THE GREENHOUSE EFFECT ON GRASSLAND PRODUCTION

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This paper examines likely global atmospheric changes, and their relative magnitude and certainties; then the most probable effect these will have on plant production; and finally, the possible end result on agricultural, and particularly grassland production.

GLOBAL CHANGES

Several billion years of vegetation growth has caused at least a 10-fold reduction in CO_2 level, and concurrently has increased 0_2 from zero to the current level of about 21%. Agriculture started about 10,000 years ago, soon after CO_2 concentration began to increase from 200 ppm to about 300 ppm during the last glacial retreat. Before industrialisation commenced in the 19th century, atmospheric CO_2 concentration was about 280 ppm. Following razing of 15-20% of the world's forests and the large scale use of fossil fuels, it has increased by 25% to over 350 ppm. Over the last decade, CO_2 concentration increased by about 0.5% p.a. and is accelarating as the rate of increase in fossil fuel increases.

Global average temperature is expected to increase with CO_2 and other greenhouse gases calculations show that the "plant-effective" temperature (ie above the base-temperature for growth) should be increasing at a rate of 0.2 -0.3% pa. However, in any specific region, greenhouse-dependant temperature change is as yet unpredictable, and even in terms of the global average an increasing trend attributable to greenhouse effects gases is not yet unequivocably detectable.

Rainfall is predicted using models to increase by 0.04 - 0.1% pa as CO_2 and the other trace gases increase. As with temperature, it is unlikely that rainfall increases will be uniform across all regions.

To summarise, CO_2 increases should be in the order of 0.5% pa and fairly uniform over the globe. Concomitant temperature and rainfall changes are likely to be about one half and one fifth, respectively, of the CO_2 rate of increase, in terms of their plant-effective ranges, and highly variable. However, a problem in predicting the future greenhouse effect is that, by the time temperature and rainfall have changed sufficiently to be discernible, CO_2 concentration will be much higher than it is now, and therefore prediction equations will have to be modified. Also, another confounding factor is the interaction between vegetation changes and consequent climate changes.

Although not accurate enough for specific regions, prediction equations for a future global warming and increased rainfall, as CO_2 equivalents rise, are however supported by past palaeo-climatic correlations. As temperatures rose, so, the geologic record shows, did rainfall and continental run-off.

But in terms of predicting future effects on grassland production, it should be pointed out that the amount known about the impact of CO_2, temperature and rainfall on grasslands production ranks in reverse order to the magnitude and certainty of these changes. That is, we know much about how field productivity responds to rainfall, something about response to temperature, and very little about responsiveness to CO_2.

EFFECT OF GLOBAL ATMOSPHERIC CHANGES ON PLANT AND GRASSLANDS PRODUCTION

Direct effect of CO2

The acquisition of C by plants for photosynthetic conversion into carbohydrates, involves three major compromises:

- Whenever CO_2 enters a plant through leaf stomata, water escapes.
- The enzyme RUBISCO which fixes CO_2 into organic matter requires N; at least 25% of the plant's N is tied up in RUBISCO. Since most of the non-fertiliser N in soil was fixed using energy from the oxidation of organic matter created by RUBISCO in the first place, this is a high price to pay on top of the inherently inefficient C-aquisition system of the biosphere.
- RUBISCO is unable to distinguish between its key substrate, CO_2, and its key photosynthetic product, O_2. The reaction that RUBISCO catalyses with O_2 produces phosphoglycolate, a metabolite which has to be converted via photorespiration into a usable form with a concomitant loss of some of the recently fixed CO_2.

Now that man is realising some of the accumulated reduced C back into the atmosphere as CO_2 derived from fossil fuels, we should expect in principle that the increasing CO_2 has the potential to increase biosphere production by alleviating the constraints imposed by these three compromises. Although the attainment of this potential may not be easy - eg, in gradually evolving to cope with diminishing CO_2 and increasing O_2 over several billion years plants may now be unable to respond to the sudden increased CO_2 resulting from man's activities - I believe that already many field and crop plants should be responding positively to increasing atmospheric CO_2.

Interacation between increased $C0_2$ and other growth-limiting external factors

Although the short term effect of CO_2 on plant photosynthesis has been well explained by research, this is inadequate to accurately predict long-term grassland yield responses to increased CO_2, for several reasons including:

- Possible altered competitive relationships with weeds, pests and diseases.
- Other limiting factors such as water, radiation, soil fertility, etc.
- Possible effects on forage quality.
- Climatic change itself may affect responses to CO_2.

However, although many agronomists and ecologists doubt that most crops, pastures, and natural vegetation would exhibit long term responses to increased CO_2, because other factors like water, fertility, etc, are limiting, my own research indicates that in many cases efficient use of scarce resources is limited by carbon availability to plants. The reasons are complex, but may involve the operation of CO_2 - sensitive plant processes other than photosynthesis.

One of these is the interaction of CCO_2 with ethylene formation by plant tissues. For example, high concentrations (eg 10% by volume) of CO_2 can be used to improve fruit storage, probably by inhibiting ethylene production by the fruit. But even modest increases above the normal ambient level of CO_2 can effect ethylene production and action. Another possibility is that modest CO_2 increeases may reduce respiration rates in plants, a phenomenon which has been measured in a number of experiments.

Interaction between increased CO_2 and temperature

This has been studies in various expeeriments, with conflicting results suggesting three possibilities:

- Above a threshold temperature, the higher the temperature the greater the CO_2 responsiveness of growth. Below the threshold temperature, growth is inhibited by high CO_2.
- There is no response to increasising CO_2 below and above the broad rather flat-topped optimum range for photoosynthesis.
- Increasing CO_2 increases growth across the whole normal range of crop growth temperatures.

The last option seems to be the mosst probable, as there is no obvious physiological explanation for negative effects of hiigh CO_2 at low temperatures; in fact, there is evidence to the contrary.

Interaction between increased CO_2 and water

Experiments have shown that because CO_2 gain is accompanied by water loss (through stomata), water use efficiency for dry matter production is improved. However, quantification of this in field situations is complicated by the current inability to measure the feedbacks impinging on field transpirration affected by higher CO_2.

Other factors

Other growth limiting factors such as N and P may also interact, with increased CO_2 in affecting plant growth. Research sugggests that increased CO_2 may increase N use efficiency, but extrapolation to the field situation is unclear. It could even be that a higher C:N ratio in plant residues could reduce N available for plant growth. Nodulation of legumes is stimulated by high CO_2, so symbiotic N-fixation should increase. There are conflicting results from research into the effects of the interaction between CO_2 and P on plant growth.

CONCLUDING COMMENTS

From the material reviewed it is clear that we are not yet in a good position to construct accurate models of the combined impact of CO_2 concentration, temperature and rainfall change on pasture production. Even if the climate modellers were able to tell us regional specifics about how climate will change we could not use them very accurately for pasture production prediction. However, what I have said suggests that in general pasture production productivity is most likely to increase as a function of anticipated global change. In those areas where pasture production occurs principally in the cool months, moister, warmer conditions will increase growth. Any summer growth of perennial pastures will tend to be increased by higher CO_2 concentrations because the CO_2 stimulation is relatively strong in warmer drier conditions. Tropical pastures dominated by C_4 grasses are unlikely to benefit from elevated CO_2 except where they are growing with extreme drought. Where tropical legumes are significant to tropical pasture production it is expected that the elevated CO_2 will increase nitrogen fixation.

There is also the possibility of some negative effects on dry matter production. For annual pastures the acceleration of the attainment of muturity owing to warmer conditions will have a tendency to reduce yield owing to quicker transition to flowering. If it turns out that the incidence of drought increases in some place then of course that will be a negative component to productivity. To some extent we can anticipate that the increased production will probably be at a lower protein content and this may be undesirable in some circumstances. Also to the extent that increased production leads to larger amounts of standing dry grass there may be a greater tendency for wild fires especially if summers become hotter.

The repercussions of these multifarious changes on trade and trade patterns are, I suggest, well beyond anybody's capability to predict. However, my suspicion is that any trade-related effects that do follow will be swamped by the repercussions of sociopolitical forces such as the massive political reorganisation and turmoil that we can expect in Europe over the next few decades and the burgeoning world population growth.

Finally, to summarise, a main thrust of this paper has been to demonstrate that direct CO_2 effects are likely to be of considerable significance to the agricultural impact of global atmospheric change, at least as great as that of average temperature and rainfall change. However, whereas the increase in CO_2 is uniform, smooth, steady and relatively predictable, change in temperature and rainfall patterns and other climatic attributes is unlikely to be uniform, smooth and steady and is as yet unpredictable in any given region. While overall warmer wetter conditions are expected, at any one location drier and even cooler conditions and different seasonal patterns are possible. Therefore surprises, and not necessarily welcome ones, may be in store for agricultural systems superimposed on the potential productivity gains from the carbon dioxide fertilising effect.