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IMPACTS OF CLIMATE CHANGE ON ARABLE CROPS – ADAPTATION CHALLENGES

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Summary: Climate change, longer growing seasons, precipitation changes, more extremes and higher temperatures will mean future crops need to be more resilient. Soils are an important resource, a complex community and a potential carbon sink which will be affected by and respond to these changes. Understanding the complex interactions between pests, pathogens, their hosts and abiotic stresses is necessary to appropriately exploit the germplasm resources available for developing future crops. There are important implications for our food security but these too comprise complex interactions.

INTRODUCTION

Adaptation of crops to the challenges of climate change will involve exploiting the continually developing technologies, resources and the expertise of our science base. The climatic change challenges are clear; increased mean temperatures, potentially longer growing seasons (Figure 1), more drought and water-logging and change in seasonal distribution, less frost and more extreme weather events. Many of the adaptation targets also are clear and can be summarised as enhancing resilience to biotic and abiotic environmental stresses. However, prediction of the specific threats to our crops can only be made when we adequately understand the complex interactions between all the components of the arable environment which will require experimentation under a range of likely climate change scenarios together with the assistance of analytical modelling tools.

RESULTS AND DISCUSSION

Over the next 75 years, if gaseous emissions continue unabated, the climate of northern Britain could become up to 3.5°C warmer in summer, 50% drier in summer, 40% wetter in winter, and have 90% less snow in certain scenarios which don't involve tipping points. Spring could arrive as much as four weeks earlier, there will be more extreme temperature and rainfall events, it is anticipated that the atmospheric CO_2 concentration will be around 90% greater, UV-B radiation may increase leading to a reduction in tropospheric ozone concentration. Perhaps as important will be the increased variability and more extreme weather events and changes in seasonal distribution of precipitation. These latter factors in particular may dictate many of the agronomic and cropping pattern changes in practice. The requirement for more resilient/adaptable crop genotypes with durable resistance coupled with functionally resilient soil and crop environments is, therefore, paramount.

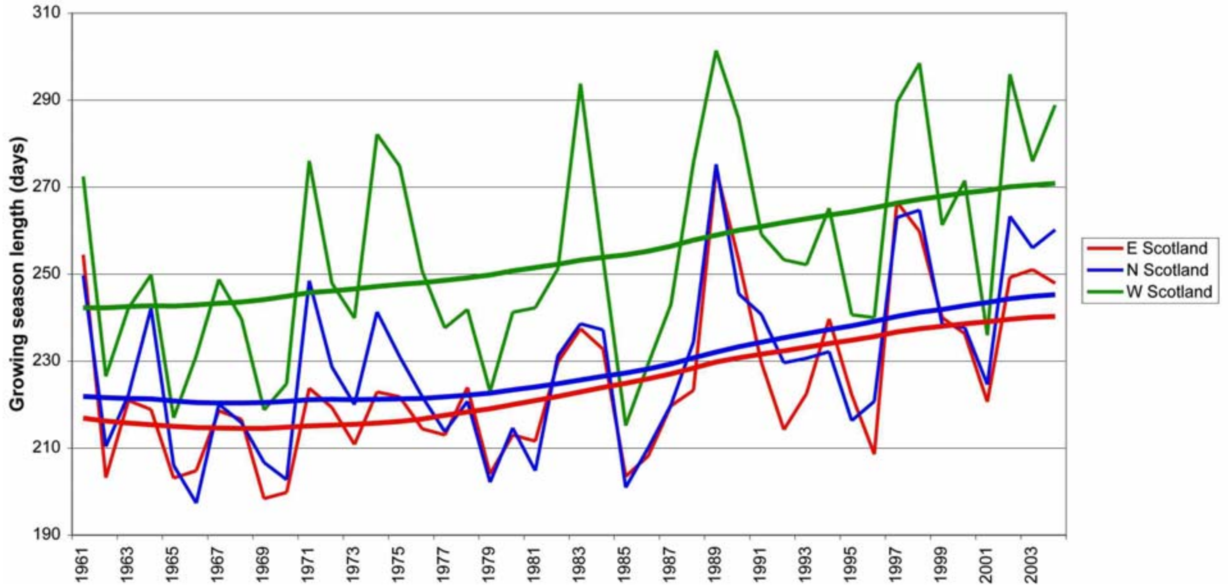


Figure 1. Length of growing season (days) each year from 1961 to 2004. © Crown Copyright [2007] the Met Office as published in Scotland and Northern Ireland Forum for Environmental Research report "A handbook of climate change trends across Scotland". Trend lines: top = W Scotland, mid = N Scotland, bottom = E Scotland

Local Recorded Changes – Implications Above and Below Ground

Global and regional air temperature data have been collected over a sufficiently long period and provide strong evidence that there has been an increase in mean annual temperature over recent decades, although the actual estimates vary. This spatial variation means that from a crop production perspective, the detailed local data are essential. Climate data collected at Invergowrie, Dundee has provided 50 years of on-site uninterrupted weather data including daily air minimum and maximum temperatures and daily soil temperatures at several depths. Unsurprisingly, these records confirm the air warming trend since the1950s reported elsewhere. They also provide clear evidence of soil warming both at the surface and, importantly, extending into the sub soil (Figure 2). The full implications of this soil warming trend are not yet clear. However, because biological processes in the soil are sensitive to increasing temperature, faster decomposition of organic residues and release of inorganic nutrients are distinct possibilities. Increased soil biological activity could lead to net loss of soil carbon if plant production and residue return has not, and does not, in the future respond to the increased temperature to the same extent. This would lead to uncoupling of the nutrient supply from mineralized organic matter if, for example, mineral N is released before or after plant demand. Clearly, more rapid nutrient supply from organic matter turnover could be a welcome opportunity, if the management options exist to take advantage of it, but at present there are insufficient data to enable accurate predictions about the effects of increased temperature on nutrient supply and demand coupling. Over-winter survival of crop pests and pathogens is also likely to be affected by warming soil and air temperatures so that local reservoirs of infection may persist more frequently from season to season, which will in turn present management challenges.

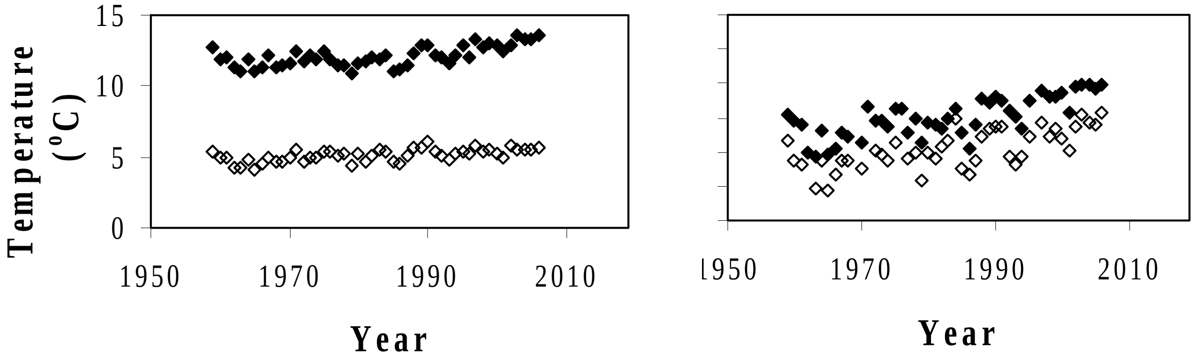


Figure 2. Annual mean maximum and minimum air temperatures and mean annual soil temperatures at 10 cm and 50 cm depth between 1959 and 2006 at SCRI, Invergowrie.

Regional variations in the direction and magnitude of climate change will drive changes in cropping patterns with resultant socio-economic impacts on rural communities in particular. Developing crops able to not just tolerate but to advantageously exploit these changes, requires a comprehensive understanding of crop genotype-environment interaction, where the environment includes the agronomy, ecology, abiotic and biotic stress and end-user requirements.

Adaptation to Biotic Stresses

With few exceptions, such as the effect of dwarfing genes on cereal yield which brought about the ‘green revolution’, most new variety introductions bring about small gains in economically-important traits such as yield, quality and disease resistance. Such progress is driven principally by market forces, but is given some specific impetus by regulatory mechanisms in some countries. In the case of disease resistance, progress is rarely incremental due to the difficulty of combining polygenic durable resistance traits with yield and quality improvements, thereby requiring the exploitation of generally non-durable major gene resistance genes. With a few exceptions, these genes are overcome by adaptation of the pathogen populations leading to classical ‘boom-bust’ cycles. Furthermore, success in controlling one pathogen often leaves varieties still exposed to other pathogens and therefore crops may still require intervention spraying.

Overall it may be fair to say that breeding plants for pest and disease resistance has matched the pest and pathogens populations’ ability to adapt under relatively stable climatic conditions. Given the expected climate change scenarios, considerably enhanced progress will be required to maintain this balance and adapt to abiotic stress, let alone achieve the real progress of broad spectrum disease resistance. Order of magnitude incremental increases in such stress adaptation are likely to be achieved only through understanding and manipulating of basal and non-host resistance mechanisms. Exploitation may be through both allele mining and GM approaches as appropriate. An example of such progress is the potato defence gene, the *wrky* transcription factor which delivers broad-spectrum resistance to bacterial pathogens in potato. It was found through fundamental research and can be delivered through GM technology. However, it was subsequently found in the cultivated potato relative *Solanum phureja* and can therefore be delivered through alternative classical breeding and marker-assisted breeding approaches. Association genetics resources are being developed in various crops which will facilitate more rapid and more precisely targeted marker-assisted breeding strategies for significant traits based on such fundamental research knowledge.

A review of the likely effects of climate change on potato pests and diseases in northern Britain generally concluded that there will be more, and that they will have greater severity (Lyon *et al.*, unpublished). For cereal diseases, the overall picture is likely to be more mixed. Diseases such as the rusts and viral diseases transmitted by insects are likely to increase. We might expect splash dispersed pathogens such as *Rhynchosporium secalis* to decrease in drier summers, but inoculum build-up could be more severe in the wetter mild winters on winter barley, and even in summer, the occurrence of more frequent heavy rain events may mean greater pathogen transmission and more severe disease. Diseases such as ramularia might be expected to respond similarly, but an additional factor to consider is that ramularia responds to stress triggers and these may be more prevalent. Likely changes in both geographic and seasonal distribution factors also need to be taken into account if misleading conclusions are to be avoided.

Interaction Effects

There is a general assumption that climate change will increase plant productivity in many crop systems if water and nutrients are not limited, which will inevitably alter the dynamics of pest organisms that exploit such plants. Such plant-mediated impacts will of course interact with the direct effects of climate change on these pests, which make changes even more difficult to predict. However, some attempts have been made to predict the consequences of climate change on insect pests in the UK with the expectation that many existing pests will become more abundant and new pests will become apparent (Cannon, 1998). In particular, an increase in temperature is likely to cause range extensions and phenological changes in pests of crops in Northern Britain. For instance, Collier *et al*. (1991) predicted that an increase of 3°C will cause cabbage root fly (*Delia radicum*) populations to become active about month earlier and several studies suggest that increased overwintering survival of aphid populations will result in more aphid outbreaks and increased virus infection further into the growing season (Zhou *et al.*, 1995). The promotion of aphid vectors and the consequent transmission of plant viruses in arable crops is particularly concerning, and illustrates the need to understand the interactive nature of such impacts for adapting to climate change.

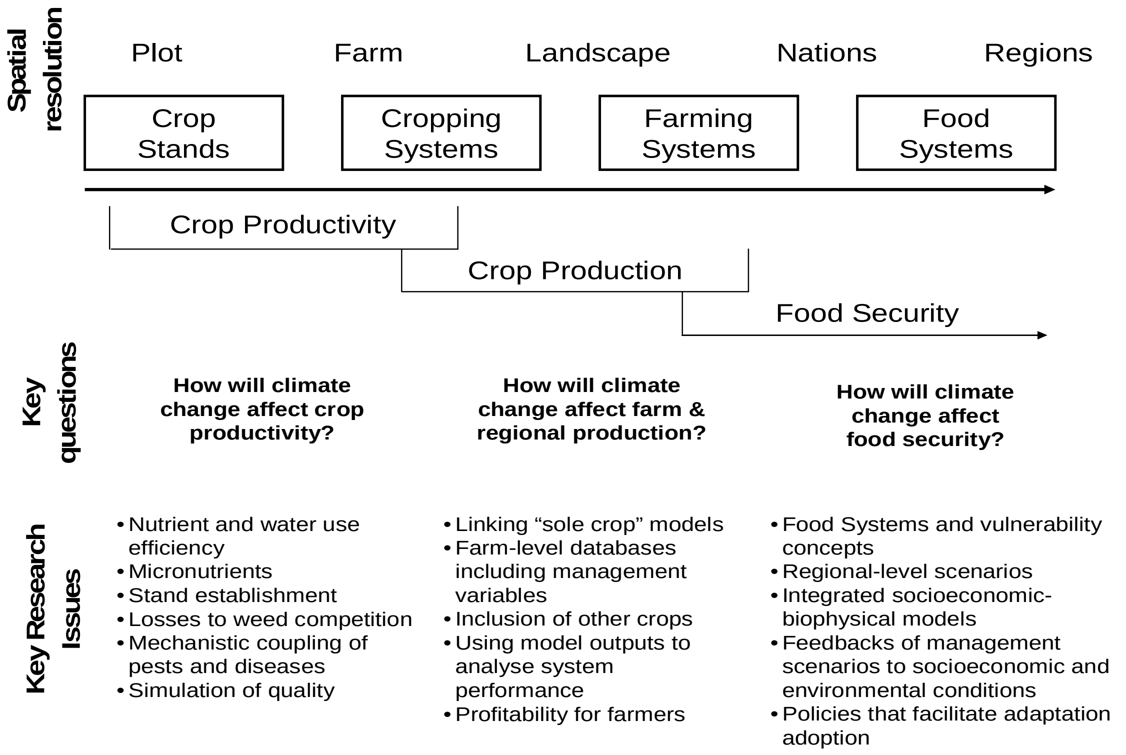
Many reviews have addressed the impacts of climate change on insect pests individually (e.g. Cannon, 1998; Fuhrer, 2003), but the new challenge will be to incorporate multi-trophic complexity and recognise that ‘normal’ symptom development in the field is often a combination of both the main causal agent and other organisms which can enhance disease and symptom expression. For example, two pieces of recent research demonstrated how elevated CO_2 promotes the performance of a below ground herbivore of barley (*Agriotes* spp. wireworms), and this root damage by wireworms then led to a 30% increase in bird cherry-oat aphids (*Rhopalosiphum padi*) above ground - the main vector of barley yellow dwarf virus. Moreover, the consequences of climate change on arable crops may manifest themselves through organisms which are not necessarily pests of the crop itself. For example, elevated CO_2 increased populations of the clover root weevil by 38% which attacked root nodules and reduced nitrogen fixation by approximately 24%. In the context of grassland rotation, this reduction in N input to the soil would most likely have negative impacts on subsequent arable crop yield.

Implications for Biosecurity

Evaluations of likely changes in pest or pathogen distribution are often based on simple climate matching. In practice, they will depend on not only the spatial and temporal detail of climate changes including changed frequency of extreme events, but also all the interactions such as those indicated above. Pest and pathogen distribution changes will also reflect cropping pattern changes whether driven through market or policy forces, and relevant adaptation measures such as resistance deployment, but also inoculum potential. New crops introduced as a result of climate change adaptation and new opportunities will have their own vulnerability to pests and pathogens.

Pests and pathogens may become a problem where they have access to a favourable environment which may include an over-wintering niche, or where conditions allow the population to build up above a significant treatment threshold. Interventions through quarantine measures, eradication, seed testing and certification and good agronomic practices and phytosanitary measures can be helpful in providing control, not simply to buy time before genetic resistance can be deployed, but also to help increase the longevity or durability of such resistance. The combined knowledge of all these processes needs to be considered in a modelling framework to help identify the most effective control strategy.

Implications for Food Security



Key questions	How will climate change affect crop productivity?	How will climate change affect farm & regional production?	How will climate change affect food security?
Key Research Issues	• Nutrient and water use efficiency • Micronutrients • Stand establishment • Losses to weed competition • Mechanistic coupling of pests and diseases • Simulation of quality	• Linking “sole crop” models • Farm-level databases including management variables • Inclusion of other crops • Using model outputs to analyse system performance • Profitability for farmers	• Food Systems and vulnerability concepts • Regional-level scenarios • Integrated socioeconomic-biophysical models • Feedbacks of management scenarios to socioeconomic and environmental conditions • Policies that facilitate adaptation adoption

Figure 3. Effects of scale on elements of food systems contributing to food security and the various questions and research issues appropriate to different scales.

Considerable progress has been made in understanding the sensitivities of crop productivity to climate change and to increases in carbon dioxide concentration and pollutants in the atmosphere. While this allows for better estimates of future crop production, the consequences for food security are complex, as food security depends on multiple social, political and economic and technological determinants in addition to the environmental factors affecting yield.

Food security is underpinned by effective food systems which comprise a set of dynamic interactions between and within biogeochemical and physical environments. They include a number of activities (producing food, processing, packaging and distributing food, and retailing and consuming food) which lead to associated outcomes (e.g. food availability, access to food and food utilisation) all of which contribute to food security. As food security is diminished when food systems are disrupted or stressed, food security policy must address the whole food system. Figure 3 demonstrates that agronomic and agro-climatic research has a leading role in the production of crops, but that the nature of key issues facilitating adaptation to climate change alters with scale, and as research questions more related to food security are formulated (Gregory & Ingram, 2008).

Conclusions

Climate change brings a new focus rather than a new direction to research into the adaptation of plants to their environment. Most of the recent and current research objectives are already addressing issues of resilience to both biotic and abiotic environment challenges. More emphasis is being placed on ‘systems’ research, the understanding of the complex interactions between organisms, their environment and each other. The parameter range relevant to the practical challenges of the next few decades is being better defined because of the improved understanding of likely climate change scenarios being discussed across the international scientific community..

ACKNOWLEDGEMENTS

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