Centre for Agricultural Strategy

The 'greenhouse effect' and UK agriculture

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Poster presentation: The 'greenhouse effect' and effects on crop yields

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INTRODUCTION

A hierarchy of models is necessary to estimate the direct and indirect consequences of the 'greenhouse effect' on mankind's activities. First, to estimate the effect of increases in radiative-active gases within the atmosphere on climate both globally and regionally. Second, to assess the influence on agriculture of climatic changes in the different agro-ecological zones of the World, particularly on crop production. Third, to evaluate the outcome of changes in agricultural productivity on regional and national economies.

It follows that comprehensive studies of the greenhouse effect require a multi-disciplinary approach incorporating a hierarchy of quantitative models. This is also the case within the second sector above, estimating the influence of climate change on crop production.

Climatic models suggest that by the year 2050 carbon dioxide concentrations in the atmosphere may double, while mean global air temperatures could increase by 3–5°C. Crop yields depend on photosynthetic activity, developmental rate, physiological age, and the partitioning of photosynthate and nitrogen to harvestable yield.

Staff from three Departments at Reading have developed a series of quantitative models which describe various aspects of the influence of environment on crop growth and development. These models not only provide a means of assessing the impact of given changes in climate on crop production, but also a sound basis for developing genotypes better suited to the climate changes, to which we are already committed as a result of the historical rise in the concentration of the radiatively-active gases in the atmosphere.

PHOTOSYNTHESIS

Increased carbon dioxide concentrations directly affect plant growth through effects on photosynthesis, photorespiration, respiration and stomatal aperture. The process of principal concern is net photosynthesis. Plants with C3 photosynthetic pathways show increased net photosynthesis rates with an increase in CO_2 above present atmospheric concentrations, in contrast to C4 plants which show little change.

However, net photosynthesis is also influenced by temperature and irradiance and, crucially, by strong interactions between the effects of CO_2, irradiance and temperature. It is important, then, to quantify net photosynthesis in relation to variations in all three factors (ie as four-dimensional models). Nevertheless, it is clear that, at least for C3 plants grown in temperate latitudes, the predicted climatic changes are likely to increase net photosynthesis. For reasons discussed below, this trend may not necessarily lead to increased crop yields.

ACCLIMATION

There is substantial evidence that photosynthetic rate acclimates to raised CO_2 concentrations such that sustained net photosynthetic rates increase far less than short-term responses to CO_2 might suggest. The extent of acclimation to raised CO_2 concentrations may vary appreciably among crops.

ONTOGENY

Potential relative crop growth rate declines during ontogeny – it declines with physiological age. Physiological age is determined principally by thermal history (accumulated thermal time). Accordingly, the potential relative crop growth rate declines more rapidly in warmer conditions.

The potential relative crop growth rate at a given physiological age is modified by the current temperature and photosynthetic rate. It is essential to recognise the importance of ontogeny when studying the response of net photosynthesis to CO_2, irradiance and temperature. It also follows that it is necessary to distinguish between crops in terms of the effect of climate changes on yield depending upon the stage of ontogeny at which they are harvested (eg in root crops as distinct from grain crops).

PARTITIONING

There is evidence that the partitioning of assimilates – both carbon and nitrogen – can be influenced by relatively small differences in temperature.

For example, in several grain legume crops we have detected significant negative relations between Harvest Index and temperature over the range from 22 to 28°C. There is conflicting evidence concerning the effect of CO_2 on partitioning, perhaps because of the variety of crops and treatments investigated.

PHENOLOGY

Over a wide range of conditions in most crops, the rate of development and thus the duration of the vegetative phase – during which photosynthetic production capacity is determined – is a linear function of temperature and photoperiod. It follows that developmental times in fluctuating environments can be modelled in photothermal-time accumulated over the base temperature.

The phenotypic duration of any cultivar must match its intended agro-ecological zone. Warmer temperatures in the temperate latitudes will reduce the duration of a given cultivar which, since dry matter accumulation is a function of intercepted radiation, will reduce crop yields.

In the UK, for example, calculations based on the photothermal development model combined with field results from date-of-sowing investigations suggest that a 2°C increase in temperature may reduce grain yields of current spring cereal cultivars by approximately 15–20%.

The photothermal model can also be applied to characterise genotypes for their sensitivity of developmental rate to temperature and photoperiod. These studies have shown that the responses to each of these climatic variables are independent. And so the photothermal model provides a basis of screening and selecting genotypes which will match changed environments.

In contrast, phenology does not appear to be greatly affected by CO_2 concentration, although there is evidence of both increases and decreases in the rate of development resulting from raised CO_2 concentrations.

FUTURE RESEARCH

It seems clear that elevated CO_2 concentrations and warmer temperatures will raise, albeit briefly, net photosynthesis rates for young leaves of crop plants under optimum conditions. However, other considerations suggest that predicted benefits of the greenhouse effect to temperate agriculture, based simplistically on such responses, are unlikely to be realised, and that unless genotypes are developed which match the new climates, harvested yields from grain crops may decline. It follows that research intending to quantify the likely effects on crop production of changed CO_2 concentrations in the atmosphere and of the greenhouse effect, will need to combine studies on all the major variables, utilising controlled environments with varying degrees of sophistication (from pot-grown plants in growth cabinets to field-grown crops under plastic).

RECENT PUBLICATIONS

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