



The BER is a standardized measure of the change in photosynthetic output as the level of CO_2 is doubled.

BER is quite simply obtained as productivity at B over productivity at A.

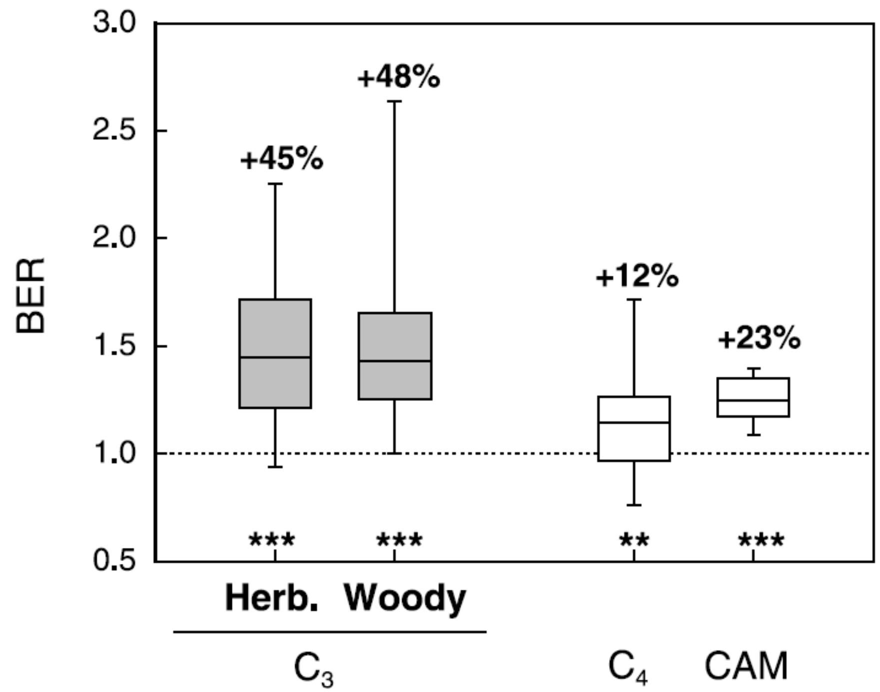
Biomass Enhancement Ratio - BER



Most of the 350 species of plants examined are more productive when CO_2 is enriched above current levels.

Only about 8% of the species do worse (BER<1.0).

Biomass Enhancement Ratio - BER



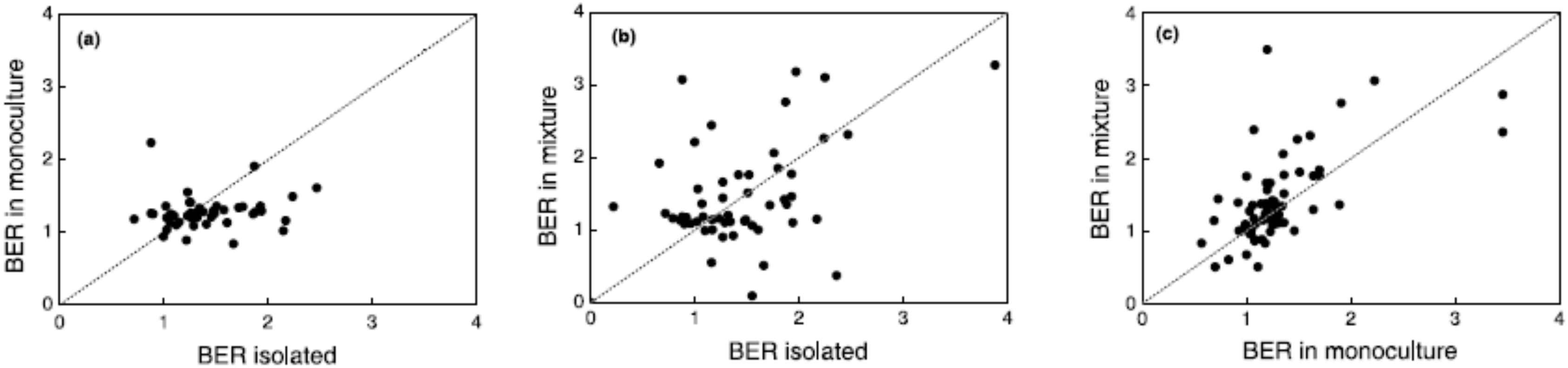
The C3 plants showed the greatest improvement among the 350 evaluated.

Because C4 plants transport CO_2 into deeper tissues they reach a saturation at elevated CO_2.

CAM are succulents that also reach saturation.

If carbon dioxide continues to increase in the atmosphere, C3 plants will have a distinct advantage and species composition of ecosystems will shift.

Biomass Enhancement Ratio - BER



Much of the research on BER has evaluated the response of single isolated plants of each of the species (large samples of each but each plant grown alone).

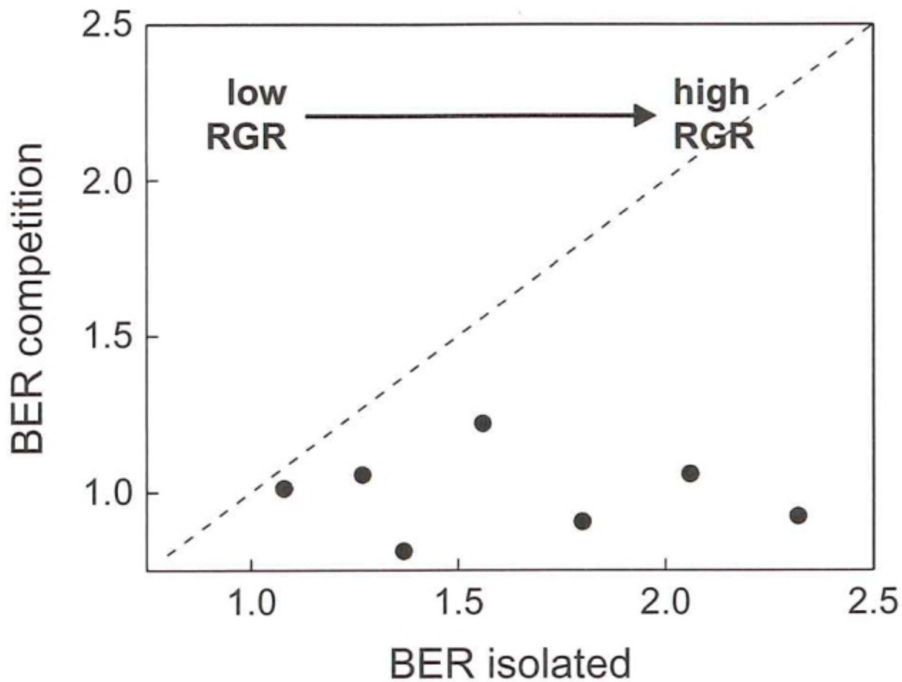
In nature that does not happen – individual plants compete.

The studies summarized examine this by comparing the BER for a number of species using isolated plants, monocultures (multiple individuals of a single species in a tray) and trays of individuals of several species.

If using isolated plants gave an accurate assessment of what happens then all the points would lie on the diagonal.

Clearly, most species do not and while C3 plants always have higher BER the actual value has to be estimated from monocultures or (better) mixed cultures.

Biomass Enhancement Ratio - BER



The bias of using isolated plants is seen even better when BER was evaluated for 7 different C3 woody species in isolation and in direct competition.

Low RGR species are from climax communities (good competitors) while High RGR species are pioneers (move in first).

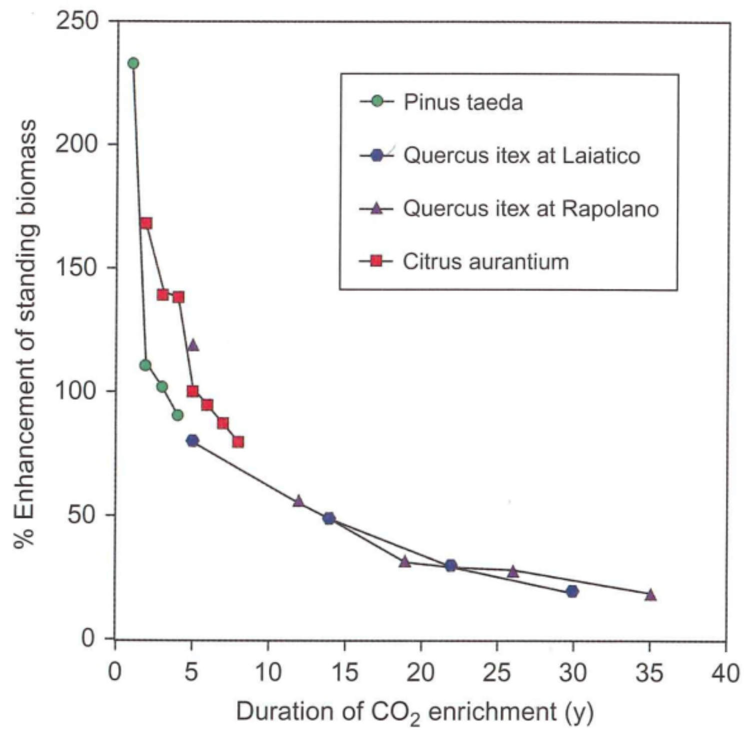
In this case, though, since pioneers are usually in isolation the “isolated” values may be the best predictor for them and it would appear they should thrive under elevated CO_2

Biomass Enhancement Ratio - BER

BER=3.0

BER=2.0

BER=1.0



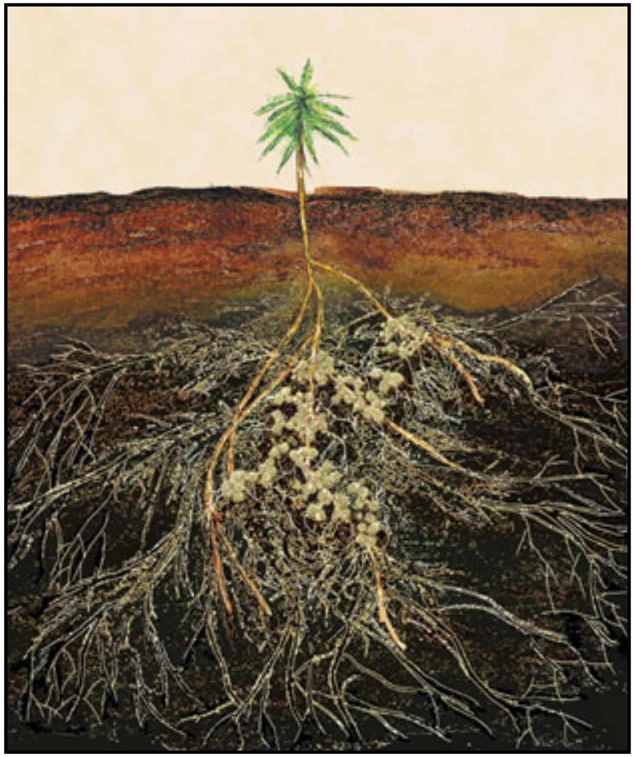
The initial enhancement from CO_2 enrichment is not sustained at a constant level.

This acclimation is likely due not to a reaction to CO_2 but to depletion of other nutrients.

The y-axis here is not BER but can be simply converted as 1+0.01*(%enrichment).

Even after 20 years exposure, they still show enhanced growth.

Mycorrhizae



Mycorrizae are mutualistic fungi that associate as nodules on plant roots and aid in nutrient uptake by solublizing minerals.

They are sensitive to both temperature and desiccation and may be negatively impacted by climate change.

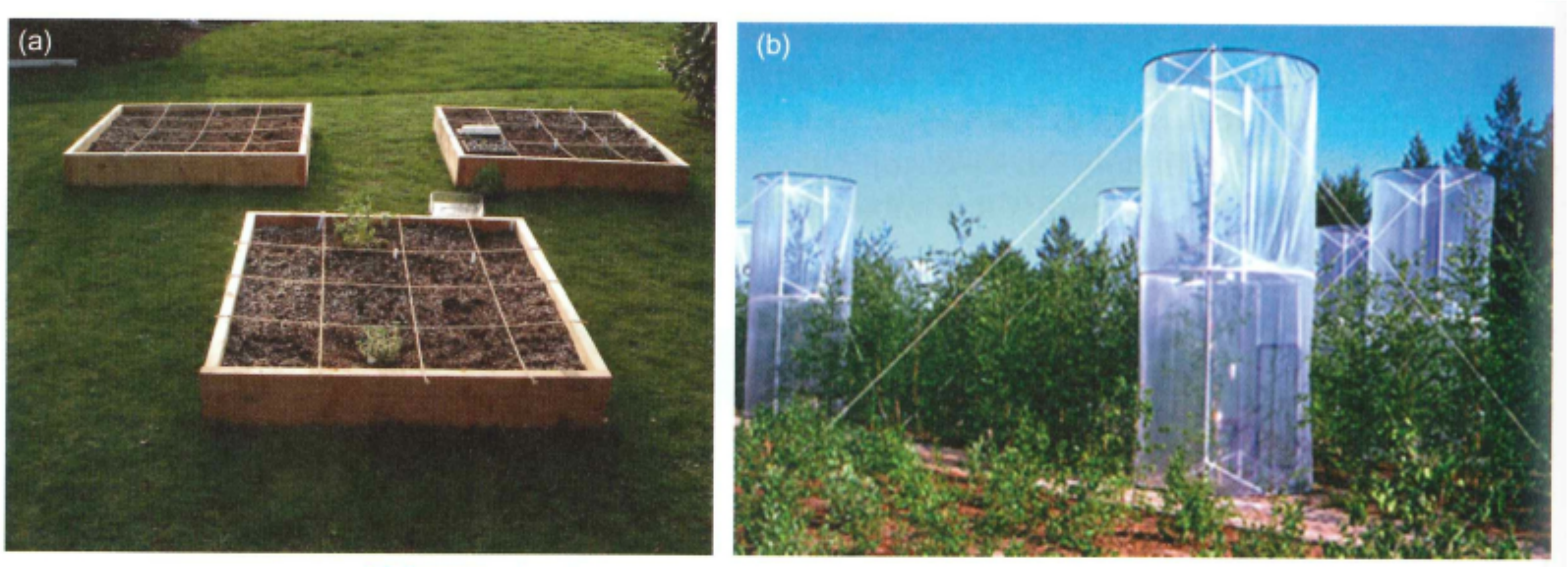
This could in turn lead to massive plant die-offs.

Warming Experiments

In some systems, heat lamps and subsurface tubes with forced warm fluids are used to warm soils to examine the effects of climate change on both soil respiration (growth of microbes and such) and plant growth (left).

In others, more passive open domes are used to concentrate and trap solar insolation.

Warming Experiments

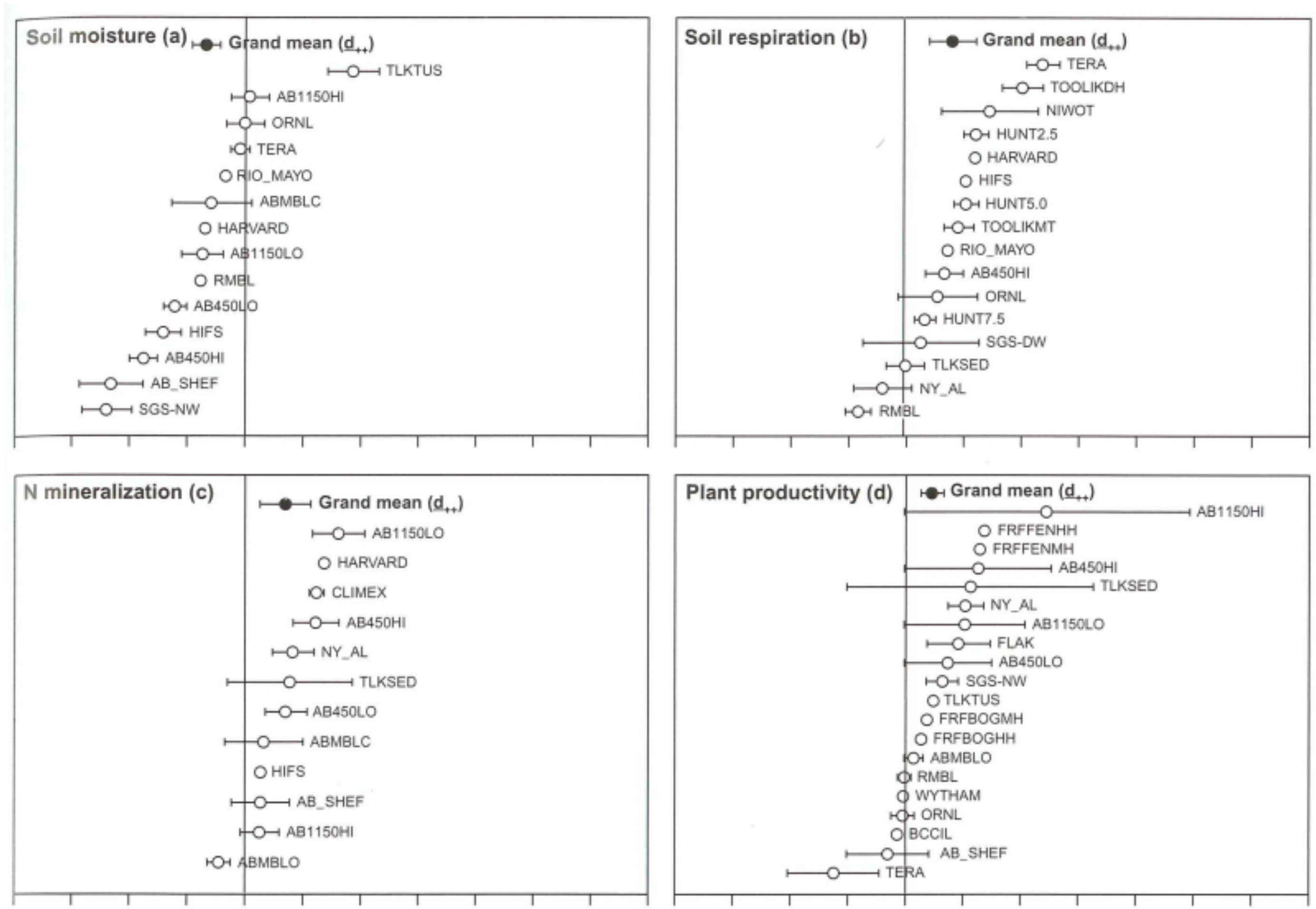


Soils and plants are often "transplanted" to lower elevation or latitude sites where ambient temperatures are higher.

Care has to be taken in such moves to account for light intensity and especially day length on latitude shifts.

Open top chambers provide localized temperature increase but can alter precipitation if it is not vertical.

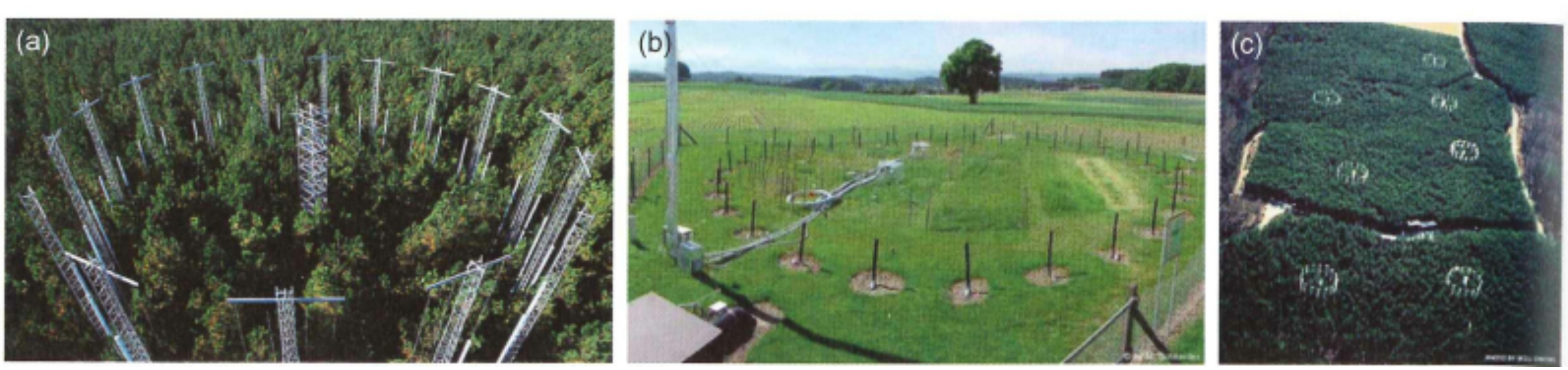
Responses to Soil Warming



Soil warming increases soil mineralization, soil respiration and plant productivity.

The increase in soil respiration may add huge amounts of CO_2 to the atmosphere and trigger run-away climate change.

Free Air CO_2 Enrichment (FACE) Experiments



Various types of systems are erected that flood the area with CO_2.

Plant growth and productivity is compared to “yoked” control areas.

Another approach is to find areas where geological formations are releasing CO_2 and compare plant growth, productivity and diversity to areas without such “seeps”.

The problem with this approach is there may be other geological or soil correlates that are influencing the plants.

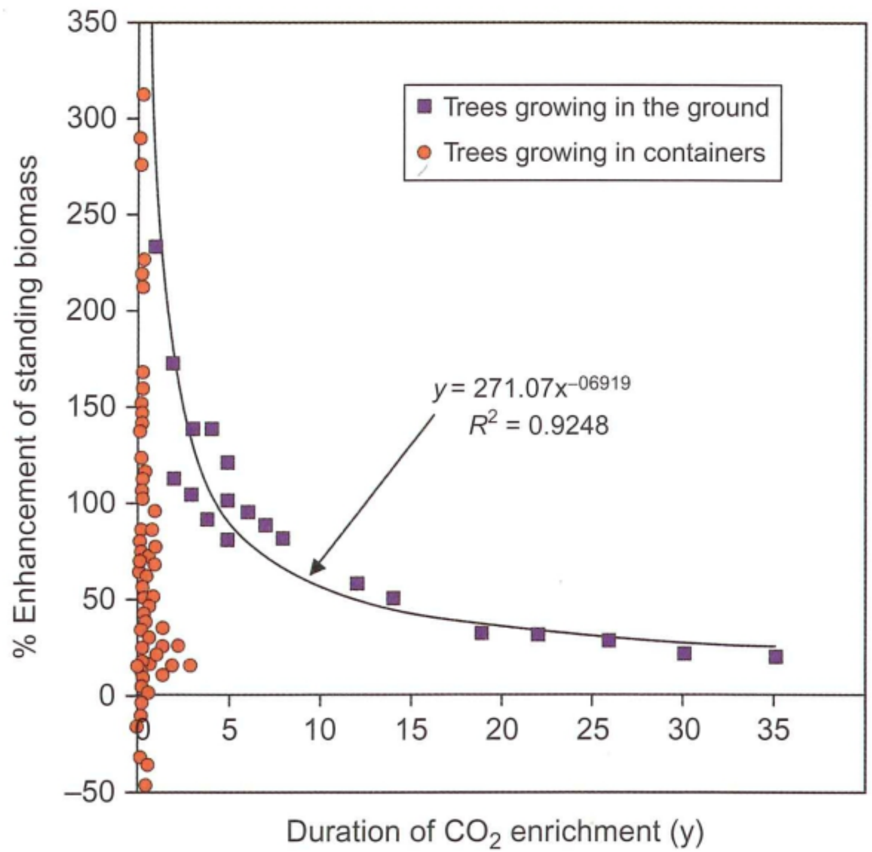
Results of CO_2 Field Experiments

Coppicing results in multiple young trunks per root system and allows evaluation of growth and leaf productivity.

In a classic study near natural CO_2 seeps in Italy it was found that initial growth under CO_2 enrichment was much higher than the yoked control but that the effect was reduced after the 3rd year.

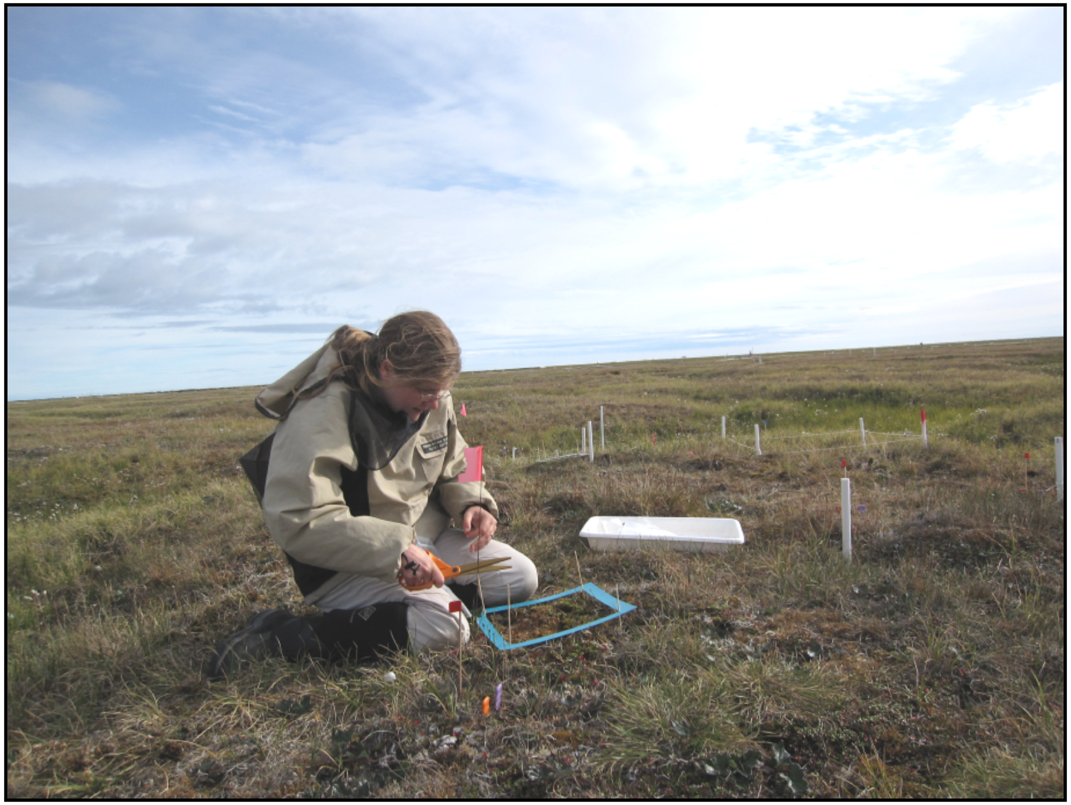
This implies that CO_2 enrichment may have more effect on younger tissue.

Results of CO_2 Field Experiments



Both enhancement and acclimation is shown in these studies of a number of species in a Maryland study.

Arctic Studies



Because the Arctic is warming disproportionately faster, studies there are crucial.

The work is new and is examining effects of warming, CO_2 enrichment, fertilization, shading and moisture.

Arctic Studies

Warming – most studies show that photosynthesis and productivity increase, at least initially. Acclimation is likely linked to nutrients being restricted by permafrost.

CO_2 enrichment – the results here are similar to those in more temperate regions with enhancement of growth and productivity. Acclimation is evident and again likely related to nutrient restriction.

Fertilization – most arctic systems are net exporters of nitrogen to migratory waterfowl. As a consequence, nitrogen addition results in enhanced productivity. Phosphorus and calcium are also limiting.

Shading – studies have shown little effect likely due to plants being adapted to periods of 24 hour light.

Moisture addition – arctic soils tend to be saturated although the water is often frozen. Mobilizing the water through warming has some effects.

Moisture removal – as these regions warm, permafrost melts and water drains from the areas turning mires into dry fields. This has a huge impact on species composition but not on productivity *per se.*

Arctic Studies

Climate change will also alter basic substrate in the Arctic and this has not been studied yet.

Permafrost forms an impervious barrier that does not let water percolate below the surface.

As permafrost melts, this changes and there is a complete change in hydrology – drainage!

Also, tundra and boreal soils are stabilized by permafrost – almost like a binder.

When that is lost, soil slumps (left) and trees lean (right) in a drunken fashion.