

## **CLIMATE CHANGE AND AGRICULTURAL PRODUCTIVITY**

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### **1. ABSTRACT**

Research performed at the AB-DLO and the Free University was intended to quantify the effects of a doubled CO<sub>2</sub> concentration on some key agronomic species and grasslands.

A set of physiological and morphological processes was studied and related to above- and below ground cycling of carbon.

The research was based on experiments and simulation studies at the level of plant, crop and soil in laboratory facilities and semi-field conditions with controlled CO<sub>2</sub> supply. Agricultural crops were grown in "Open Top Chambers" or greenhouses and grasses in transparent tunnels made of Lexan. Soil processes and root respiration were studied in the Wageningen Rhizolab. Photosynthesis and assimilate partitioning were measured simultaneously in the photosynthesis laboratory. Simulation models appeared to be useful tools to quantify the consequences of elevated CO<sub>2</sub> and climate change on the productivity of grasses and crops with different growth strategies.

### **2. RESULTS**

#### **2.1 Photosynthesis and productivity**

In general, a doubled CO<sub>2</sub> concentration enhanced photosynthetic rates of leaves by 25-50%. This stimulated the development of leaves and therefore the amount of intercepted light increased. The combined effect of CO<sub>2</sub> on photosynthesis and the increased light interception was an improvement of the yield by 30-60%.

It was established that the stimulation was not a temporary one. Results from experiments with summer wheat and faba bean, showed that the CO<sub>2</sub> response of wheat remained equal over the season and for faba it even increased towards the end of the season. A remarkable observation was the decreased respiration of soil and roots for grasses under elevated CO<sub>2</sub>. The consequence of this might be a net positive effect on productivity.

The ranking for the CO<sub>2</sub> effect was: faba bean, spring wheat, grass, potato and winter wheat, in a decreasing order. The increase of the harvested products, pods, grain etc. was equal to the total dry matter increases, which means that the

harvest index was unaltered by CO<sub>2</sub>. The CO<sub>2</sub>-driven increase in production, however differed over seasons and between years. The positive effects on grasses and winter wheat were much smaller during winter than during summer. Differences between years and species were explained in terms of differences in timing on which developmental stages were reached until harvest [1,2]. Thus environment interacted differently for the respective crops.

## **2.2 Simulation models**

Simulation studies were of great help to resolve these interactions. A simulation model for potato production predicted a significant interaction between the CO<sub>2</sub> effect and a specific cultivar property, called earliness. In comparison with an early cultivar a late cultivar is characterised by later tuber filling and later leaf senescence.

Averaged over the years 1988-1991, a simulated increase of the CO<sub>2</sub> concentration from 350 vpm to 700 vpm increased tuber dry matter production by 22% for late cultivars and 29% for early cultivars. The effects were smaller for late cultivars, irrespective of the occurrence of a drought period. The higher benefit for early cultivars compared with late cultivars is due to their relatively low Leaf Area Index (LAI) and the concomitant higher positive effect of CO<sub>2</sub> on the light utilization efficiency [2]. This effect is enhanced by a relatively higher positive effect CO<sub>2</sub> on of the Leaf Area Duration (LAD) for early cultivars.

## **2.3 Regrowth from storage**

Pastures are regularly defoliated by grazing or mowing. As a consequence of the removal of photosynthetic tissue, the plants have to remobilize carbon from reserves that were stored in the stubble. These reserves consists mainly of sugars that were obtained from photosynthesis prior to the defoliation. It was found that elevated CO<sub>2</sub> increased the amount of reserves. Strong interactions exist between the amount of biomass harvested and the CO<sub>2</sub> effect on the biomass produced in the next cut. There is an optimum for the cutting height to gain the largest effect for double CO<sub>2</sub>.

In the first days after cutting, growth of grasses is mainly sink limited. The amount of stored carbohydrates in the stubble only set the lower limits for potential regrowth. After about one week of regrowth, the supply of assimilates for regrowth becomes limiting due to photosynthetic restrictions. Doubled CO<sub>2</sub> had a strong positive effect both on tillering and the rate of refilling the storage pools to be used after a next defoliation.

## **2.4 Effect of temperature**

Higher temperatures were synergistic with elevated CO<sub>2</sub> on photosynthetic rates of leaves. Doubled CO<sub>2</sub> stimulated photosynthesis of grasses and winter wheat much more in summer than in winter, partly due to the temperature- and partly due to light interactions. This tentatively would lead to the conclusion that elevated temperature would enlarge the beneficial effect of doubled CO<sub>2</sub> on plant productivity. This however appeared not to be the case. Simulation models of grasses and potato, predicted a shorter growing period at higher temperatures due to an accelerated senescence of the leaves. The advantage of a faster leaf

appearance rate and leaf elongation rates in spring were adversely affected by a faster senescence of the leaves. In addition annual crops developed faster, which shortened the time between emergence and harvest and therefore decreased the amount of intercepted radiation and thus the amount of accumulated biomass.

### 2.5 Nitrogen interaction

As an overall response, high  $\text{CO}_2$  leads to a decrease of the nitrogen content in the biomass mainly due to an increase in the amount of starch and other carbohydrates. This effect however is relatively small and in most cases it is of minor importance compared with the effect of other environmental parameters (Figure 1).

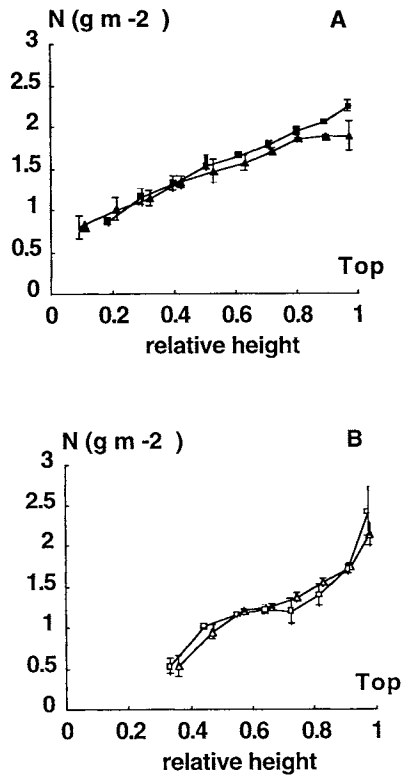


Figure 1: Nitrogen concentration ( $\text{g m}^{-2}$  leaf area) of leaves of faba bean against relative plant height as affected by  $\text{CO}_2$  concentration ( $\text{LCO}_2$  squares,  $\text{HCO}_2$  triangles) at low (A) and high (B) plant density.

A shortage of nutrients reduces the positive effect of elevated  $\text{CO}_2$ . Because large areas in the world are characterised by low amounts of available nitrogen, the expected positive effects on plant production on a global scale have to be considered in this respect. We found that part of the  $\text{CO}_2$  stimulation might be retained under low nitrogen because the plant seemed to require less nitrogen in the tissue. This was concluded from the findings that the nitrogen contents of wheat and faba bean were reduced under doubled  $\text{CO}_2$  and optimal nitrogen supply. However, the total amount of nitrogen that was taken up on a surface area basis was higher under double  $\text{CO}_2$ . This can be explained by the bigger root system of those plants with which a larger volume of soil could be explored for nutrients. Obviously, this can only be the case when the soil volume that is concerned contains any nitrogen. In other cases nitrogen becomes limiting even sooner.

### **2.6 UV-B effects**

Faba bean was shown to be very sensitive for UV-B radiation (280-320 nm). Current outdoor UV-B levels already had an effect on the growth of this plant, although UV-B levels in that open top chamber experiment were very low. Both  $\text{CO}_2$  and UV-B had a significant effect on biomass at all three harvests [3]. The highest UV-B level decreased biomass with 44% in ambient  $\text{CO}_2$  and 55% in elevated  $\text{CO}_2$  at the final harvest (41 days). Without UV-B total biomass was stimulated 34% by elevated  $\text{CO}_2$ . This stimulation was only 7% at the highest UV-B level. The 10 kJ treatment already decreased total biomass at the final harvest of ambient grown plants whereas this treatment had no effect on total biomass of plants grown under double  $\text{CO}_2$ . At the highest UV-B treatment total biomass of elevated grown plants was less than the biomass in the ambient grown plants in the 0,6 and 10 kJ treatments.

### **2.7 Uncertainties**

While plant growth is stimulated under elevated  $\text{CO}_2$ , not all species react in the same way. Interactions between developmental stages of different species and environmental factors are involved such as light, temperature and nutrient supply. The background of this is not known with sufficient certainty. This aspect is of major importance for plants which grow in competition with each other especially in natural vegetations. A project for further research is in preparation, involving simulation models and "Open Top" experiments.

Elevated  $\text{CO}_2$  may lead to more carbon stored in the vegetation. Through an increased root growth it may lead to an elevated carbon pool in the soil, too. The consequences for the total carbon balance may be considerable. The question remains whether carbon or nitrogen is the controlling factor in this process. This will be the challenge and the subject of forthcoming projects.

## **3. GENERAL CONCLUSIONS**

### **3.1 Above ground**

We conclude that the response to doubling the  $\text{CO}_2$  concentration varies to a great extent and that this variation can partly be explained by differences in

development of specific crop species during the season and interactions with weather conditions.

Apart from the uncertainties given above, it is expected that a doubling of the CO<sub>2</sub> concentration will result in an increase in production of 15-50 %. An increase in temperature will partly neutralise the effect of CO<sub>2</sub> because it decreases the length of the period for growth of annual crops and it increased the turn-over of life leaves into dead litter for grasses.

In order to achieve an increase in production, increased input of nutrients is required.

### 3.2 Below ground

When nitrogen is not limiting, a doubling of the CO<sub>2</sub> concentration stimulates the allocation of carbon to the roots and the soil. This may increase the storage capacity of the soil for carbon. The ultimate effect for the carbon cycle will depend on the stimulation in the long term, the availability of nutrients, the effects of higher temperature and the decomposition rates of soil organic matter.

### References

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