Crop diversity - new opportunities for low-input industrial crops?

A.C. Newton & J.S. Swanston

Modern cereal varieties have generally been bred for agricultural systems, where short-term optimisation of the environment for plant growth is achieved by high inputs and soil loosening with intensive tillage. Many traits have thus been selected against and lost from the elite germplasm today's breeders utilise. For example, modern varieties use fertiliser nitrogen very efficiently but may have reduced ability to access soil nitrogen compared with old varieties. Similarly, disease escape characteristics such as leaf habit and straw length are important where inoculum is present, but waste resources that could be put into grain fill where fungicides are used. However, any loss in grain yield may be compensated for through reduced fungicide use, and increased exploitation of the total biomass.

Agriculture has become dependent on non-renewable sources of fuel and agro-chemicals. Recognition of this has encouraged development of lower-input cultivation and also the use of crop plants as sources of fuels and chemical feedstocks. Increasingly, too, uses are being sought for crop residues such as straw. One example of industrial use is bioethanol (alcohol) derived from cereal grains or sugar cane and used as a partial petrol replacement. At present, despite considerable lobbying from farmers' groups, there is no production in the UK, although there is considerable expertise in distilling alcohol from cereals, particularly in Scotland. Work done in several areas at SCRI can greatly assist in producing optimal raw materials, particularly wheat, for distilling.

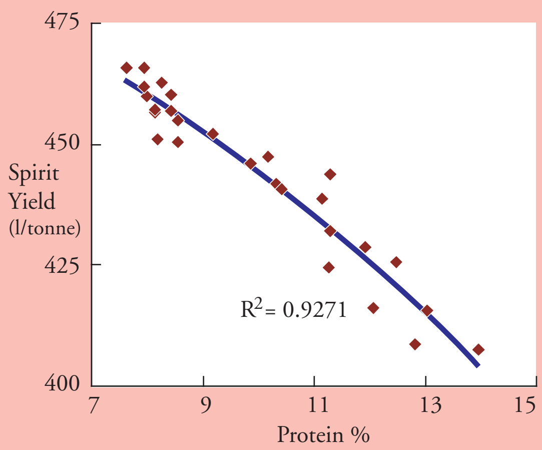

Figure 1 Spirit yield (litres/tonne) plotted against protein content for 9 samples from each of 3 varieties of wheat.

Collaborative work with the Scotch Whisky Research Institute has shown the strong negative correlation between spirit (alcohol) yield and grain protein content (Fig.1).

As a 1% increase in protein reduces spirit yield by approximately 9 litres per tonne, distilling wheats should be cultivated under conditions leading to low N levels, but this may have a deleterious effect on yield. In addition, the best yielding cultivars such as Deben give less alcohol than varieties like Riband and Consort but have better disease resistance to, for example, *Septoria tritici*. While this presents a target for plant breeding, varietal mixtures may offer a short-term solution. Data from an SCRI trial (Fig. 2) shows that a mixture containing Deben gave spirit yields comparable to those of the other components. Grain yield of the mixture was very similar to that of Deben, and in a bad disease year Deben would contribute to lower disease whilst the mixture would compensate for its poor lodging characteristics.

Growing crops as heterogeneous mixtures of species, varieties or near-isogenic lines, not only enables contrasting traits present in different varieties to be grown as a crop together, but also allows exploitation of spa-

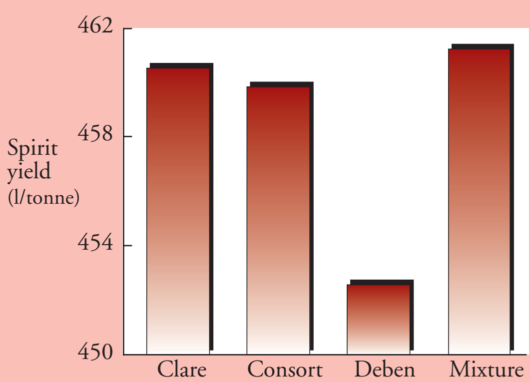

Figure 2 Spirit yields of 3 cultivars and an equal proportion mixture of the 3, from SCRI trial.

Figure 3 Barley field trials of mixtures at SCRI.

tial and temporal complementarity and synergy. In the lifetime of an arable crop it is exposed to many different environments both spatially in different parts of a field and in different parts of the crop canopy, and temporally throughout the season. To expect a single genotype to be able to respond optimally to all these stresses be they biotic (e.g. fungal pathogens) or abiotic (e.g. frost, low nutrients, high humidity etc), may be unreasonable. Mixing different genotypes together can considerably enhance the options a crop phenotype has from which it can respond, making it a much more resilient production system. Whilst we are seeking to understand these characters in single genotypes, their range of expressions can be immediately extended by simply accessing more and diverse genotypes and deploying them together.

Complex cereal cultivar mixtures reduce disease compared with the mean of their component monocultures thereby reducing pesticide inputs. They also yield more, for example up to 15% in winter barley thereby utilising nutrients better, or allowing reduced fertiliser inputs for the same yield. Such results can be achieved with current cultivars, thus only utilising a very restricted and highly selected portion of the potential variability and synergies potentially exploitable. Strategies for combining modified crop agronomy (lower inputs) with appropriate germplasm should also include accessing landrace and old varieties for deployment in genotype mixtures, where synergies and compensation between intelligently designed component combinations can be exploited for maximising resource exploitation. Attributes now deficient in modern varieties include increased straw biomass. Straw is currently used for energy (heat and electricity) production in Denmark, but may also be a source of fermentable sugars, if problems relating to initial breakdown of the cellulose fraction and fermentation of the 5-carbon sugars, deriving from hemicellulose can be overcome.

Other desirable attributes to re-introduce include some disease resistances, ability to utilise soil nitrogen, allelopathy, and interaction with micro-organisms such as mycorrhiza. Mixtures are likely to have greater climatic extreme resilience such as drought or cold tolerance. However, they are equally effective for obtaining greater productivity from high yield potential, benign environments, particularly utilising modern varieties bred for such conditions. There is nevertheless the potential to design the heterogeneity to minimise compromises and maximise synergies given knowledge of the nature and probability of the stress factors. Variation range not utilised may be costly to yield or quality, so design parameters should have tolerances appropriate for given production systems to be balanced and thereby resilient, i.e. having greater buffering capacity for both biotic and abiotic stresses, within reasonable risk ranges.

It is assumed that mixtures must be homogeneous for all the components, but this does not take into account the effect of Genotype Unit Area. For control of pathogens discontinuity of susceptible host genotype is a component of epidemic control, maximising barrier effects. Whilst the proportion of susceptible hosts may remain constant, spatial distribution of the resistant host affects its efficacy. It is difficult to control spatial geometry of plants with normal farm drills for cereals, but the degree of patchiness may affect mixtures efficacy and for different diseases in different ways depending partially on spore dispersal gradients. Furthermore, these spatial interactions with epidemiological factors may be different again from both above and below ground resource exploitation interactions.

Figure 4 Variability in morphological characteristics of barley which can be exploited in mixtures.

Spatio-statistical analyses are helping us design the best compromise.

In a very practical way researchers across Europe and beyond are coming together to better understand how to exploit genotype synergies and other parameters in a European Union funded, European Science Foundation managed Cooperation in Science and Technology Action (COST Action 860) 'Sustainable low-input cereal production: required varietal characteristics and crop diversity' (SUSVAR, www.COST860.dk) in which we at SCRI in collaboration with colleagues in SAC are committed participants. Such heterogeneity approaches can be utilised in many crops, and we have cited bioethanol as an example. We have exploited this heterogeneity approach with adapted modern germplasm for malting quality spring barley and demonstrated advantages for the grower, maltster, distiller and the environment. In winter barley we have demonstrated over 15% yield gains. In winter wheat we have also demonstrated quality advantages and industry acceptance for distilling. All these utilised only the genetic variability found in elite germplasm as we grew crops under conventional agronomic practices. However, in collaboration with ADAS we are gaining understanding and developing wheat germplasm with better nitrogen utilisation characteristics for a range of end-users. Fast-track and full exploitation of such germplasm is likely to be in heterogeneous combinations where production systems and end-user constraints permit, assuming the end-users preconceptions have been appropriately challenged.