Grass roots for improved soil structure and hydrology
Grasslands are truly multifunctional. They represent 65% of all UK agricultural land (Humphreys et al., 2006) and dominate the landscape in western and northern areas, sustaining the rural economy through significant roles in supporting both livestock agriculture and the leisure and tourism industries. However, as explained below, they also provide “hidden” benefits for the environment through the growth and turnover of their complex subterranean root systems. Grasslands in the UK tend to prevail in those agricultural regions where rainfall is greatest, including the uplands where the majority of our major river catchments rise. The percentage land cover occupied by grasslands improved by man for livestock use varies markedly in the four countries of the UK, occupying 13.8% of Scotland, 30.3% of England, 42% of Wales and 54% of Northern Ireland (Fuller et al., 2002). Although the rainfall in regions dominated by grassland is high compared to other parts of the UK, periods of drought do occur regularly in these areas, both in the summer and, more surprisingly, also in winter.

Developments in UK grass breeding to combat climate change

(i) Water deficit
Across the UK, periods of excessive rainfall and drought are increasing in frequency and intensity due to the changing climate, leading to significant losses of forage yield and compromising grass persistence. In response, the DefraUNK programme LK0688 at IBERS is aiming to increase the water use efficiency of our major cultivated grasses (yield/unit of water consumed). For Italian ryegrass (Lolium multiflorum), “precision breeding” has already achieved an 88% improvement in yield by the incorporation of selected drought resistance genes from related fescue species. The next objective is to bring about a similar level of enhancement in the water use efficiency of perennial ryegrass (Lolium perenne), the agricultural grass of choice for UK farmers, through incorporation of the same fescue-derived genes. In particular, we are investigating the development of deeper root systems, and plants that can respond to signals of drought stress by promoting root growth extension to achieve better access to water that may lie deep within the soil.

(ii) Water surplus
Although water deficit is becoming an increasing problem for grassland agriculture, and for heavily populated urban areas, the growing number of extreme rainfall events are of equal, if not greater, national concern. In recent times, the financial and infrastructural repercussions of flooding, particularly in lowland areas in regions of Cumbria, Humberside and Gloucestershire, have been major and very costly. As improved UK grasslands dominate large land areas where rainfall is greatest, they have an important role to play in mitigating against the rapid and excessive releases of rainwater from the soil. The presence and management of vegetation influences soil water balance by trapping precipitation, controlling evaporation and directing the uptake of water through the roots, as well as augmenting the bio-physical structure of the soil, including rhizosphere-soil porosity.

Above ground, grass species differ in their efficacy for restricting excessive water releases, depending on their growth habit (erect or prostrate), the size and strength of their foliar canopies, and the extent of water loss from foliage through transpiration. However, grass species also contribute an unseen benefit below ground through the growth, turnover, and architecture of their root systems. With varying effectiveness, they will mitigate against excessive releases of water by generating an improved soil structure and porosity that will influence both soil water retention and govern the speed of water release. As reticular networks, grass roots will also stabilise soils, preventing erosion and thereby helping to sustain fragile ecosystems. Enhanced soil stability serves to reduce releases of harmful greenhouse gases and water pollutants. Roots provide further environmental safeguards through their large scale capability for carbon.
sequestration (see articles by Scullion et al., Gwynn Jones et al. and Hodgson et al. in this issue) and represent a major resource for carbon (C) input to soils. The overall implications for soil C sequestration will depend on the quantity and characteristics of plant deposition inputs to the soil, the root distribution within the soil and their interactions with soil physical and biotic components.

**Lolium x Festuca spp. (Festulolium) hybrids: new holistic designs for grasses for UK agriculture in a changing climate**

Until quite recently, plant and soil scientists have operated largely independently of one another, with a generally poor understanding of each other’s research interests. The potential benefits of integrating these studies are now becoming increasingly apparent however. Holistic multidisciplinary studies are needed to manipulate grass crop designs to achieve efficient water and nutrient use, sustainable forage production and to modify soils so as to provide an environmental service. A good example of such collaboration has been the recent formation of a consortium of grass geneticists and physiologists from IBERS with soil hydrologists from Rothamsted Research and soil physicists from Lancaster University, operating jointly in the BBSRC-funded research programme, SuperGraSS. The objective was to initiate a new research strategy for grass development that combined sustainable forage production with patterns of root growth suitable for improved soil structures to aid water retention and delay sediment release. Some of the major research findings from the collaboration are outlined in the following paragraphs.

Researchers at IBERS aim to harness the forage quality of ryegrasses (*Lolium* spp.) with genes for beneficial environmental traits found in related fescue (*Festuca*) species, several of which are native to permanent UK grasslands. These fescues tend to be more resilient to climatic extremes than the ryegrasses (Humphreys et al., 2006), and combining such attributes together in one hybrid genotype will produce grasses with improved persistence and resilience to climate change (Humphreys et al., 2003). Synthetic ryegrass x fescue hybrids are thus being created at IBERS and elsewhere as *Festulolium* (Ghesquière et al., 2010). In association with Germinal Holdings, IBERS released their first *Festulolium* cultivar AberNiche to be accepted onto the NIAB Recommended cultivar list in May.

*Figure 1. Novel Festulolium hybrids using ryegrass and North African fescues.*
2011. However, such hybrids can also occur naturally in the form of the little studied natural hybrid of Lolium perenne and Festuca pratensis, Festulolium loliaceum. This natural hybrid species is chiefly found in mature water meadows where it is concentrated on waterlogged anaerobic soils. As it consistently occupies this niche, where its parental species find difficult to colonise and establish, Festulolium loliaceum may well be an excellent source of genes for adapting for growth in waterlogged soils. Given the increased occurrences of localised or widespread flooding, this is an increasingly important plant breeding objective. Outcomes of the SuperGraSS project, detailing the impact of an IBERS-generated synthetic cultivar of Festulolium loliaceum, cultivar Prior, on soil structure and hydrology are described below.

SuperGraSS has demonstrated that, compared with ryegrass, certain fescue species produce stronger roots more able to penetrate hard compacted soils. Incorporation of these fescue traits into our major cultivated grasses should therefore increase soil porosity and enhance soil water-holding capacity, thereby mitigating against surface run-off and flooding.

A number of previous laboratory studies have described how roots change soil hydraulic properties (e.g., Whalley et al., 2005), demonstrating improvements to the water release characteristics of soils that tend to be associated with either an increased number of larger pores in the rhizosphere or an increase in overall water repellence. As root activity tends to increase the number of large pores in the soil, and as it is known that certain fescue species such as Festuca arundinacea var. glaucescens produce larger deeper rooting systems than ryegrass (Durand et al., 2007), it is thought that such plants achieve their proven overall greater drought resistance both by their capacity to access water deep in the soil and by their ability to restructure soil to aid in its water retention.

The extent of rooting depth thus has significant biophysical effects on soil, including improvement of rhizosphere-soil porosity. Vegetation directly controls the amount of water that a unit of land can ‘absorb’ through what is referred to as the storage capacity of the ‘effective soil depth’. Rooting depth determines the soil volume from which plants are able to draw water and, influenced by various key soil hydraulic properties, defines the water capacity available to the plant. The response time of stream flow and water discharge from a precipitation event is thus determined by a combination of climate (mainly rainfall), antecedent weather and soil conditions, physical catchment properties, vegetation characteristics, and ecosystem management.

In a hydrological study undertaken at the Rothamsted Research North Wyke Research Station, run-off measurements were taken following 34 separate precipitation (rainfall) events during 2007-2008 at different times of the year, comparing the effects of a range of grass root systems. The IBERS-bred Festulolium loliaceum amphiploid (2n = 4x = 28) cultivar Prior was consistently more effective at both soil water retention and reducing run-off than any of the six other species cultivars tested, including the parental species L. perenne and F. pratensis. These pilot-scale field experiments found that 70% of rainfall was lost as run-off from soils under a highly productive National-Listed L. perenne cultivar, with 50% losses from plots of a F. pratensis cultivar. By contrast, Festulolium cultivar Prior restricted run-off to a mean of only 35% of the total rainfall. At IBERS, in a pipe experiment, root growth measurements of the same cultivars, managed in an identical way to the North...
Wyke field plots, were obtained over the same time-lines. Convincing evidence was found, supported by examining soil cores taken from the North Wyke field trials, that rapid growth and turn-over of roots in the Festulolium hybrid was the major mechanism associated with the reduced run-off compared to either of the parent species.

Soil samples taken from the North Wyke site indicated that changes to soil structure were in part due to the physical rearrangement of soil particles by shrinkage and that this factor differed between grass species sown (Gregory et al., 2010). However, evidence from the IBERS study indicated that an initially high root growth throughout the soil profile by the Festulolium cultivar, followed by a significant reduction of root biomass at greater depths leaving extensive areas of dead or decaying roots, were the principal factors for change in soil structure. We surmise, therefore, that a combination of different temporal and spatial patterns of root growth and turnover (death) is the primary characteristic responsible for the increased soil water retention properties of the Festulolium hybrid.

In an independent study undertaken by the University of Nottingham, the potential impacts of grassland reseeding on soil hydrology using the Festulolium Prior cultivar were assessed. The impacts were anticipated to be highly variable depending on factors such as location, climate, weather and year. In the Nottingham research (Henshaw, 2009, personal communication), the potential soil structural effects of the Festulolium hybrid were investigated at the Pontbren experimental catchment, a site operated since 2004 by the Flood Risk Management research consortium run by Imperial College London, the Centre for Ecology and Hydrology, Bangor, and the University of Nottingham itself. From modelling studies, it was concluded that increases in sub-surface water storage and/or soil infiltration rates were likely to have positive flood risk management benefits. A consistent 50% reduction in run-off compared with ryegrass plots at the hill-slope scale (as seen at North Wyke) would achieve run-off reduction benefits similar to, if not greater than, those enabled by tree planting. While rainfall interception losses are likely to be less significant than those under tree cover, the wider potential ground coverage of the Festulolium cv. Prior is likely to result in a greater aggregate increase in soil moisture storage. The extent of the rooting depth and the spatial distribution of the root structure are likely to control the magnitude of this difference. Assuming that peak streamflow reductions similar to those associated with tree planting could be achieved, reseeding improved pastures with the Festulolium cultivar could therefore be expected to result in a significant reduction in sediment losses at Pontbren. As a result, any reduction in run-off following introduction of the Festulolium cultivar may, in addition to flood control, also help to reduce the transfer of soluble nutrients and pesticides from farmland to watercourses and, thus, deliver a range of water quality benefits.

It is concluded that, given positive support from all the relevant stakeholders, commercial use of the Festulolium cultivar would achieve both an efficient and persistent grass crop when exposed to either summer or winter stresses. It would additionally contribute significant environmental benefits through the effective control of water release and nutrient run-off following precipitation.
References


Figure 3. Novel Festulolium hybrids using ryegrass and North African fescue species (large plants for drought resistance and for large strong root systems)