ESF Workshop Report – CO_2 & Water

In the wider public the release of large quantities of carbon dioxide through fossil fuel burning and forest destruction is commonly associated with the greenhouse effect and global warming. While CO_2 enrichment of the atmosphere is likely to contribute to climatic changes, this gas is also the major food for the biosphere, a facet of global change that has had much less publicity, although the processes involved are far better understood than those of climatic effects. A greater availability of CO_2 is known to stimulate plant photosynthesis and, provided other resources permit, to stimulate plant growth.

Yet, there is a third, less acknowledged effect of CO_2, the direct influence of its atmospheric concentration on the degree of the opening of leaf pores (stomata). The higher the concentration of CO_2, the less open these pores are which, at a given climatic situation (temperature, humidity), will reduce the loss of water vapour from leaves. Since ca. 70% of all water, which is evaporated from the terrestrial surface passes through such pores, this phenomenon has potentially far-ranging consequences for the globe's hydrology, but also on the above-mentioned climate effects and plant growth effects. A reduction of plant transpiration causes less moisture entering the atmosphere and causes more moisture to be retained in soils. The latter could mitigate drought effects or enhance the flood risk, depending on the prevailing weather.

The 35 participants of this workshop, held in Basel between 18 and 20 August 2002, summarized and discussed the current knowledge in this timely field of research. Starting at the leaf level, there was consensus that most plants examined reduced stomatal gas diffusive conductance when exposed to elevated CO_2. Experimental evidence is also accumulating that the earlier suggested influences of CO_2 concentration on stomatal density cannot be confirmed. The bulk of information from outdoor CO_2 enrichment experiments reflects no such anatomical adjustments in leaves, and it seems such presumed signals from historical or geological records cannot be separated from influences of atmospheric humidity and cloudiness, because these changes covary with CO_2 concentrations.

However, three types of observations repeatedly made, indicate that leaf stomatal responses to elevated CO_2 cannot directly be scaled to predict transpiration.

(1) There is an enormous, so far unexplained variation in responsiveness among different plant species. Even among similar functional types such as crops or grassland species the reduction in leaf conductance to a doubled CO_2 concentration varies between less than 15% and ca. 50%. In trees, reductions vary between close to zero and 30% with a remarkable unresponsiveness of adult conifers compared to deciduous angiosperm trees. In other words, species matter.

(2) The stomatal response depends on ambient humidity. Across climatic regions and across a large range of species and functional types of plants, relative responses have been found to be strongest when soil moisture and atmospheric humidity are high and become very small at lower soil moisture and humidity. This pattern can also be seen during a single day. In short, the stomatal effect is large when potential transpiration is low, and it is small when evaporative demand is high and, thus, potential transpiration is high.

(3) The stomatal signal does not translate 1:1 in a transpiration signal, which becomes drastically reduced at the canopy or stand level due to a number of buffering factors, among which aerodynamic boundary layer conductance seems to play a key role. The denser and lower in stature plant communities are the greater is this aerodynamic limitation to gas exchange. A second important factor is leaf temperature. A reduction of transpiration causes leaves to become warmer (daily averages of 0.1-0.5 K had been estimated for a doubling of CO_2 disregarding an enhanced greenhouse effect and/or climatic feedback). Canopy warming itself enhances the vapor gradient to the atmosphere and stimulates vapor loss. A third, often presumed component, a general increase in leaf area index, could lead to more intense vapor loss per unit of land area. Such a trend had neither been found in crops nor became such trends evident in closed forests, but a periodic increase in LAI associated with biomass responses had been seen in temperate grassland.

The interplay of the primary physiological effects of CO_2 on stomatal aperture and those three modulating factors lead to a suite of actual transpirational and hydrological consequences. In **grassland and herbaceous crops** the limited evidence on evapotranspiration suggests an average reduction of below 10%, commonly more close to 5% at the ecosystem scale - much smaller than the stomatal responses measured at the leaf scale in the same studies. However, such small reductions in daily water loss can accumulate into very significant reductions of soil moisture depletion. Thus, soils may retain more water. In periodically dry regions the biological effects of these water savings seem dramatic. Earthworms have been shown to produce 30% more casts, nutrient availability and microbial activity become significantly enhanced, mesic species have a greater growth advantage, invasive species become more aggressive, the duration of the active growing season is prolonged. It almost seems like the stomatal effects on water (and associated nutrient effects) are sufficient to explain productivity effects of CO_2 enrichment (a mean of plus 15% had been reported in the literature) with no additional stimulatory effects through photosynthesis necessarily needed to explain this growth stimulation.

In **forests**, the elegant method of sap flow monitoring in stems of trees permits direct estimates of actual water loss. The evidence available for four experimental forest sites, an evergreen *Pinus taeda* plantation in North Carolina, a deciduous *Liquidambar styraciflua* plantation in Tennessee, a poplar plantation in Italy, and a deciduous old growth forest in Switzerland show rather small and variable water savings. A best approximation to date may be savings between 5% and 10%, similar to grasslands, again perhaps closer to 5%. The actual CO_2 effect on transpiration also strongly depended on environmental conditions with humid periods showing greater relative (but smaller absolute) effects and dry periods showing very little or no stomatal responses to CO_2. Such responses were also documented for Mediterranean trees around natural CO_2 springs. Similar to the grassland studies soil moisture savings under such CO_2-enriched forest canopies had been documented.

A major part of the workshop was dedicated to the question of how such results would scale to the landscape or continental level. There was consensus that all CO_2 enrichment experiments lack atmospheric feedbacks in the sense that any reduction of vapor loss by vegetation would create a less humid atmosphere, which in turn would stimulate vapor loss. Often criticized open top chamber experiments may inadvertently be more realistic in this respect (chamber humidity is affected in the right direction) than canopy free air CO_2 enrichment (which of course has many other advantages). Such feedback may be irrelevant in downwind coastal areas where the climate is largely dictated by the ocean, and in semiarid regions where the local vegetation has very little influence on the climate. The most sensitive regions may be relatively humid inland areas where regional climate feedback may become significant.

Models of elevated CO_2 effects on climate via feedbacks in ecosystem water relations also reported average water savings of less than 10% - however, with varying combinations of underlying mechanisms. For instance, many models assume increasing leaf area index (not what most experiments revealed), which may somewhat offset the water savings introduced by overstimates of stomatal responses. The workshop ended with a recommendation to modellers to perform simulation experiments that use empirical approximations of actually observed moisture savings in the range of 5-10%, and couple such responses to the atmosphere, producing climatic feedbacks at landscape level, and thus, help to overcome the shortcomings of experimental trials in the absence of better stomatal models.

The current estimates of water savings, as small as they might be, should have significant consequences for catchment water balance and continental hydrology. To which extent the stomatal responses to elevated CO_2 will affect hydrology will largely depend on the species present and the humidity regime. One remarkable insight of the workshop was that stomatal responses to CO_2 enrichment are small in atmospherically highly coupled systems, such as needle-leaved conifers, moderate in broad-leaved deciduous trees, and large in dense, low stature vegetation. It seems that stomatal and aerodynamic limitations to gas exchange balance each other in such a way that transpiration responses to elevated CO_2 may be similar irrespective of vegetation type. This should simplify the modelling of large-scale processes.

Participants agreed on summarizing the results of the workshop in four commissioned synthesis papers for a major international journal. This work is now in progress. The new insights on CO_2 effects on water relations will be implemented in research programs of the two most active international scientific networks in this field, the TERACE and FACE networks of GCTE/IGBP. It was felt, these activities must be international, and a European-only network would not seem desirable.

The group's major message to society was that, in addition to any other effects of elevated atmospheric CO_2 concentration, their direct influence on water relations is likely to induce substantial ecosystem changes. In dry areas, greater plant biomass production may be anticipated where nutrients permit. In humid and wet areas increased runoff of precipitation water may add to the risk of flooding. Climate change could enhance or diminish these direct CO_2 effects on vegetation, depending on region. The 5%-10% water savings in response to a 200-300 ppm increase in CO_2 concentration observed in a number of different ecosystems provide a guideline for modellers to implement such vegetation responses into their climate models.

The Global Change and Terrestrial Ecosystems (GCTE) core project of IGBP has organized the following workshop:

CO_2 AND WATER

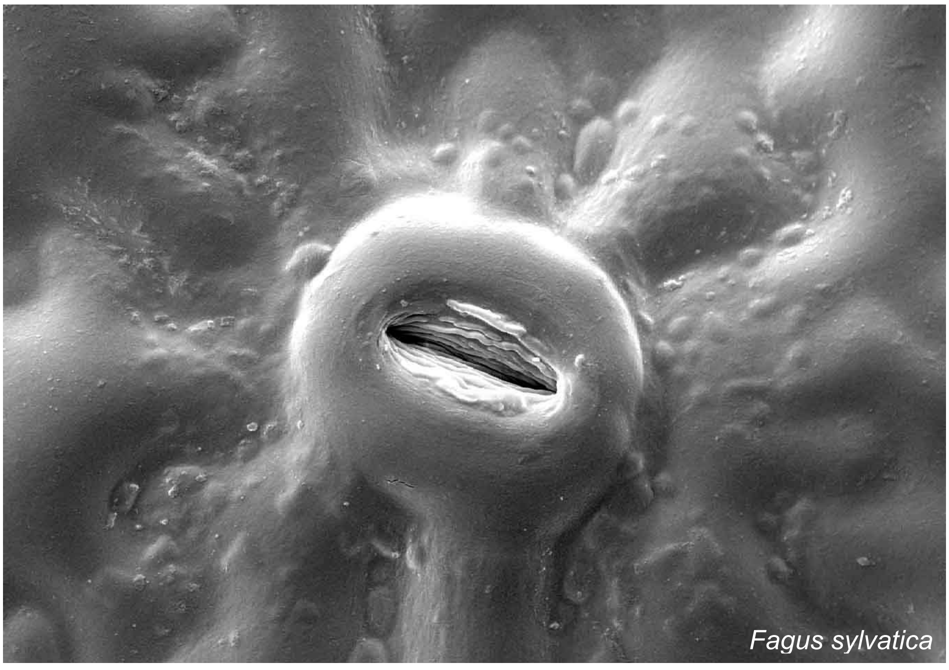
Basel (Switzerland), 17-20 August 2002

The biosphere - atmosphere - hydrosphere loop driven by plant responses to CO2 enrichment

A **European Science Foundation** (ESF) funded exploratory workshop with overseas partners
Organizers: Christian Körner (Basel), Diane Pataki (Salt Lake City)

There is an urgent need to sum up current understanding of direct influences of elevated CO2 on water consumption of leaves, whole plants, communities, ecosystems and larger scale units. Across these scales, feedback effects from soils, biodiversity, and the atmosphere need to be assessed. Conclusions with respect to biodiversity, hydrological and climate consequences should be reached. The workshop aims at bringing together the best available field data, obtained under as realistic as possible conditions for agricultural systems, grass- and range-land as well as forest systems. Modelling approaches will illustrate larger scale implications. The plan is to produce a synthesis volume. Attending the meeting implies contributing to a written product.

- Venue: The workshop will be for a group of approximately 35 people and will be held at the Botanical Institute of the University of Basel in the neighbourhood of the medieval “Spalentor” city gate, with accomodation across the street, all very close to old downtown Basel. Arrival must be August 17.
- Students: A limited number of students from the Universities of Basel and Zürich will be invited attending the lectures as part of their summer school options. Student subscriptions through mco@unibas.ch



Fagus sylvatica

Programme

Saturday 17 August

19:00 Welcome dinner in the Botanical Gardens

Sunday 18 August

(I) Initial effects: Stomatal responses to elevated CO2
(each theme may be split into 2 presentations)

08:30 Opening of the workshop
Christian Körner, Diane Pataki
08:40 Physiological basics: The mechanism of stomatal response to elevated CO2 concentration
James Heath
09:10 Fingerprints of stomatal control: stable isotopes (past - present - future)
Jim Ehleringer, Rolf Siegwolf
09:35 Stomatal responses in crops - an overview
James Bunce

10:00-10:30 Coffee break

10:30 Stomatal responses in temperate grass- and rangeland vegetation
Alan Knapp, Christian Körner, Gail Taylor
10:55 Stomatal responses in dry land vegetation
Diane Pataki, Wayne Polley
11:20 Stomatal responses in young trees
Gerhard Kerstiens, Franco Miglietta
11:45 Stomatal responses in mature trees
David Ellsworth, Christian Körner, Rich Norby, Antonio Raschi

12:10-14:00 Lunch break in the Botanical Gardens

14:00 General discussion and synthesis, part I

(II) Whole plant and stand level water fluxes

14:45 Coupling leaves and the atmosphere
Paul Jarvis
15:15 Soil moisture feedbacks I
Pascal Niklaus
15:35 Soil moisture feedbacks II
Bill Parton

15:55-16:30 Coffee break

16:30 Crop water relations
Hans-Joachim Weigel
16:55 Forest tree water fluxes I
Stan Wullschleger
17:15 Forest tree water fluxes II
Steeve Pepin
17:35 Forest tree water fluxes III
Ram Oren, Gail Taylor
17:55 General discussion and synthesis, part II

19:00 Surprise dinner

Monday 19 August

(III) Biometric and biodiversity responses

08:30 Root responses
Rich Norby
08:55 Shoot responses
Stephan Hättenschwiler
09:20 Biometric ratios
Rob Jackson

09:45-10:15 Coffee break

10:15 Biodiversity effects I, temperate grasslands
Paul Leadley
10:40 Biodiversity effects II, dry grasslands
Jack Morgan
11:05 Biodiversity effects III, arid grasslands
Jose Grünzweig
11:30 General discussion and synthesis, part III

12:00-15:00 field trip to the Swiss Canopy Crane (SCC) in Hofstetten, picnic

(IV) From stand to landscape level responses

15:00 Coupling of fluxes of CO2 and water in Global Vegetation Models
Franz Badeck, Stephen Sitch
15:25 Hydrologic consequences of CO2 changes at the global scale
Dieter Gerten, Stephen Sitch
15:50 Climatic feedbacks
Mike Coughenour

16:15-16:45 Coffee break

16:45 General discussion and synthesis, part IV

(V) Global scale consequences

17:15 Biosphere responses and effects on the climate system
Steve Running
17:40 GCMs in the light of plant CO2 responses
Colin Prentice
18:05 General discussion and synthesis, part V

19:15 Departure for dinner (city center)

Tuesday 20 August

(V) Round up session: A realistic magnitude of vegetation water savings and the consequences; future research emphasis

08:30 5 working groups (I-V)
Chairs: Ehleringer, Jarvis, Körner, Jackson, Prentice

10:00-10:30 Coffee break

10:30 reports of the working groups
Working group nominees
11:45 Future networking activities
12:15 End of workshop

12:30 Lunch at the students restaurant (optional)

14:30 Panel meeting for press release (by invitation)
15:30 Press conference organized by ProClim Switzerland (Swiss Academy of Sciences)
17:00 End of press conference

CO2 and Water Workshop
Basel 17.-20.08.2002

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