National Diploma

Farm Business Management

Handout 9

The Impact of Climate Change

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THE IMPACT THAT CLIMATE CHANGE CAN HAVE ON PLANT GROWTH AND AGRICULTURAL SYSTEMS

Introduction

This short article discusses how elevated CO_2 together with increases in drought and high temperature may impact upon the growth and development of plants, particularly with reference to some agricultural systems.

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1 The greenhouse effect and climatic extremes

1.1 Introduction

Concentrations of carbon dioxide (CO_2) in the atmosphere have increased from pre-industrial levels of about 270 µmol mol^{-1} to current concentrations of 360 µmol mol^{-1}. Increases in greenhouse gases in the atmosphere, such as CO_2, methane and nitrous oxide, are predicted to result in a rise in mean temperatures of 2–3°C by the year 2050 and even by as much as 4.5°C by 2100 AD together with more frequent episodes of water deficit and higher temperature events.

In the future it is thought that the increase in CO_2 and other greenhouse gases will cause an increase in global mean temperature, with larger increases at high latitudes than elsewhere and larger increases during winter than summer.

Via various models, scientists have predicted that, for the UK, there is in all seasons and for all scenarios a southeast to northwest gradient across the UK in the overall magnitude of the climate warming, with the southeast warming more rapidly than the northwest.

Web-based resources on climate change and impacts on agriculture:

- BBC Weather Centre covers the basics of climate change science
- BBC Weather Centre on extreme weather
- BBC News covers the heatwave of 2003
- UK's Climate Impact Programme considers UK agriculture and climate change
- UK's Climate Impact Programme on observed UK climate trends
- University of Reading website on agriculture and climate change
- Environmental Change Institute podcasts

2 The effect of elevated CO_2 and climatic extremes on plant growth

2.1 Plant structures: leaves and roots

CO_2 enrichment of the air in which crops grow usually stimulates their growth and yield. Plant structure and physiology are usually markedly altered; this includes increased leaf expansion and cell wall extensibility and often cell turgor pressure, leading to increased leaf and root growth. If increased turgor pressure is alone insufficient to account for increases in leaf growth under elevated CO_2, then cell wall relaxation (extensibility), cell division or both may also be affected.

Simplistically, scientists have suggested that increased leaf size, if associated with larger cells, suggests that cell expansion has been stimulated, whilst increased leaf size, if associated with more cells, suggests that cell division has been stimulated.

However, various studies have reported differences in the various cellular mechanisms driving leaf expansion, which can vary between species and seasons; thus, one or other mechanisms may play a larger role, but this is beyond this introductory unit. Similar studies have focused on roots and such similar mechanisms for increased root length and/or biomass under conditions of elevated CO_2.

2.2 Seasonal growth

Contrasting seasonal growth responses to elevated CO_2 and temperature in certain species suggests that pasture management may change in the future.

The grazing season may be prolonged, but whole-season productivity may become more variable than today. This is shown by studies of perennial ryegrass where, in spring, increased leaf extension occurred in elevated CO_2 whilst in summer it was reduced. In high temperature it was reduced in both seasons.

In elevated CO_2 × temperature, leaf extension increased in spring, whilst in summer it decreased. Many organisms are near their tolerance limits and some may not be able to persist under hotter conditions. Higher temperatures in arid regions with cold winters may mean spring growth occurs earlier. Water reserves gained during the winter may, in some cases, be depleted earlier.

2.3 Climate change and agriculture

Climate change will affect agriculture through effects on crops and weeds, soils, insects and disease. In terms of crops, the main climatic variables that are important are temperature, solar radiation, water and atmospheric CO_2 concentration. However, whilst plant development is generally increased by temperature, CO_2 enrichment can accelerate it even further in some cases, whilst in other cases it may have no effect or retarding effects in other cases.

Plant growth and crop yields depend on temperature and temperature extremes. The optimum range for C3 crops is 15–20°C and for C4 crops it is 25–30°C. The variation in temperature requirements and temperature extremes of different cultivars of the same species, and among species, is quite wide for most crops. C3 plants are sensitive to higher CO_2 and typically respond with an increase in photosynthesis and growth, whilst C4 plants don't respond so dramatically. Typically, field-grown crops, such as winter wheat, carrot, cauliflower and onion, have been shown to increase leaf area and biomass during early crop growth under elevated CO_2 conditions compared with ambient conditions.

Water stress has often been observed to be ameliorated by increasing concentrations of CO_2. By inducing the partial closure of stomata, water is conserved. A study of plant responses to atmospheric CO_2 enrichments under conditions of environmental stress concluded that the relative growth-enhancing effects of elevated CO_2 were greatest when resource limitations and environmental stress were most severe.

Web-based resources on plant growth and CO_2:

- BBC Weather Centre on extreme weather on agriculture
- Center for the Study of Carbon Dioxide and Global Change web page on 'Interaction of CO_2 and light on plant growth – summary'

- Friends of Science website on CO_2 and plant growth
- Science Daily article 'High carbon dioxide boosts plant respiration, potentially affecting climate and crops'.

3 The effects on yield and phenology

Through global warming, an anticipated increase in temperature can potentially have various effects, e.g. pikelet sterility in rice, reversal of vernalisation in wheat, reduced formation of tubers in potatoes, loss of pollen viability in maize. Yields can be severely affected if temperatures exceed critical limits for periods as short as 1 h during anthesis (flowering). Flowering is a very important event in crop development, as it is a phase which is particularly vulnerable to environmental stresses (Roberts et al., 1993).

It is thought that extreme temperatures are more important than average temperatures in determining plant responses. Crop yields are affected by net primary productivity and also by the phenology of crop development. Increased temperature can speed phenological development, reducing the grain-filling period for crops and lowering yield. Crop yields were greater under elevated CO_2, but warmer temperatures reduced the duration of crop growth and, hence, the yield of determinate crops such as winter wheat and onion; but the yield of carrot, for example, an indeterminate crop, increased progressively with temperature (Wheeler et al., 1996).

In terms of temperature, a 12-day period of high temperature stress close to anthesis reduced spring wheat root biomass from 141 to 63 g m^{-2} (Ferris et al., 1998) by the end of the elevated mean temperature period, whereas mean temperatures over the treatment period had no effect on either above-ground biomass or grain yield at maturity. Interestingly, it was increasing maximum temperatures over the mid-anthesis period which was related to a decline in the number of grains per ear at maturity. Grain yield and harvest index also declined sharply with maximum temperature. This study suggested that high temperature extremes may reduce yields considerably.

Elevated CO_2 can aid the recovery of plants from high temperature-induced reductions in photosynthetic capacity. Ferris et al. (1998) grew soybeans for 52 days under normal air temperature and soil water conditions at atmospheric CO_2 concentrations of 360 and 700 µmol mol^{-1}, but then subjected them to an 8-day period of high temperature and water stress. After normal air temperature and soil water conditions were restored, the CO_2-enriched plants attained photosynthetic rates that were 72% of their unstressed controls, while stressed plants grown at ambient CO_2 attained photosynthetic rates that were only 52% of their respective controls.

In the same study total biomass was 41% greater under elevated CO_2 than under ambient CO_2 but reduced by high temperature, water deficit and high temperature × water deficit under both CO_2 concentrations. At maturity, seed dry weight and number per plant under elevated CO_2 were increased by an average of 32% and 22% respectively compared with ambient CO_2. The same parameters were reduced after high temperature × water deficit by 29% and 30% respectively in ambient CO_2 and elevated CO_2. Seed filling was earlier under high temperature and high temperature × water deficit. The rate of change in harvest index was unaltered by CO_2, while it decreased under the combined effects of high temperature × water deficit. Seed number explained 85% of the variation in yield, but yield was also related linearly to photosynthesis during seed filling, suggesting both are important determinants of yields under stress.

More recently, results from some open-field experiments using free-air concentration enrichment technology have indicated a much smaller CO_2 fertilisation effect on yield than currently assumed for

C3 crops, such as rice, wheat and soybeans, and possibly little or no stimulation for C4 crops, which include maize and sorghum.

- ‘Assessment of observed changes and responses in natural and managed systems’
- ‘Seed yield after environmental stress in soybean grown under elevated CO_2’
- ‘Temperature × CO_2 interaction – plant growth response (agricultural crops)’
- ‘Food-crop yields in future greenhouse-gas conditions lower than expected’