The SCRI LEAF[1] Innovation Centre:
Agro-ecosystem research which develops and promotes sustainable agriculture strategies and policies for Scotland, UK and Europe

A.N.E. Birch, B. Boag, A.C. Newton, S.C. Gordon, B. Fenton, G. Malloch, P.D. Hallett, P.P.M. Iannetta, S.E. Stephens, S. Neilson, G.M. Wright, B. Marshall, B.M. McKenzie, G.R. Squire, P. Gill & R.Wheatley

Linking Environment and Farming (**LEAF**) was established in 1991 to bridge the gap between farmers and consumers. For the first time in the UK groups of farmers, environmentalists, food and agricultural organisations, consumers, government and academics from institutes, agricultural colleges and universities have got together to coordinate and promote a unified environmental management system for the farming industry. LEAF was established to develop and promote Integrated Farm Management (IFM), motivated by a common concern for the future of farming and to develop a system of farming that is realistic and achievable for the majority of the UK's farmers. IFM combines the best of traditional farming methods with modern technology, allowing farmers to manage their farms in an informed, professional and caring way. LEAF's whole farm IFM policy, backed by current agro-environmental research, provides the basis for efficient and profitable production which is economically viable and environmentally responsible. IFM integrates beneficial natural processes (e.g. enhanced soil nutrient cycling and biocontrol of pests and diseases using natural enemies) into modern farming practices.

Figure 1 LEAF demonstration farm event.

LEAF's aims are to minimise environmental risks while conserving, enhancing and re-creating that which is of environmental importance, using advanced technologies. LEAF is the leading organisation in the UK promoting and developing IFM, encouraging the uptake of IFM by farmers through practical guidelines, on-farm demonstrations (Fig. 1) and the LEAF Farm Audit for best practice. There are now 45 different lines of food produce that display the LEAF Marque Logo in UK stores. These products are being featured at major UK events including Wimbledon Tennis Championships (Fig. 2), the Royal Show and the Royal Highland Show. The Royal Show exhibit featured Integrated Pest Management tools for raspberry pests, developed by SCRI. The LEAF network now includes 45 Demonstration Farms (LEAF's farmer membership covers 15% of the UK land area and is increasing) and 19 Innovation Centres across the UK (Fig. 3). LEAF is supported by SEERAD, Defra and other governmental bodies, the RSPB, Scottish Natural Heritage, the National Trust and by European-wide initiatives, via the European Initiative for Sustainable Development in Agriculture (EISA; http://www.sustainable-agriculture.org/). Ingrid Clayden, representing SEERAD, recently said "I am very happy to be here representing SEERAD and I hope that my presence demonstrates our appreciation for the work done by LEAF in Scotland. I also hope that what I am about to say is seen as an endorsement of the LEAF objectives and the ways in which LEAF seeks to improve farming." The UK Secretary of State for the Environment also supports LEAF, saying "I am very pleased to see this leading example of good practice. It is providing a vital inspiration for farmers who are looking for a profitable and environmentally-friendly

Figure 2 LEAF Marque strawberries at Wimbledon 2004.

[1]Linking Environment and Farming (LEAF) (website www.leafuk.org).

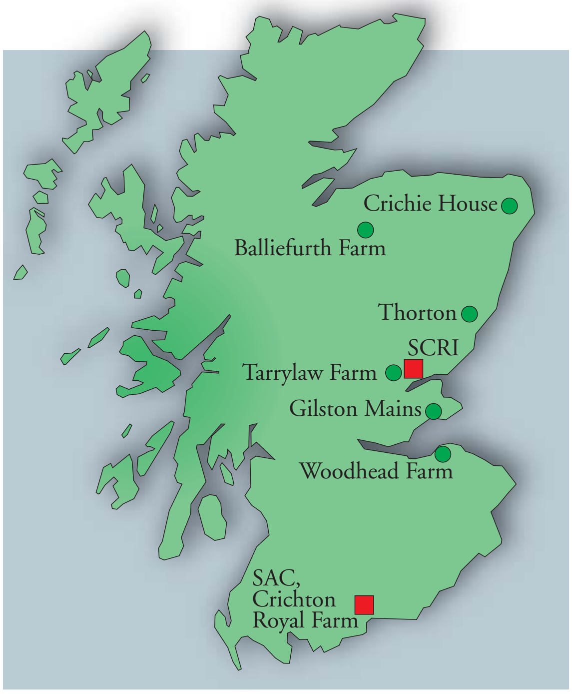

Figure 3 LEAF Scotland map showing Demonstration Farms (●) and Innovation Centres (■).

future. I commend the foresight of LEAF and its members in promoting a realistic and sustainable future for farming."

SCRI joined LEAF as an institutional member in 2002 and was invited to be the first SABRI LEAF Innovation Centre in Scotland in 2003. Our role, with the other Innovation Centres, is to promote current agro-ecological research and to pioneer new approaches that steer and support policy on sustainable land management and integrated farming. The Innovation Centre and related education and public communication of science projects (see below) are open to a wide range of visitors and 'end-users' of our research, including farmers, the general public, schools, environmental groups, the agro-industry sector, supermarket supply chains, governmental policy makers and politicians.

SCRI's on-site environmental research SCRI together with BioSS have extensive expertise on experimental design, data collection (ranging from molecular, gene, cellular, organism, through to ecosystems, landscapes, regions and countrywide), statistical analysis and numerical modelling. Besides developing fundamental and strategic research, we have the capability to demonstrate IFM principles and to develop IFM tools (e.g. pest- and disease-resistant crops; pest trapping technologies; eco-friendly, plant-derived alternatives to synthetic pesticides; molecular ecology and

Figure 4 *Myzus persicae,* a key pest and virus vector on several UK crops. This pest is being intensively studied using molecular ecology and population genetics approaches involving SCRI, SASA, SAC and Rothamsted International (described in following article by Fenton *et al).*

epidemiology of virus vector aphids (Fig. 4)). SCRI also develops research as policy aids for SEERAD, Defra, the EU and developing countries, on important issues like risk:benefit analysis and biosafety of genetically modified crops. Funding for agro-environmental research at SCRI comes from a wide range of sources including SEERAD, Horticultural Development Council (HDC), Defra Hortlink, the EU, the International Organisation for Biological Control and the Swiss Agency for Development and Cooperation.

Learning from natural ecosystems: Use of barley variety mixtures to stabilise yield and suppress diseases. One of the factors which aggravate sustainability problems in agriculture is the use of monocultures, where every plant in a crop is genetically identical. The environment in which each of these plants grows is heterogeneous, but the plasticity of the plant's phe-

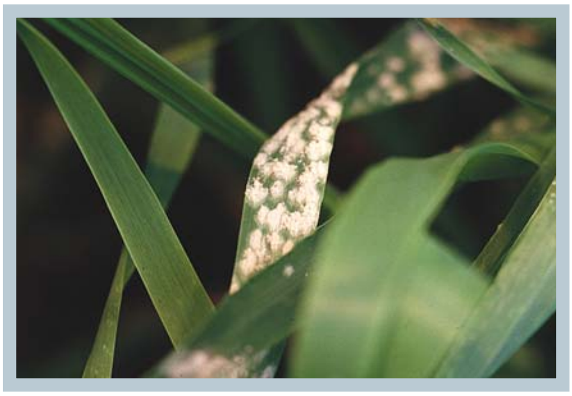

Figure 5 Barley with powdery mildew disease, which reduces yield and increases fungicide usage.

notype to respond to this is limited by the genes expressed in this single genome. Compare this to natural ecosystems, or even to field margins, headlands and hedgerows, where there are not only mixed species, but also genotypes within the species. Observe where disease epidemics occur – in the crop where there is no barrier to the spread of an adapted pathogen and where there is a concentration of plants which are susceptible. Consider also that the highest yielding variety in one year in a particular field is often not the highest yielding in all fields or even in the same field in different years. In other words, growing monocultures leads to vulnerability to stress, be it from pathogens (biotic), or the weather (abiotic), and to instability (Fig. 5).

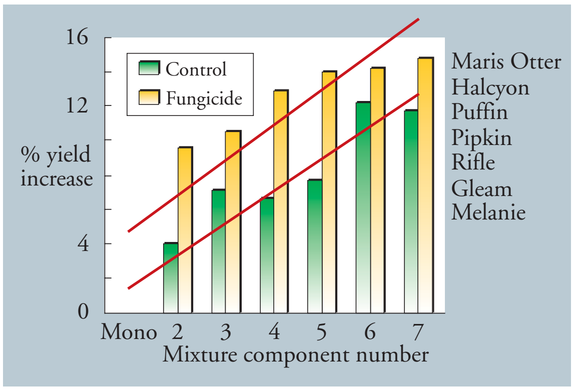

Figure 6 Yield advantage of mixtures compared with the monoculture mean showing increasing benefit with higher component variety number in the mixture.

The solution to these problems is simple - exploit heterogeneity by mixing varieties, or even species where end-user constraints allow. In this way we increase the plasticity of the crop to respond to stress by providing a wider genetic base from which to express the genes which result in the phenotype. Therefore there is much more likely to be a plant which can respond well in every part of the field. There are also likely to be plants which respond well at any given time. The result is a better and more stable yield and higher quality crop, through better utilisation of resources (Fig. 6). Better utilisation of resources applies to nutrients, water and light interception. To access the nutrients and water roots are required in all the appropriate parts of the soil at the right time. Again, heterogeneity, plants with varied rooting characteristics, will give the crop advantages.

In our work to reduce inputs, especially pesticides and nutrients which have a negative impact on the environment, increasing the plasticity or buffering capacity of crops by increasing heterogeneity is an essential component. The issues this raises, particularly quality issues perceived by end-users, are being addressed and often found to be either groundless or can be easily remedied. Indeed, some of the anticipated problems have turned out to be benefits such as unexpected enhancement of alcohol yield from barley mixtures used in distilling (Fig. 7). They may also have advantages in new crop uses such as for bioethanol fuel production where yield component utilisation options are different from, say, barley for whisky distilling.

In farm practice audits, crop agronomy considerations should include not just variety choice, fertilisers, time of planting, pesticides etc, but also use of crop heterogeneity, variety mixtures or blends to enhance the flexibility, plasticity, buffering capacity, or resilience of the crop. It is not the answer for all crops, but it can certainly be considered for far more than are currently being entertained.

Minimising environmental stresses: The soil disturbance experiments This experiment began in 2003 to examine how disturbing soil with tillage influences plant productivity, soil sustainability, and agricultural ecosystems. Physical disturbance was manipulated using cultivation common in Scottish agricultural production, newer approaches aimed at minimising soil damage and nitrate losses to ground water, and potentially harmful practices chosen to manipulate the soil biophysical environment. Our aim is to produce different soil environments to underpin fundamental research on ecosystem dynamics and plant sciences, and support applied research on soil tillage.

The design of the field experiment using five tillage treatments combined with different nitrogen inputs to

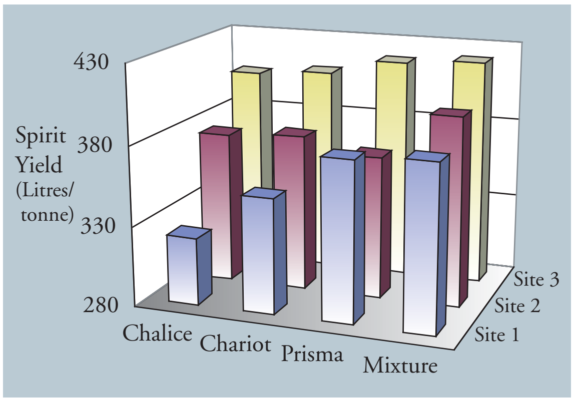

Figure 7 Spirit yield from barley monocultures and mixtures showing highest yield and yield stability across sites from the mixtures. Trials grown by SAC.

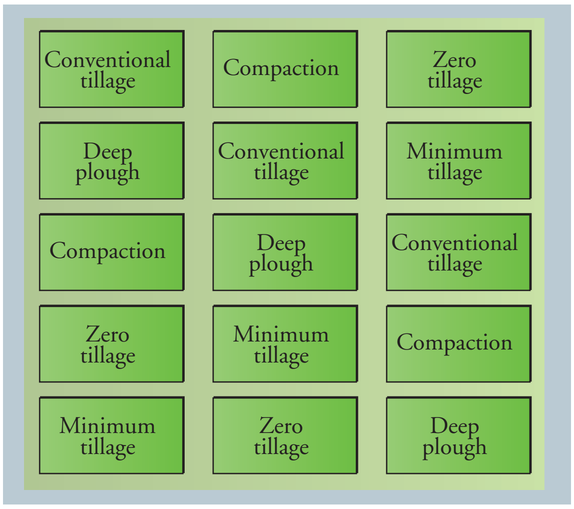

Figure 8 Soil disturbance. Experimental treatments are (1) Conventional ploughing to 20cm (mouldboard); (2) Zero Tillage (direct drilling); (3) Minimum Tillage (disk only); (4) Heavy Disturbance (ploughing to 40cm and disking) and (5) Heavy Compaction (heavy tractor wheeling). The buffer between plots provides a 'bank' for insects and soil organisms.

study disturbance effects on winter barley ecosystem over several years is shown in Fig. 8.

Overlaying the soil disturbance experiment, we are studying how four winter barley cultivars, planted in monocultures and all combination of mixtures, interact with the different soil conditions. Mixtures may, on average, outperform monocultures as the greater diversity in plant characteristics is better at exploiting the soil and aerial environment and withstanding stresses like pathogens and poor weather. There are already some obvious visible differences that can be seen in the field experiment (Fig. 9). The difference in plant height across the different beds of barley is due to different fertiliser rates, the shorter plants having half the normal level. Crop residues can be seen on the surface of the Zero Tillage sites, where plant pathogens are also higher.

This experiment incorporates a wide range of disciplines and state-of-the-art approaches in ways not done previously. We are collecting data about the plants, soil and environment. SCRI ecologists are examining the impact of soil disturbance above and below ground, on the crop, associated weeds, soil micro- and macro-organisms and invertebrate populations. Chemists are monitoring the forms and cycling of plant nutrients and carbon. Soil scientists are determining the structure of the soil, the water available to plants, and the resilience of the soil to environ-

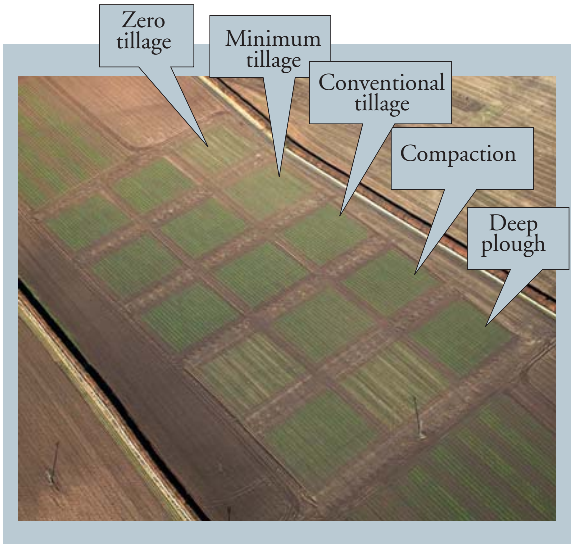

Figure 9 Soil disturbance trial showing the arrangement of 30 x 34 m treatment areas in one of the replicates.

mental stresses. This work underpins that of the plant scientists investigating the physiological response of plants, the spread of pathogens, root proliferation, and the performance of barley mixtures under different levels of soil disturbance. Future work will extend to controlled laboratory studies and smaller field experiments on different soils. We expect this work will help unravel the complexity of agricultural ecosystems, and feed into SCRI's plant breeding and genomics programmes by generating understanding of plant-soil interactions, and lead to environmentally sustainable land management.

Research on LEAF Demonstration Farms One such programme monitors and manages raspberry beetle (Fig. 10) without pesticides by understanding ecological connections between wild host plant reservoirs,

Figure 10 Raspberry beetle adults are attracted to both the reflected colour and scent of raspberry flowers.

open field crops and protected crops. This long-term, chemical ecology research was initiated in 1992 when Swiss collaborators in Wadenswil provided SCRI scientists with white sticky traps, using visual attraction, as a means of monitoring raspberry beetles (white traps reflecting wavelengths similar to raspberry flowers Fig. 11). Between 1994 and 1996 SCRI entomologists and phytochemists developed sensitive electrophysiological and behavioural bioassays to identify the key volatile chemicals emitted from raspberry flowers which attract raspberry beetle to its host for feeding, mating and egg laying (Fig.12). The combination of colour and smell, mimicking a giant host flower, has enhanced trapping rates by up to fifty times compared with the original white sticky trap. Enhanced traps have been tested in several European and Scandinavian countries under an EU funded CRAFT project (1998-2000) entitled RACER. The white sticky trap is now so effective that it becomes saturated by raspberry beetles after 2-3 days. SCRI scientists and an HDC-funded PhD student are currently testing an improved trap with a slow release attractant that lasts all season, in collaboration with a specialist UK company. Pilot studies on a local LEAF farmer's plantation in Fife during 2004 have already demonstrated that raspberry beetles can be effectively monitored and trapped emerging from wild hosts (wild *Rubus* species, hawthorn Fig. 13). It is hoped that the new, improved beetle trap at optimal positioning in field and tunnel-grown raspberries will manage this important pest below economic levels, without having to use current levels of conventional pesticides. A new research proposal (Defra Hortlink), involving SCRI and other institutes together with raspberry growers, supermarket chains, ADAS and an IPM company, is being now approved for submission so that UK end-users can benefit from SCRI's IPM tools and systems for a range of crops.

Figure 11 White sticky trap for monitoring raspberry beetles emerging from wild host plant reservoirs (wild raspberries, brambles, hawthorn) before raspberry crops flower.

Environmental management of the SCRI research farm The establishment of SCRI as a LEAF Innovation Centre to demonstrate new areas of research in sustainable agriculture has increased the ground area dedicated to 'green' activities (Fig. 14). A range of minimum tillage treatments were applied to sowings of winter barley to assess their effects on crop performance and yield. Various projects under the Countryside Premium Scheme were continued and extended including tree wind-breaks, species-rich grassland (Fig. 15), beetle banks and mixed native hedgerows (Fig. 16) (hawthorn, blackthorn, elder,

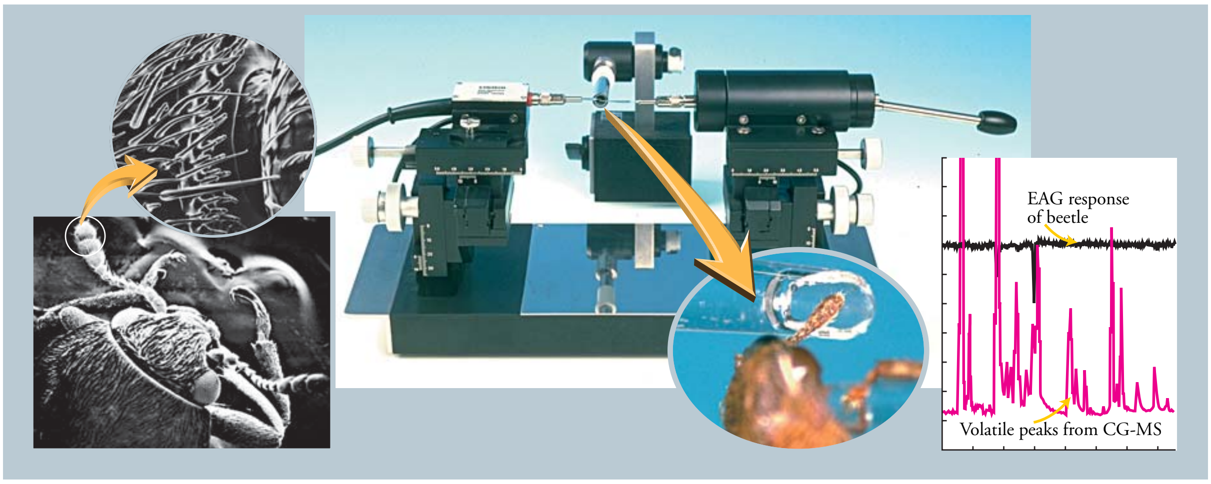

Figure 12 An electro-antennogram (EAG) coupled to a gas chromatogram-mass spectrometer (GC-MS) was used to identify the key raspberry beetle attractants from the hundreds of volatile chemicals in the flower odour.

Figure 13 SCRI's improved raspberry beetle trap with a lure of slow release floral attractant which lasts all season in open field raspberry plantations or within plastic tunnels.The trap is being developed and tested with several commercial partners.

Figure 15 Wild flower strips have been sown as special field margins to promote beneficial insects including pollinators, predators and parasitoids as well as other soil organisms, which all help by providing "ecological services" to crop plants.

hazel, alder, holly and dog rose). The 10-hectare broad-leaf woodland (oak, ash, birch, wild cherry, hazel and rowan) under the Woodland Premium Scheme had extensive maintenance work carried out during the summer months to remedy weed and rabbit problems.

The SCRI farm is not a LEAF Demonstration Farm nor is it a commercial farm in that we often have to encourage adverse environments such as in pest and disease nurseries and reservoir areas to assess plant response to these biotic stress factors and select for genetic resistance in our plant breeding material.

The presentation of experiments has been improved by the grassing of field roadways, reducing the need for herbicide sprays and enhancing the biodiversity within the grass sward around experimental plots. 'The Living Field Community Garden' (see Environmental Education) is being set up to show the links between science, agriculture and the environment by the use of demonstration plots, interactive exhibits and information boards. The site includes a small pond, with adjacent bog area, and a wild flower meadow with hedges and trees to provide shelter for a variety of birds and insects. This initiative complements the Institute's other environmental and sustainable agriculture activities.

Wildlife Audit The Scottish Crop Research Institute has been intensively farmed as a horticultural and arable farm for 50 years, with no livestock during that period. This has meant that there are very few refugia for wildlife. Although there are some hedges, these are mainly beech and until recently there have been very few native berry bearing shrubs and trees on the farm that might be used by birds e.g. hawthorn. An initial wildlife audit was undertaken during the April 2003

Figure 14 Aerial view of the experimental farm at SCRI.

Figure 16 Mixed species hedgerow provides food and nesting places for birds.

Figure 17 Peacock butterfly on *Buddleia*, an example of biodiversity promoted on SCRI's farm by using environmentally-sensitive farm management methods

and a range of animals and bird species were recorded but generally in low numbers. Blackbird, oystercatcher, woodpigeon, grey partridge, shelduck, curlew, pheasant, chaffinch, house sparrow, songthrush, pied wagtail, mallard and skylark were observed. Of these, shelduck, blackbird and oystercatcher were known to nest, the latter two species around the farm buildings. There were occasional signs of squirrels (probably red) and foxes on two of the fields, while roe deer were observed in one field. Rabbits, in relatively low numbers, were found virtually throughout the farm but in a few fields they were present in sufficient numbers to probably cause damage to crops, at least at the field margins. Nests and runs used by both field mice and voles were also seen. It is interesting to note that, although they are known to be present, no hedgehogs were seen during the survey and there was no evidence of moles on the farm which probably reflects low earthworm populations. There was also no evidence of badgers or of bats using any of the buildings.

The sowing of grass strips around the margins of some fields for wildlife (Fig. 15) should encourage a number of ground nesting birds e.g. partridge but the results of the survey in April/May 2004 did not significantly differ from that of 2003, except that yellowhammers were relatively common in 2004. Although significant benefits for wildlife resulting from changes in farming practices and management will take time, it is expected that they should become manifest in the next few years (Fig. 17).

Environmental education LEAF gives SCRI access to a group of farmers interested in reduction of agrochemicals and promoting environmentally friendly farming practices. This aids the two way flow of ideas which enriches research and solves problems for farmers. It also enables SCRI research to be carried out on LEAF members' farms.

Promotion of SCRI is enhanced by the LEAF Innovation Centre status. In March we promoted a joint LEAF/St Andrews University meeting "What is Environmentally Friendly Food Production?" The SCRI research on the impact of tillage and compaction on soils was presented by Dr Geoff Squire and aroused much interest amongst the farmers present. Rights of way through the Institute farm have been made into a "Science Stroll" and notice boards were made by joinery students at Dundee College and SCRI staff (Fig.18). There are two at present, with plans for more at strategic points on the walk giving information on what walkers might expect to see. There is information about SCRI and the environmental research conducted here and, by the wild flower meadow, an illustration of a food web and pictures to aid the identification of wild flowers and insects.

We have collaborated at events like the Royal Show and the Royal Highland Show by distributing information about LEAF and by LEAF promoting our environmental research. The LEAF exhibit at the Royal Show incorporated a poster showing the raspberry beetle traps referred to earlier.

The public welcome opportunities to access information on crop science and its' relevance to their everyday lives. Visits to SCRI by schools, college, university and other groups are extremely popular and have been increasing over the past year (Fig. 19).There is a high level of interest in how agriculture, science and the environment are related.

Figure 18 SCRI LEAF Innovation Centre Information board as part of the 'Science Stroll' for public awareness of our environmental research.

Figure 19 Dundee University Students visiting SCRI.

To assist public understanding of the complexities of these interrelationships, SCRI established an educational garden in early 2004, called the Living Field Community Garden. (Fig. 20). The garden consists of several different habitat demonstration areas, an experimental plot area, composting boxes, a wormery and demonstration boxes showing different soils and root systems. Information boards explain the garden and its contents. The garden is aimed at people of all ages and is located alongside the SCRI Science Stroll. Funding to help establish the garden was obtained from the BBSRC.

Figure 20 Living Field Community Garden.

SCRI are also producing an educational CD and web pages for schools called the Living Field (Fig. 21) that has been funded by the Scottish Executive Education Department (SEED) with support from Learning and Teaching Scotland. This educational resource covers agriculture, environment, science and nature, following the Scottish 5-14 National Guidelines for environmental science. The first three parts are aimed at primary schools and the fourth part is aimed at first and second year secondary school.

Figure 21 The Living Field educational resource.

SCRI was invited to exhibit at the Great Yorkshire Show on 13th – 15th July 2004 as part of the universities exhibit. This prestigious event is held annually in Harrogate and this year the attendance was just over 124,000 people (Fig. 22). Bruce Marshall, Joyce McCluskey and Gladys Wright from Ecosystem Management & Biology Dept presented research on 'The Importance of Seedbank Biodiversity' with a 'hands-on' educational display targeted at the general public. Three different activities were set up using computers, microscopes and seeds. The computer activities included the Arable Seed Identification System (ASIS), which can be found at www.scri.sari.ac.uk/asis, 'The Living Field' and an activity to exhibit the diversity of arable seedbanks, examining seeds including size, colour, shape and unusual textures using microscopes and finally sowing seeds for taking home.

Figure 22 Members of the public were enthusiastic about SCRI's display at the Great Yorkshire Show. Comments and feedback from the public are generally very positive and the SCRI staff involved found the exhibition over the three days to be very rewarding and worthwhile.