Environmental Change

Lesley Torrance

Our society faces serious threats posed by environmental change and increases in global population which will impact on food, energy and water security. The UK Climate Impacts Programme predicts that in the next 75 years Britain will become warmer, with drier summers and wetter winters and greater volatility resulting in unpredictable extreme rainfall and temperature events. Innovative solutions are required to adapt to, or mitigate, these effects and to promote environmentally and socially sustainable economic growth. Some of these effects are already apparent in Scotland; for example, this year we have experienced the wettest November in 50 years with other indicators such as earlier aphid migrations.

At SCRI we are conducting research to identify and counter risks from environmental change and develop solutions that will sustain the competitiveness of our agricultural industry while maintaining a vibrant and economically successful rural environment. The articles in this section illustrate the work we are doing on plant pathology, physiology and genetics to study the effects of temperature and water availability and increased pest and disease risks on Scottish crops.

Dormancy in blackcurrant and the potential effects of future climatic conditions

Rex M. Brennan, Hamlyn G. Jones*, Joanne R. Russell, Peter E. Hedley, Linzi Jorgensen, Chris A. Hackett & Sandra Gordon

One of the key environmental factors affecting cropping of woody fruit species is winter temperature, through its effect on the dormancy cycle. The degree of chilling received by the plants during the dormant period, to fulfill a chilling requirement that varies between species and cultivars, has profound effects on budbreak, flowering and ultimately fruit quality. In the UK, a study of historical data using a range of models for assessment of winter temperatures indicated a decline in levels of winter chilling over the past 50 years. Projected future increases in temperature suggest that in northern latitudes these will be proportionately greater in winter.

Blackcurrant is grown widely across northern temperate regions of Europe and also in New Zealand for commercial processing. UK production is based entirely on the SCRI 'Ben' series, from the earliest release 'Ben Lomond' in 1972 to the more recent 'Ben Starav' and 'Ben Klibreck' (2008). Blackcurrant has a relatively high chilling requirement, ranging from <1300 h below 7.2°C for some New Zealand cultivars to over 2000 h for some late-flowering Scottish types such as 'Ben Lomond'. Plantations of high-chill cultivars in southern locations, such as Kent and Herefordshire which have received insufficient chilling during recent UK winters, have suffered erratic budbreak and a subsequent reduction in harvested quality.

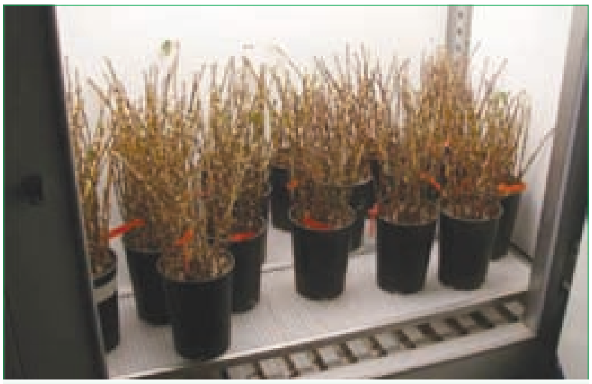

Figure 1 Phenotyping of blackcurrant cuttings for chilling requirement.

The response of blackcurrant genotypes to chilling temperatures was examined using controlled environment facilities at SCRI (Fig. 1). Hardwood cuttings of diverse genotypes were treated at chilling temperatures for periods between 5 and 21 weeks, after which the cuttings were moved to forcing environments so that budbreak and flowering could be assessed. The data were analysed using novel curve-fitting approaches, from which it was established that the various genotypes had very diverse chilling responses, with some cultivars, for example 'Ben Avon', responding only slowly to chilling temperatures while others, for example the French 'Andega', responding much more rapidly. Additionally, the calculation of an effectiveness coefficient for the different temperatures showed that the most effective chilling temperature varied between genotypes. Using this information, a high throughput method of phenotyping blackcurrant breeding progenies and advanced selections is under development, to assess their chilling requirement and enable the selection of environmentally resilient 'Ben' cultivars into the future. Collaborations with Plant and Food NZ are facilitating the use of low chill germplasm in the development of new progenies, and further investigation of climate effects on blackcurrant dormancy and development is planned across Scandinavia and northern Europe as part of the 'Climafruit' project in the EU Interreg North Sea programme.

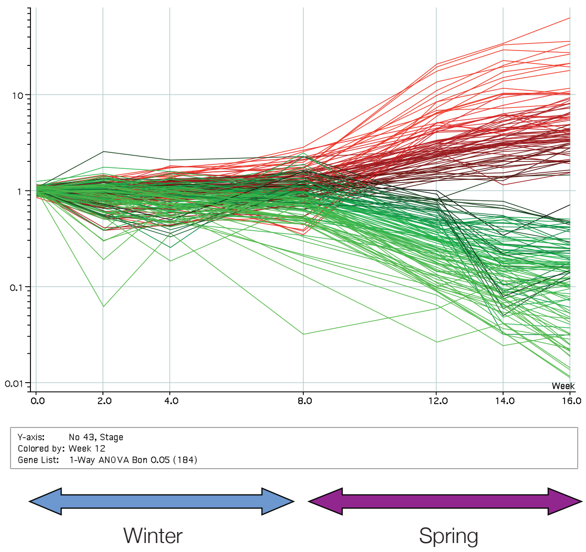

Figure 2 Microarray analysis of blackcurrant buds at dormancy break showing differential expression of genes.

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At the molecular level, putative Quantitative Trait Loci (QTL) linked to budbreak and flowering traits have been identified on the genetic linkage map for blackcurrant, and further analysis is in progress using an extended reference population. Dormancy break and subsequent development is controlled through the coordinated action of large numbers of genes in woody plants. Differential gene expression during dormancy and budbreak in blackcurrant has been investigated (Fig. 2), and key genes associated with budbreak have been identified and mapped on the blackcurrant linkage map. Initial steps have been taken to develop associated markers that will then be deployed in the characterisation of the diverse *Ribes* germplasm in downstream breeding and mapping populations. The information on candidate genes will also have relevance to other woody species apart from blackcurrant.

The role of carotenoid cleavage products in heat responses of potato

Raymond Campbell, Laurence Ducreux, Wayne L. Morris, Peter E. Hedley, Glenn J. Bryan, Gavin Ramsay & Mark A. Taylor

The cultivated potato exists in a variety of forms originating from diverse environments such as coastal areas in Chile and dry Andean valleys at high altitude. The types finding favour across the world, including tropical and sub-tropical areas, are often those with high yield potential, bred in Europe and North America from a stock with its ultimate origins primarily in Chilean material and poorly adapted to high day and night temperatures. In fact most potato cultivars bred in temperate climates respond to high day and night temperatures with a reduced number of stolons (underground stems that form tubers) and tubers, and altered carbon partitioning to the tuber,

Figure 3 The *CCD4* silenced phenotype was characterised by early sprouting during tuber development or by the formation of chain tubers. These effects were observed in 20 out of 33 independent RNAi lines.

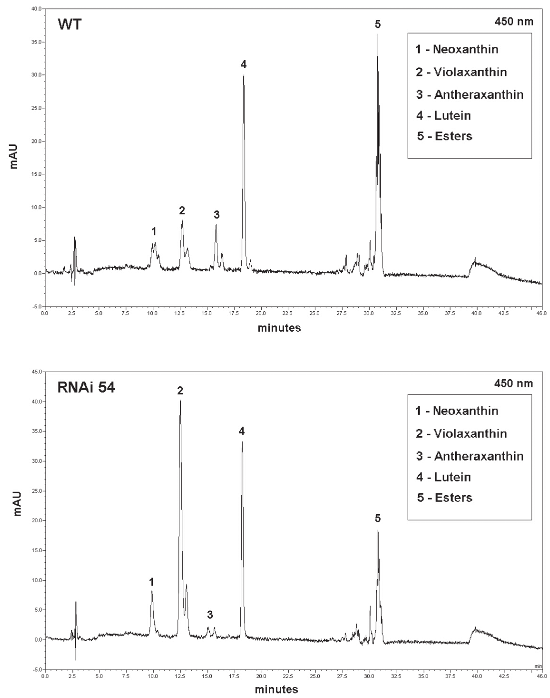

Figure 4 HPLC analysis of tuber carotenoid content in a *CCD4* silenced tuber compared with wild type (WT). Note the large increase in the violaxanthin peak in the *CCD4* silenced tuber.

resulting in a significant loss of tuber yield and quality. Climate changes due to global warming are expected to similarly affect the potato crop with warmer winters and summers predicted to increase abiotic stresses. Temperature fluctuation also causes economically significant damage to the potato crop. Growth under cool temperature interrupted by periods of high temperature leads to heat sprouting, chain tubers and secondary growth of tubers. This has serious effects on economic yield and tuber quality. These effects are due to a fluctuation in the level of stimulus that causes tuber formation to alternate with more stolon-like growth. This physiological problem can be a serious problem for some cultivars exported to or trialled in Mediterranean climates, and in the longer term may also affect tuber production in the UK.

The mechanism of heat sensing in plants is not fully understood, however it is known that the potato circadian clock can integrate environmental signals and thus modulate the level of tuberisation stimulus. It is also becoming apparent that signals derived from carotenoid pigments, by the action of carotenoid cleavage dioxygenases (CCDs), are potent regulators of plant growth and development. The classic example is abscisic acid, a well characterised carotenoid derived plant growth regulator. More recently it has been demonstrated that other members of the CCD family are involved in the biosynthesis of strigolactones, a newly discovered class of plant growth regulator that control plant branch structure. At SCRI we silenced the expression of the potato *CCD4* gene and this resulted in a dramatic phenotypic change. Tubers from silenced plants exhibited a heat sprouting phenotype even though they were not exposed to heat stress (Fig. 3). The phenotype was even apparent in tubers grown under *in vitro* conditions. Analysis of carotenoid content in the silenced tubers revealed that the carotenoid violaxanthin was the likely substrate for the CCD4 as its level was elevated several fold in the silenced lines (Fig. 4). There is no evidence for changes in abscisic acid or strigolactones in these plants. We are currently investigating the nature of the carotenoid derived signal that is implicated in temperature perception by these observations. Additionally we are investigating

whether elevated levels of *CCD4* expression can result in protection from heat stress and increased tuber yields under fluctuating temperature conditions, thereby identifying a clear gene target for future potato breeding strategies.

Root traits for a changing physical environment

Tracy A. Valentine, A. Glyn Bengough, Paul D. Hallett & Blair M. McKenzie

With increasing constraints on the use of fertilisers and irrigation water worldwide, crops need root systems better able to grow in soils containing limited water and nutrient resources. Plants must be able to place their roots close to where these resources are located in the soil profile. We have been studying how plant genotype influences the growth and distribution of its roots, at scales from the laboratory to the field, with a view to developing better ways of identifying, and ultimately screening for, desirable root traits. Another equally important aspect is evaluating the physical restrictions to root growth that occur in a range of soil types, so that factors limiting root growth can be quantified and used to identify the most important physical restrictions throughout a field season. This information will be used to develop improved soil management practices and the breeding of plant varieties suited to particular soil conditions.

In a recent survey of more than 50 farms in the east of Scotland we found that, even when soil water availability was close to optimal, nearly 40% of soils had strength sufficient to mechanically impede root growth. Seedling screens confirmed that soil physical conditions were limiting root elongation to less than half of the unimpeded rate in a similar percentage of sites examined. The impact of changes in climate and

Figure 5 The influence of genotype and interaction with the environment in the ability of barley plants to access subsoil water, leading to differences in plant height and potentially crop productivity.

farming on plant and crop performance will depend not only on the severity of these physical limitations to roots, but also on the frequency, duration, and timing of these limitations. Rainfall patterns are predicted to become more erratic due to climate change and may result in more frequently waterlogged soil while at other times periods of drought may result in increased soil strength. Changes in farming such as decreasing tillage to save fuel may adversely affect soil conditions. Soil compaction, particularly of the subsoil, could be exacerbating the limitations to root growth.

We have developed techniques to study the spatial distribution of the roots of both seedlings and more mature plants. The angular spread of seedling cereal roots, measured in two dimensions using a gel plate screen developed at SCRI has been found to relate

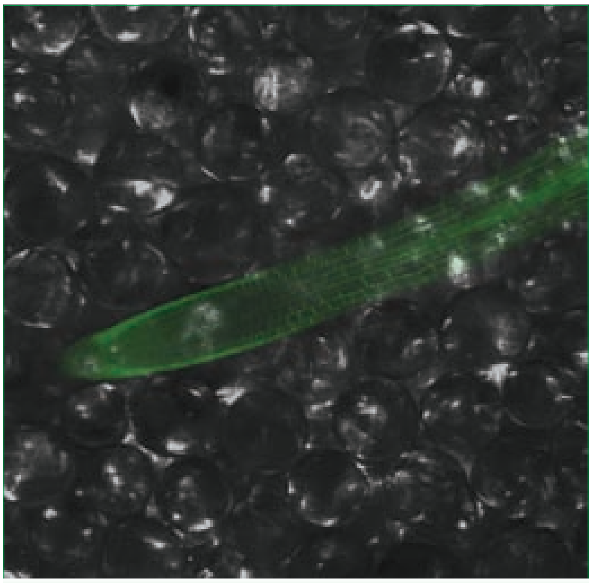

Figure 6 Root tip behaviour under physically inhibiting environment: Live imaging techniques of plant–environment interactions in a model system using fluorescently labelled roots and glass beads.

closely to root spread and water extraction by mature drought tolerant cereal plants. The angular spread of roots in two dimensions from a range of contrasting genotypes was also found, by X-ray tomography, to relate closely to root spread in three dimensions. We have also developed a field method for screening the ability of crop genotypes to access subsoil water, and this is demonstrating both the influence of genotype on this root trait and the importance of deep root growth even relatively early in the growth of spring sown barley (Fig. 5). The importance of root tip traits in the ability of roots to overcome soil physical restrictions is being explored at the individual plant and individual root tip scales using live imaging techniques (Fig. 6) and by linking to root growth models of soil exploration. Mechanisms used by roots to overcome stress, such as producing a lubricating layer or changing the properties of soil, are a major component of our research in this area.

Risks of new or emerging pests and pathogens posed by environmental change

Lesley Torrance, Ian K. Toth, David E.L. Cooke, Brian Fenton, Vivian C. Blok & Alison K. Lees

Environmental factors greatly influence the incidence and geographical distribution of pests and diseases. The availability of a susceptible host together with optimum conditions of temperature and humidity are major factors in determining whether a pathogen can establish in a new location. Adaptation to the predicted environmental changes will affect Scottish agronomic practices as well as the spectrum of non-crop species grown. Some examples of the likely changes in pests and disease threats to potato production in Scotland and the research being done to counter these threats are discussed.

Virus diseases are the major cause of seed potato degeneration causing down-grading of seed crops. Aphids transmit viruses from plant to plant (Fig. 7) and transmission early in the season has a major effect on virus incidence in the harvested tubers. Scotland has an effective aphid monitoring programme and this

has shown that some of the main virus vector aphids are appearing earlier, when they could be spreading viruses. If this trend continues it may change the areas of Scotland with a natural advantage for production of healthy seed potatoes and require earlier applications of insecticides. In collaboration with industry we are conducting research to establish effective aphid-

Figure 7 Aphid virus vector.

borne virus control strategies. However, the most effective long term disease control is achieved through resistant crops and we have found a new source of extreme resistance which is effective against three important aphid transmitted Potyviruses (PVY, PVA, PVV). Current research is focused on developing molecular markers which can be used to deploy the resistance in breeding programmes. *Phytophthora infestans,* the cause of late blight, has been shown to be a highly adaptable pathogen that can respond rapidly to changing environmental conditions and overcome major host resistance genes. Late blight will pose a continuing threat to Scottish crops. Aided by the recently published whole genome sequence, we are making major advances in understanding the function and evolution of *P. infestans* pathogenicity factors. We are also generating valuable data on the response of the current pathogen populations to moisture and temperature criteria which are relevant to current and future prediction and control of late blight in Scottish crops. Adaptation of the potato cyst nematode (PCN)

to environmental changes and the potential for higher multiplication rates are also being examined. The risks of hatching and completion of a second generation during the growing season and the potential for selection of populations with faster generation times are being assessed in relation to integrated management of PCN.

Figure 8 *Dickeya solani* on ware potatoes cv Agria imported to UK from Spain. Tubers show Cheesy Rot and breakdown of the vascular ring (very similar to that of Ring Rot).
Picture supplied by Eric Anderson (Scottish Agronomy)

Figure 9 *P. kernoviae* infection of rhododendron.

Threats from non-indigenous diseases include the introduction by contamination of infected planting material, e.g., the bacteria *Dickeya dianthicola* and *D. solani* (formerly *Erwinia chrysanthemi*) on potato tubers (Fig. 8) and the nematode *Meloidogyne chitwoodi* in adherent soil particles. These pests and pathogens have been intercepted on potato seed tubers and are currently responsible for major disease losses in Europe. We have rapid and sensitive diagnostics to detect *M. chitwoodi* and are working with SASA (Science and Advice for Scottish Agriculture) and FERA (The Food and Environment Research Agency) to develop similar diagnostics for *Dickeya.* These diagnostics are important for monitoring the movement of these pests and pathogens, and complement our work on the biology of the diseases they cause.

Environmental change will also alter the spectrum of plants growing in natural, semi-natural ecosystems and gardens in Scotland. Associated threats from invasive pathogens are thus also being studied. In a collaborative project on *P. ramorum* and *P. kernoviae* (Fig. 9) knowledge and molecular markers derived from research on *P. infestans* are being used to assess the risks posed to Scottish heathland ecosystems.

These examples are just a few of the many threats that will face agricultural production systems now and in the future. Our work provides robust evidence and analysis to advise policy makers in Scottish Government and the private sector to help combat these threats. An outcome of this work suggests that a re-evaluation of the current operation of the ‘Safe Haven’ certification scheme to protect Scottish seed potatoes is worthwhile.