# Utilising Diversity for Sustainable Agriculture

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# Introduction

Agricultural sustainability is a key target for the European Union and its member states, outlined in the reformed Common Agricultural Policy. An estimated 60% increase in agricultural production is needed by 2050 to feed the growing global human population. To achieve this with sustainable use of resources, farmers and policy-makers need advice on crop types and land management that will maximise the productivity and efficiency of agricultural systems and limit environmental damage.

Sustainable land management requires increased resource efficiency, which is central to the Scottish Government 2015 Economic Strategy, along with practices that reduce greenhouse gas emissions and promote efficient use of fertilisers and pesticides. At the same time, protecting biodiversity and ecosystem services is fundamental to the objectives of the Scottish Land Use Strategy and Scottish and EU Biodiversity Strategies. Increased biodiversity can improve a range of functions in agricultural systems, including productivity, pollination, pest and disease regulation, and resilience to stress.

This booklet summarises research to assess the benefits to agricultural sustainability of introducing diversity at crop, field, farm and regional scales. Analysis of spring barley populations has shown that there is potential to enhance crop productivity by exploiting trait diversity amongst barley landraces (Chapter 1). Target traits could include root traits that improve soil penetration and crop performance in reduced input systems, as these traits vary considerably amongst modern cereal varieties (Chapter 2). Root traits are particularly important for enhancing crop performance under less intensive soil cultivation practices, which alter soil compaction, structure and aeration (Chapter 3). Practices that reduce nutrient losses are a key component of soil management; a tool that tailors phosphorus fertilisation to the crop type and soil phosphorus status could improve phosphorus use efficiency in Scottish soils (Chapter 4). Nitrogen is another important nutrient applied to most crops to optimise yield and quality and there is a need for alternative sources of nitrogen to reduce synthetic fertiliser use. Legume crops are capable of enhancing soil fertility by providing a biological supply of nitrogen and can be used as part of a strategy to enhance nitrogen efficiency; greater inclusion of legumes in the rotation can partially displace synthetic nitrogen fertilisers (Chapter 5). Similarly, soil organic matter content, which tends to be low in agricultural soils, can be stabilised through careful design of crop rotations and managing organic waste inputs (Chapter 6).

Practices that increase the diversity of crop and non-crop components of the field can contribute ecosystem services that benefit agriculture. For example, crop variety mixtures could be designed to promote the survival of rare arable plants (Chapter 7), while sustainable management can increase non-crop biodiversity and, in some cases, contribute to pest regulation (Chapter 8). At the farm scale, sustainable farming to achieve the goals of enhanced crop production and biodiversity requires long-term integrated management (Chapter 9). Farm-scale practices could be accompanied by regional scale ‘engineering’ of land use; for example by designing field arrangements that allow long-term regulation of crop pests over large areas of the agricultural landscape (Chapter 10).

The research presented in this booklet highlights many of the challenges associated with achieving agricultural sustainability and illustrates how incorporating diversity into cropping systems at a range of scales can enhance ecosystem services and agricultural production.

Alison Karley
alison.karley@hutton.ac.uk

# Contents



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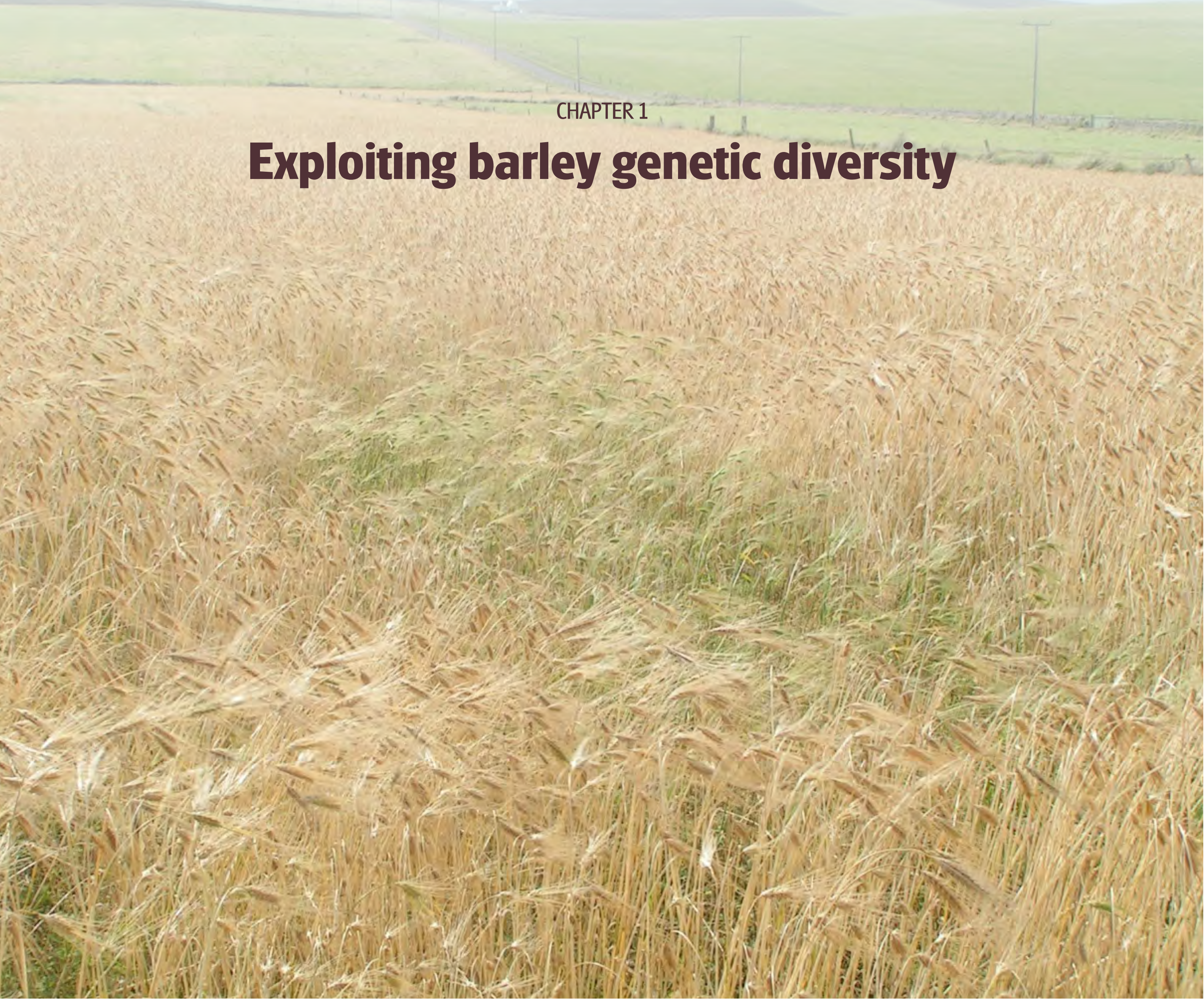
CHAPTER 1

# Exploiting barley genetic diversity



## Background

Barley has become Scotland's most important and valuable crop. The successes during the last 100 years of crop breeding for high yielding varieties that are responsive to agronomic inputs, have significantly increased production. However, with changing climate and limited resources this type of approach is now considered unsustainable. The major challenge is to develop varieties that at least maintain current yields whilst placing production on a more sustainable and resilient footing. This requires a better understanding of adaptation in particular environments. Locally adapted cultivars or traditional landraces are as yet untapped sources of new variation, having been grown for hundreds of years, surviving both changes in climate and agricultural practice. We have sourced a collection of landraces from the UK, with **the aim of examining these for genetic and phenotypic diversity, in order to develop germplasm resources for future use.**

## Approach

The collection is based on two-row (i.e. grain is present as two parallel rows down the ear) spring barley accessions from England, Ireland and Wales and six-row (i.e. grain in six rows down the ear) spring barley accessions from the Scottish islands; collections date from early 1900s, originally held at the Scottish Plant

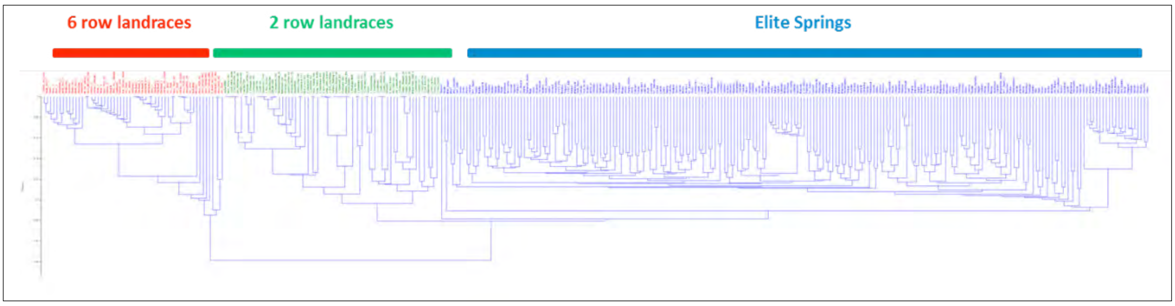



**Fig. 1: Genetic relationship between two-row and six-row UK barley landraces and modern cultivars ('Elite Springs').**

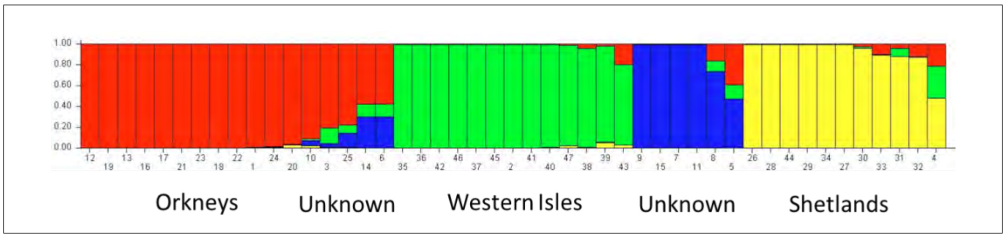



**Fig. 2: Genetic analysis identifies four unique groups from Scottish landraces which correspond to their islands of origin (Red: Orkneys, Green: Western Isles, Yellow: Shetlands). Each line represents an individual with similar genotype. Several accessions from 'genebank' have an unknown origin and are intermediate between clusters.**

Breeding Station and then as part of the John Innes Institute Cereals collection. All accessions, together with modern cultivars and a collection of lines from Scandinavia, were genotyped using over 1000 gene based markers. Life history traits which are important in adaptation to particular environments were scored for the collection grown at a single location over several years. Flowering time as measured by days to heading (i.e. when the ear emerges) is a major component of yield in response to environment.

## Results

- Landraces are clearly distinct from modern cultivars (Fig. 1). The two-row landraces group with six-row landraces rather than with the two row modern accessions. The number of unique gene variants in the landraces is three times that observed in modern cultivars (44 and 14 respectively).
- Scottish landraces are geographically clustered. The accessions collected from different Scottish Islands showed geographical structuring, with six-row barley accessions from Orkney and Shetland being genotypically and phenotypically different from those originating from the Western Isles (Fig. 2).
- Considerable variation for important agronomic traits has been detected within the landraces. Compared to the elite and two-row landraces there is a greater range in traits, such as flowering time, in six-row landraces. Understanding the genes that control flowering and hence yield will allow us to develop crops that are suitable for the changing environment.

## Conclusion

To exploit potentially useful genetic variation in barley landraces, a programme of breeding has begun. This strategy emphasises the importance of connecting landrace collections to state-of-the-art genomics tools and phenotyping, ultimately allowing targeted breeding approaches that provide barley resources for our future needs.

Authors: Joanne Russell *(James Hutton Institute)*
Contact: Joanne Russell (joanne.russell@hutton.ac.uk)

CHAPTER 2

# Root traits for sustainable agriculture

## Background

Significant variation exists in the way agricultural land is managed both within farms, across Scotland and beyond. This includes, but is not exclusive to, previous cropping, pre-sowing tillage methods, number of passes of vehicles during cropping to apply inputs such as pesticides or weed control, and/or fertiliser additions. Each of these processes, along with the underlying soil type, can have an effect on the soil environment. In addition to this, changes in climate, such as increased heavy rainfall, may cause significant issues like waterlogging, resulting in damage to both soil and cropping systems. Changes in agricultural practices, either through recent intensification of land use, or towards practices that are more sustainable, alter the soil environment in which the crops grow. Root systems of crops are critical to the plant’s interaction with the soil environment. Focussing on cereals such as barley, **the aim of this research was to better understand the relationships between root structural and functional characteristics (or traits) and the soil structure and function.**

## Approach

We studied the status of soil in fields across Scotland and in experimental systems with varying tillage regimes, or that were aimed at

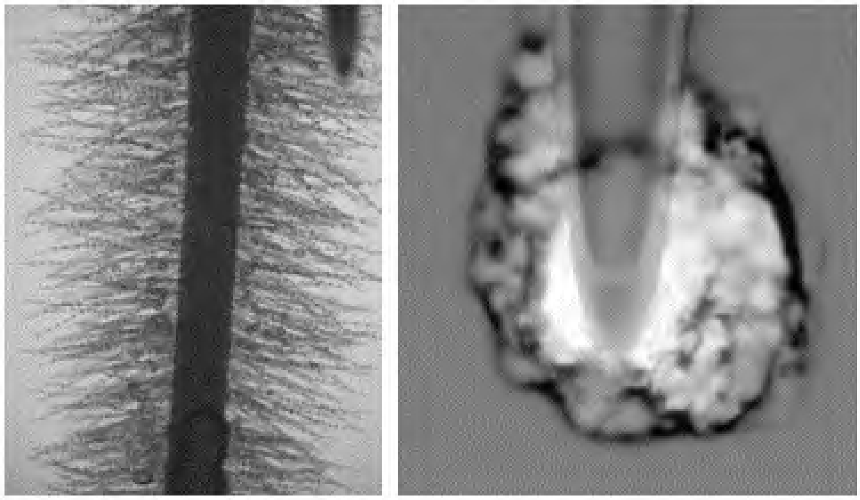


**Fig. 1: Barley root with hairs (left) and barley root meristem tip, border cells and mucilage (right).**

finding sustainable farming solutions, using these data to gain an understanding of some of the structural variation in soil under different conditions. Using barley as a model, methods were developed to allow the screening of crop seedlings to understand individual root behaviour under different soil conditions and variation in these traits between crop varieties. Further screens have been developed to quantify root traits, such as root hairs and border cells (Fig. 1), root width and ability to penetrate and elongate in compacted soils. Comparisons have been made between seedling performance and mature plant performance in both greenhouse systems and field conditions under different tillage systems. It is not usually possible to measure all traits at all different scales, therefore, methods have to be adapted to the scale of the plant to be measured. Multivariate analyses have been developed that encompass multiple soil and root traits, along with high throughput techniques for the statistical analysis of many traits individually.

## Results

- Farm soil collected from fields under different soil management practices varied significantly in structure. Barley roots exploited soil pore structure when pores of the correct size were available.
- This demonstrated a potential trade-off between barley plants utilising energy to grow through harder soil with which they can maintain greater root surface contact, compared to rapid root elongation through soil pores, which may allow a large root structure to be created but within a confined soil space.
- Plant traits thought to be involved in this interaction between soil structure and root growth vary widely within several barley populations, and include root hair length, border cell numbers, underlying root growth rates, root structure and trait expression at different growth stages.
- The ability of barley roots to interact with soil has an impact on nutrient and water uptake, and on physical and biological interactions in soil. These interactions are captured in the rhizo-sheath trait, which is simply the weight of soil which adheres to roots upon excavation; this trait could be used for genetic improvement of crops grown under reduced inputs.

## Conclusions

Our results show that root elongation can be significantly limited under current soil conditions. Evidence of changes in barley root traits linked to breeding suggests changes in root traits have occurred over the last 50 years in parallel to the changes in farming systems. Therefore, along with the range of root traits found, there is significant scope to match the new breeding targets to a more sustainable soil environment.

Authors: Tracy Valentine and Tim George *(James Hutton Institute)*

Contact: Tracy Valentine (tracy.valentine@hutton.ac.uk)

CHAPTER 3

# Sustainable soil management – some lessons from 12 years continuous barley under contrasting tillage

## Background

Soil is the fundamental resource that underpins all agriculture by delivering a range of functions essential both for plant growth and for environmental protection. Functions include anchoring and providing resources for the crop, filtering water, preserving biodiversity and resisting erosion. For soil management to be sustainable there may be trade-offs between production and other ecosystem functions and services. Soil management practices should ideally improve plant growth but also improve soil quality to enhance a range of other soil functions. Such practices commonly include decreasing the extent or frequency of tillage (e.g. Ploughing vs Minimum-Till [i.e. shallow non-inversion] vs No–Till) or compaction. **The aim of this research was to investigate changes in soil structure that result from a change in tillage**, which can take multiple years to reach a new functional condition.

## Approach

We established a long-term soil management experiment in Mid-Pilmore field at the James Hutton Institute's Invergowrie site in 2004. This is on a sandy soil, typical of the agricultural areas of eastern Scotland. We focused on barley as the dominant cereal in Scotland, grown continuously to test treatment resilience. Using combinations of field and laboratory testing we have quantified the impact of different management practices on the extent and seasonal variation in soil strength and stability, soil structure, fluid permeability and nitrous oxide emissions.


**Fig. 1: Soil in the No-Till treatment.**

## Results

- After ten years of monoculture, crop production decreased significantly with the No-Till treatment (Fig. 1), which was the first tillage system to eventually provide no economic yield.
- Several factors seem to have contributed to the system failure in the No-Till. While the undisturbed No-Till soil structure remained stable at depth, the soil surface became hard (Fig. 2) and much of the topsoil developed compact structures.
- This hard surface led in turn to poor crop establishment, the weed burden became uncontrollable by herbicide alone and crop growth became restricted and patchy.
- The aeration conditions and nitrous oxide emissions remained satisfactory in the No-Till system, despite its lower soil quality, because this soil type provided satisfactory aeration under all tillage treatments.

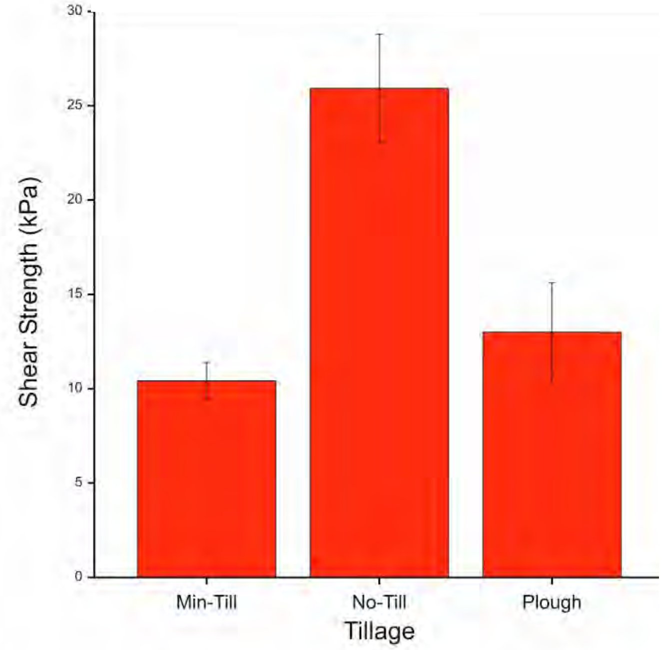



**Fig. 2: Soil surface shear strength in the different tillage treatments.**

## Conclusion

Whilst soil functions such as stability can improve under No-Till systems, other functions related to the productivity of annual cropping and to wider environmental impact, such as structural quality and fluid flow, respond positively to some form of soil cultivation.

Authors: Blair McKenzie *(James Hutton Institute)*, Bruce Ball and Joanna Cloy *(Scotland's Rural College)*

Contact: Blair McKenzie (blair.mckenzie@hutton.ac.uk)

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CHAPTER 4

# Managing the phosphorus fertiliser requirements of Scottish soils

## Background

Modern agriculture relies on phosphorus (P) fertiliser additions to maintain high crop productivity. Phosphorus fertilisers are added to soil to build P fertility and maintain a reserve sufficient to meet crop demand. Over-fertilisation is wasteful and may adversely affect water quality, whereas under-fertilisation may reduce crop yields. In addition, P is a non-renewable resource with high energy costs of production and easily-mined resources are becoming depleted. The efficient management of soil P is challenging because of the varying ability of Scotland's soils to mediate availability of P to plants. In Scotland, soil testing for P fertiliser requirement usually involves laboratory extraction of the soil with reagents such as solutions of acid ammonium acetate or acetic acid, but the resultant advice usually takes no account of soil type and its individual P sorption capacity (PSC). **The aim of this research was to develop a more refined approach in which the P sorption capacity is estimated from other soil properties.**

## Approach

When soluble P is added to soil as a fertiliser, a large proportion becomes fixed to reactive mineral surfaces such as iron (oxy)hydroxides. Using data from the National Soil Inventory of Scotland and an advanced chemical model, we have produced a phosphate-P sorption map for Scotland. The sorption of P is influenced by a range of factors that include the concentration

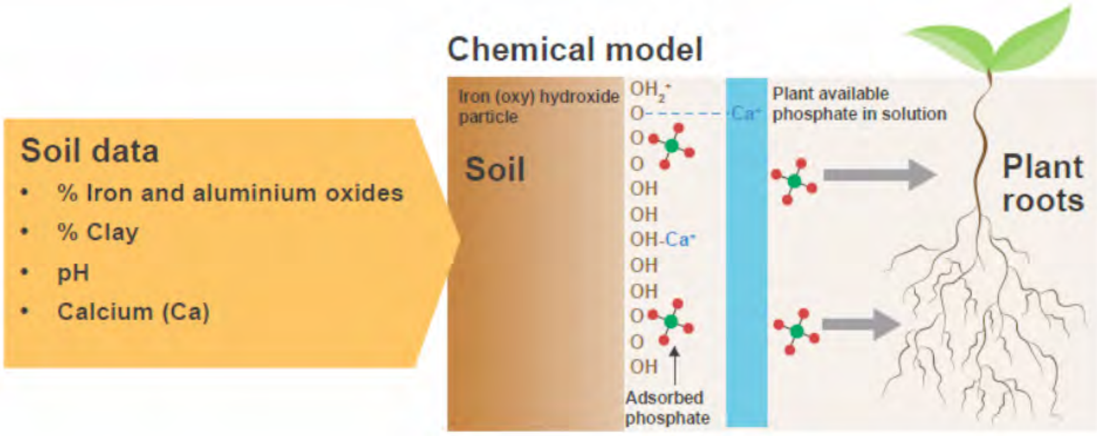


**Fig. 1: Chemical model.**

of amorphous iron and aluminium oxides, clay, calcium and the soil pH (Fig. 1), and can be divided into P fixing categories based on capacity for P sorption (Fig. 2). A high P fixing capacity soil (e.g. PSC3, Fig. 2) means that more P is required compared to those with a low P fixing capacity where less is required.

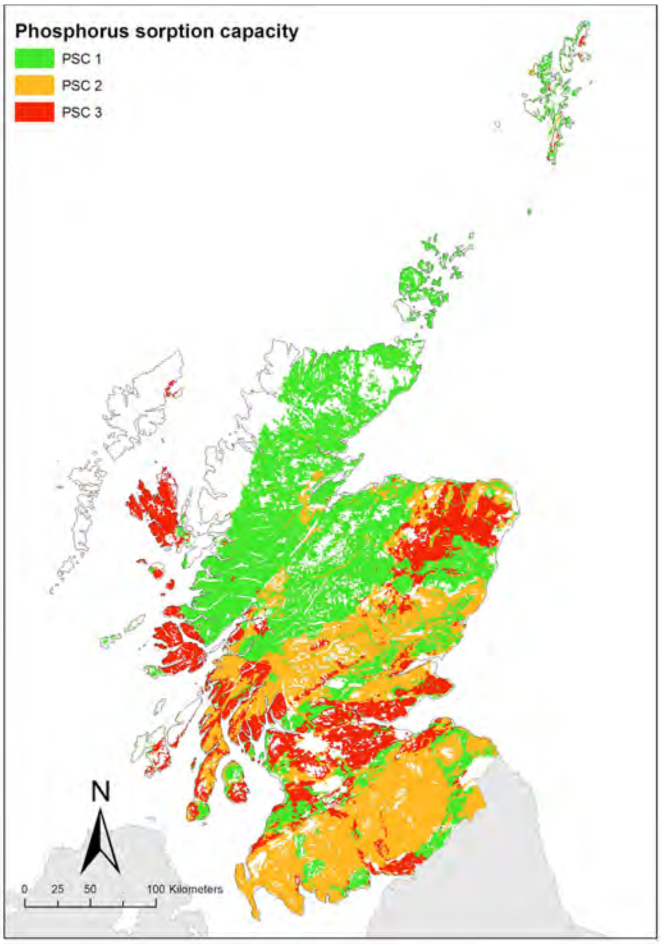


**Fig. 2: Map of Scottish soils categorised from low (PSC1) to high (PSC3) P sorption capacity.**

## Results

- By providing rates of application of P fertiliser tuned to intrinsic soil properties there will be a better match to crop demand. Soil with a low P fixing capacity will be less likely to become over-fertilised, whereas soils with a high P fixing capacity will be less likely to be under-fertilised.
- The model helps understand the complexities of P loss by leaching and aquatic process involving desorption of P from soil eroded into water bodies.

## Conclusions

By providing rates of application of P fertiliser tuned to intrinsic soil properties there will be a better match to crop demand. The estimated P sorption capacity of soils, obtained by modelling fundamental chemical processes, has provided a platform for understanding of the complexities of P lost by leaching into water bodies, the effect of bulky organic fertilisers on P sorption processes in soils and the solubilisation of soil organic P by plant root exudates. This work has resulted in a technical report to SEPA (http://www.sepa.org.uk/media/138637/sepa-p-report-12-10-2012.pdf) assessing the potential risks to water quality from P leaching, and a technical note from SRUC to aid farmers in adjusting their P fertilisation regimes (TN 668).

Authors: David Lumsdon, Charles Shand, Malcolm Coull *(James Hutton Institute)*, Tony Edwards, Alex Sinclair and Bill Crooks *(Scotland's Rural College)*

Contact: David Lumsdon (david.lumsdon@hutton.ac.uk)

CHAPTER 5

# Legume supported crop systems

## Background

The excessive use of man-made nitrogen (N) fertilisers has been identified as a major cause of environmental dysfunctions associated with intensive agricultural practices. Despite the short-term profitability of intensive fertiliser use, productivity levels per hectare have stabilised over the long-term in several parts of the world, including Scotland. In natural vegetation systems, legumes such as peas and beans are 'pioneer plants' which occur most commonly in soils of low nutrient status, where they help enrich soil fertility and support plant succession. This occurs by virtue of their capacity to 'fix' inert atmospheric nitrogen ($N_2$) into biologically useful forms - ammonia initially, and then more complex nitrogenous compounds. Legumes also capture bound soil phosphorous, which helps ensure high levels of productivity. **The aim of this research was to assess the potential for legumes to contribute to productivity and N fertility of arable-grass crop systems.**

## Approach

Agroecological approaches suggest that domesticated legumes, as crops, are essential to provide a renewable source of essential nutrients and encourage N cycling and efficient nutrient use. We assessed the quantity and source of N in faba bean grains harvested from plots that were managed either with 'sustainable' treatment (reduced soil tillage and chemical inputs) or using typical 'conventional' practices at the James Hutton Institute's Centre for Sustainable Cropping at Balruddery Farm. Nitrogen derived from biological N fixation (BNF) was determined using the $^{15}N$ natural abundance technique. Nitrogen

| Faba bean variety | Conventional treatment | Sustainable treatment |
|---|---|---|
| Fuego | 160 | 111 |
| Pyramid | 229 | 198 |
| Ben | 146 | 310 |
| Tattoo | 252 | 307 |
| Maris Bead | 229 | 280 |
| Average for all varieties | 203 | 241 |
| **% increase in sustainable over conventional** | | **19** |

**Table 1: Quantities of grain nitrogen (in kg N ha$^{-1}$ y$^{-1}$) acquired from soil and air by biological nitrogen fixation in five varieties of faba bean. Grains were harvested from field halves in 2012 that were managed either sustainably or conventionally.**

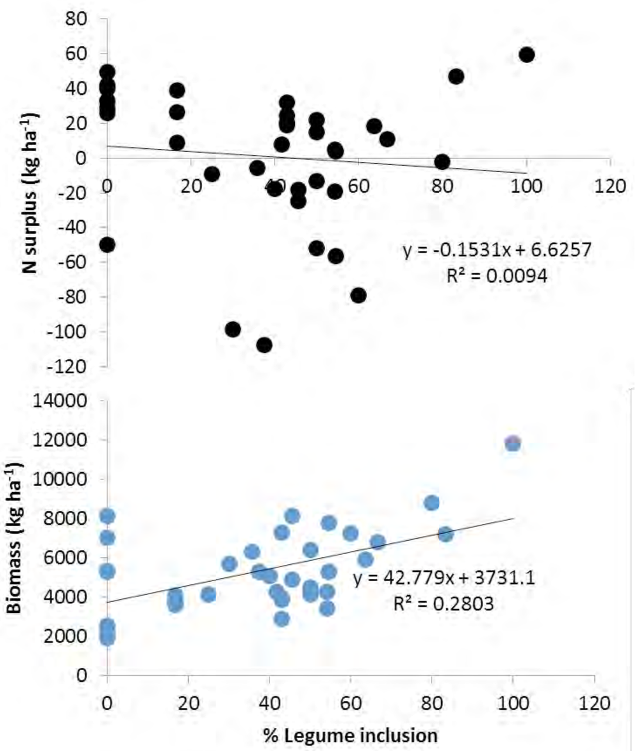


**Fig. 1: An analysis of crop rotations which included no legumes (n=7), or increasing legume inclusion (n=22). Trends in response to the level of legume inclusion (%) are shown for N surplus (kg ha$^{-1}$ y$^{-1}$) and yield as biomass (t ha$^{-1}$ y$^{-1}$).**

assimilated from soil was estimated by deduction from total N levels. In addition, an analysis was conducted of historical data gathered from countries throughout Europe to compare performance of legume-based and non-legume crop-rotations.

## Results

- On average, 85% of the total N in faba bean crops was derived from air, but the amount fixed varied between faba bean varieties and crop management.
- Highest N levels were found for three varieties (Table 1) grown under 'sustainable' management using only renewable N sources. This increased capacity was mainly due to N assimilated from soil, and probably due to improved soil quality in the 'sustainable' treatment.
- Analysis of historical data (Fig. 1) demonstrated that as the proportion of legumes in the rotation increased, yield (as biomass) also increased while N-surplus, a source of eutrophication and reduced water quality, was not detrimentally affected.

## Conclusions

We emphasise the importance of: 1) breeding new crop varieties (legume and non-legume), and novel cropping approaches that exploit renewable N sources and encourage natural nutrient cycling; 2) development of diagnostic and remedial services for farmers so that they can optimise the performance of legume supported cropped systems; and 3) the introduction of government policies that strengthen capacity and demand for legume production as a means of reducing N fertiliser inputs and limiting environmental damage.

Authors: Pete Iannetta, Graham Begg, Euan James, Alison Karley, Cathy Hawes, Mark Young, Nick Birch, Tracy Valentine and Geoff Squire *(James Hutton Institute)*

Contact: Pete Iannetta (pete.iannetta@hutton.ac.uk)

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CHAPTER 6

# Soil organic matter in the SRUC Tulloch long-term legume based crop rotations trial

## Background

Maintenance of soil organic matter is widely regarded as a key factor in developing long-term sustainability of soils. The choice and management of crops in rotation will have an influence on the rate of change in the amount of soil organic matter present, as well as the composition of that organic matter. In turn, these will have an influence on soil structure as well as the biological and chemical processes taking place in the soil, all of which impact on productivity. **The aim of this research was to compare the influence of the different crop rotations on soil organic matter at SRUC's long-term legume based rotation trial at Tulloch, Aberdeen (pictured above).**

## Approach

The replicated field trial at Tulloch, established in the early 1990s, is certified by the Soil Association and is the oldest organically managed crop rotation trial in Europe that includes grazing livestock. Soil organic matter has been monitored since trial establishment using the common measure of loss on ignition. Originally the trial

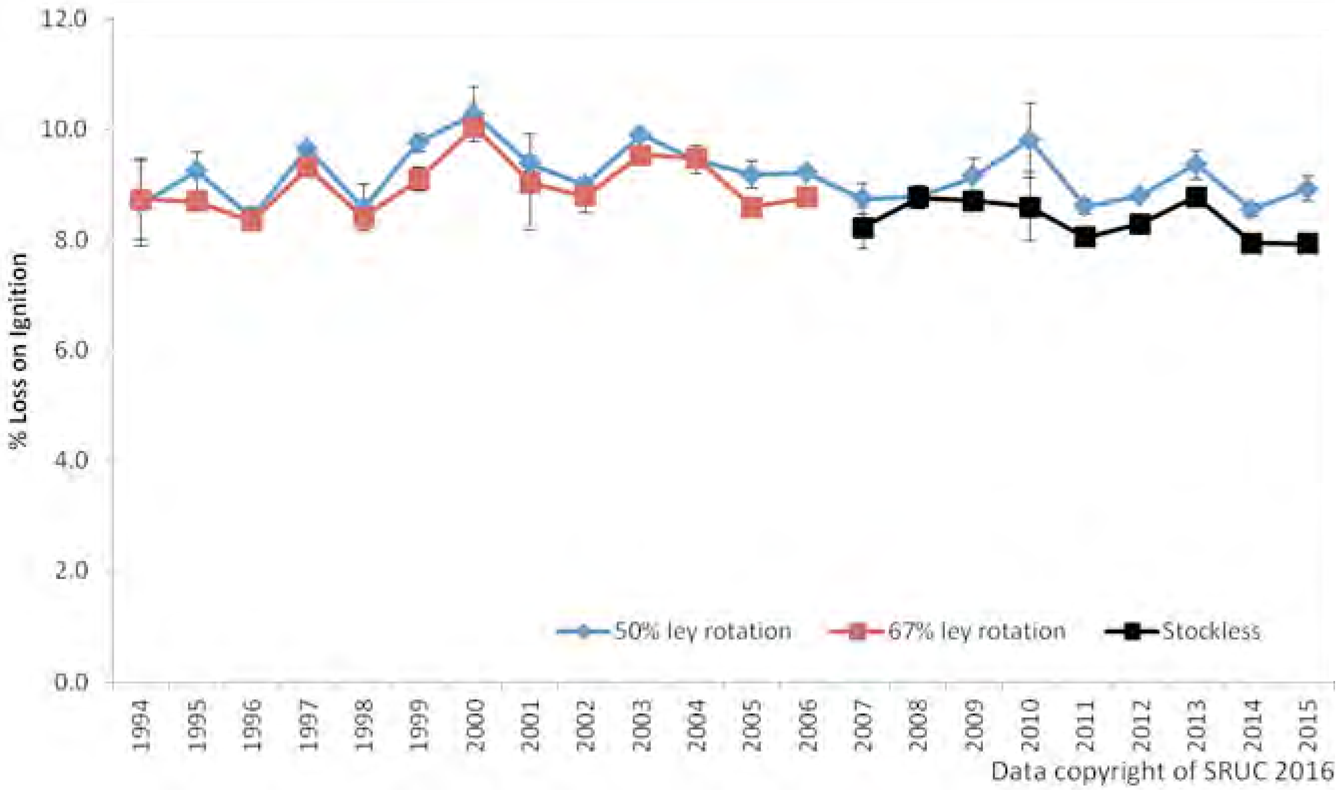



**Fig. 1: Soil organic matter (measured as loss on ignition) following conversion to organically certified land in three different organically managed crop rotations at Tulloch, Aberdeen.**

compared two ley/arable rotations comprising: a) **50 % ley rotation** (3 years of grass/white clover followed by spring oats, swedes and undersown spring oats) and b) **67% ley rotation** (4 years of grass/white clover followed by spring oats and undersown spring oats). These rotations included sheep grazing on the leys or alternatively, sileage cuts with sheep-grazed aftermaths plus farm yard manure application. In 2007, rotation 'b' was changed to **a stockless rotation** (grass/red clover, potatoes, spring wheat, spring beans, spring barley, and spring oats). All cereals and beans are undersown with white clover, with the exception of oats which are undersown with a red clover/ ryegrass mixture.

## Results

- The two stocked organic rotations maintained soil organic matter over the 21 years of data collection (Fig. 1).
- The stockless system shows a marginal decrease in soil organic matter over the nine years of data capture compared to the stocked system, which is surprising given the vastly different levels of inputs and other crop husbandry between the two systems.
- The data highlight the variability in soil samples analysed over space and time, and also the critical need to look at soil organic matter in the long term (over decades) rather than short term in order to distinguish significant treatment effects.

## Conclusions

Despite the widely different crop sequences and management in the rotations being compared, changes in soil organic matter content have been very small, even after 21 years. Although the stockless rotation has much lower inputs and greater levels of cultivation than the stocked system, there appears to be only a slight reduction in soil organic matter. In soils like these, where the organic matter content is relatively high, the key management focus will be how best to maintain, rather than increase, levels of soil organic matter, with rotational choice just one part of the jigsaw.

Authors: Christine Watson and Robin Walker *(Scotland's Rural College)*

Contact: Christine Watson (christine.watson@sruc.ac.uk)

CHAPTER 7

# Crop diversity and rare plant conservation

## Background

In areas where farming is relatively intensive, for example in high-yielding cereal production systems, biodiversity is in substantial decline. Many different components of biodiversity have been affected by the adoption of modern farming techniques, particularly some plant species that used to be common in arable fields but now are rare in these habitats. Factors causing their decline include improved seed cleaning, herbicides and the switch to winter cereals. It is therefore important to develop approaches that conserve these rare plants whilst enabling crop production to continue. **The aim of this research was to assess whether cereal mixtures might have beneficial impacts on rare arable weeds.**

## Approach

A previous glasshouse experiment indicated that mixtures of cereal varieties (rather than the monocultures that are typically grown) might have beneficial effects on the establishment and growth of some rare plants. In order to test whether cereal mixtures could have this beneficial effect under field conditions, we established a field trial at the James Hutton Institute's Invergowrie site. Seeds of the target rare plant *Valerianella rimosa* (Fig. 1) were sown into plots with different barley monocultures and with a 5-variety barley mixture at a range of sowing densities. We then assessed the establishment and growth of *Valerianella*.

**Fig. 1: The target species *Valerianella rimosa* growing within one of our experimental plots.**

## Results

- The barley crop, particularly some plots of the low-density barley mixture, promoted early season *Valerianella* abundance (Fig. 2a), but by the time of crop harvest there were no differences in abundance between plots with and without barley.
- The biomass of common weeds was reduced by the barley crop (Fig. 2b); the previous greenhouse study indicated that this may result from crop competition forcing them to take a more conservative growth strategy.
- Although at the time of harvest *Valerianella* plants in plots with barley were smaller, reproductive effort (overall seed production) did not differ between plots with and without barley.
- The beneficial effect of the barley crop on *Valerianella* abundance was not simply due to the suppression of common weeds; increased numbers of *Valerianella* plants were observed early in the season at a time when the common weed community was still developing.

## Conclusions

Crops - and perhaps in particular crop variety mixtures - could create a niche for some rare arable plant species. These results are tentative; we need to test this effect on a wider range of rare plant species and assess the long-term viability of any establishing populations. They do, however, point to the possibility of integrating rare plant conservation into the management of the crop, rather than trying to conserve these plants in uncropped areas, for example in buffer strips where competitive common weeds can dominate.

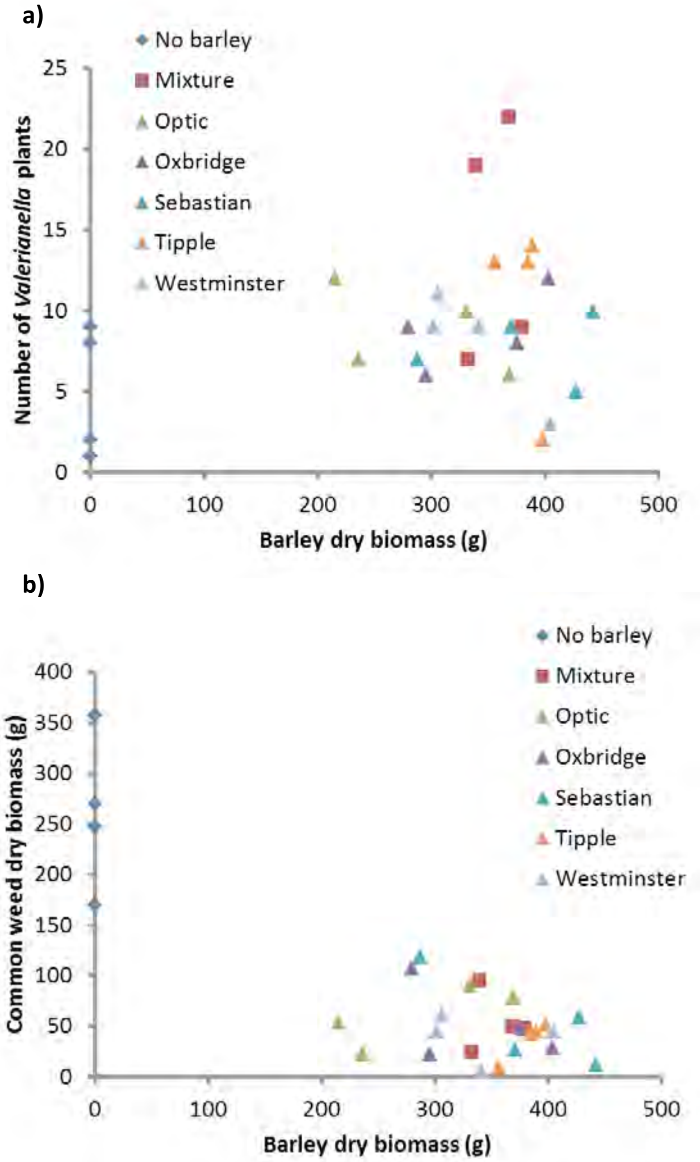


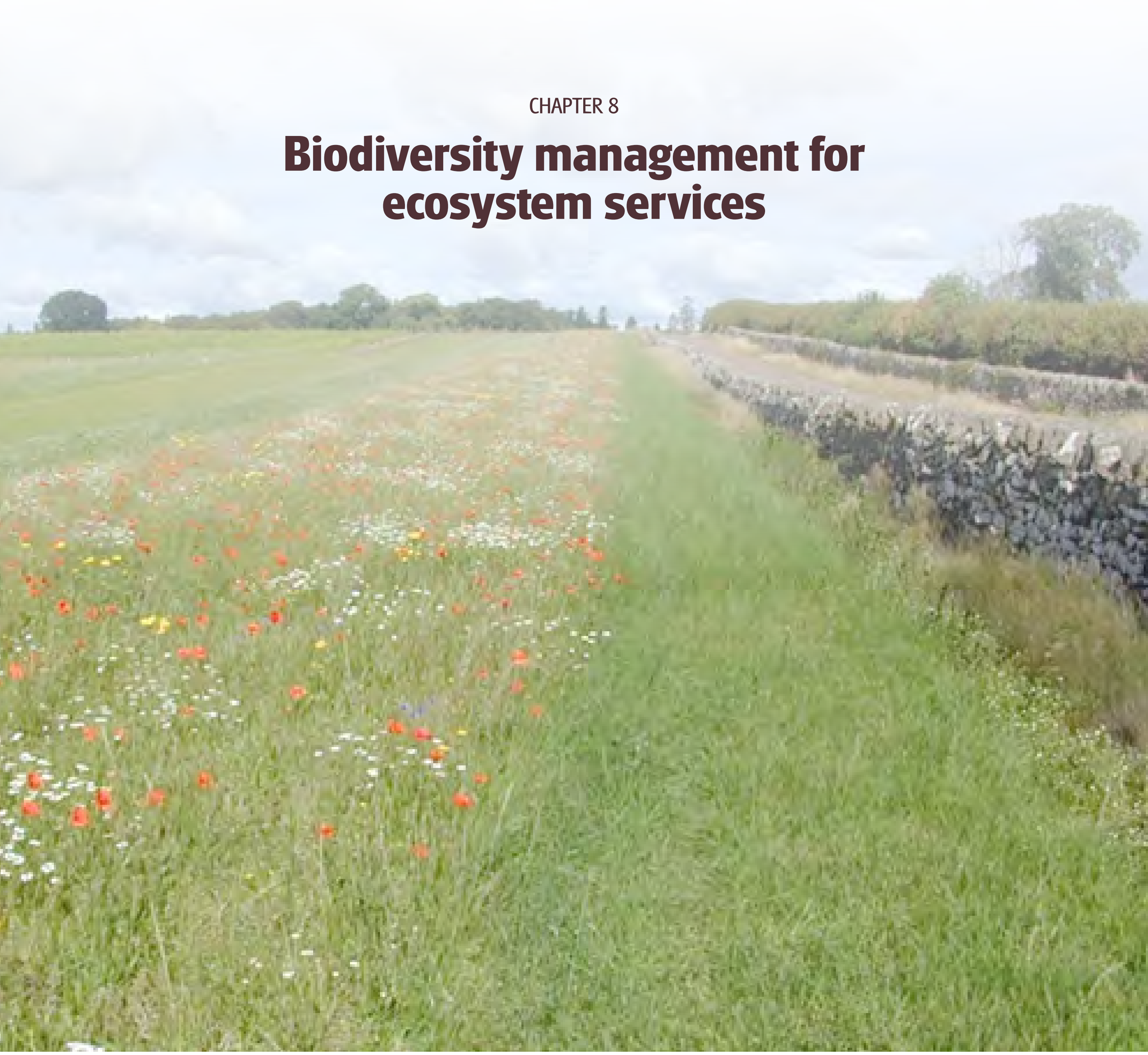

**Fig. 2: a) Early July abundance of *Valerianella* plants and b) harvest time (late July) biomass of common weeds in 0.7 m x 0.7 m plots plotted against the harvested biomass of the barley crop. These data come from barley plots sown at 120 seeds $m^{-2}$.**


Authors: Rob Brooker, Alison Karley, Adrian Newton, Robin Pakeman *(James Hutton Institute)*, Christian Schöb *(University of Zürich)* and Luna Morcillo *(Universitat d'Alacant)*

Contact: Rob Brooker (rob.brooker@hutton.ac.uk)

CHAPTER 8

# Biodiversity management for ecosystem services



## Background

Arable-grass production systems represent approximately 35% of the agricultural area in Scotland and play a critical role in food and energy production. Over recent decades, however, these crop systems have suffered major declines in the abundance and diversity of non-crop plants, invertebrates and higher animals to the point where ecological processes, including arable-grass production itself, may be jeopardized. Plant productivity and resilience to biotic and abiotic stresses can respond positively to increased diversity, and increased diversity can also promote essential ecosystem services such as pollination and pest biocontrol. **The aim of this research was to investigate whether enhancing the biodiversity in agricultural systems can promote system function and associated ecosystem services, increasing the sustainability of agricultural production.**

## Approach

This research investigated the impact of management on biodiversity and ecosystem services at plot, field and farm scales. We have characterised genetic and functional biodiversity in model non-crop species and conducted small-scale experiments to measure the response of biodiversity and ecosystem functions to changes in management and abiotic stress. This has been complemented by field-scale observations using the James Hutton Institute's Centre for Sustainable Cropping at Balruddery Farm and farm-scale observations using a network of commercial farms to test effects of management on biodiversity, productivity and other functions such as pest biocontrol.

**Fig. 1: Phenotypic differences in leaf shape in Shepherd's purse is linked to genetic and functional variation.**

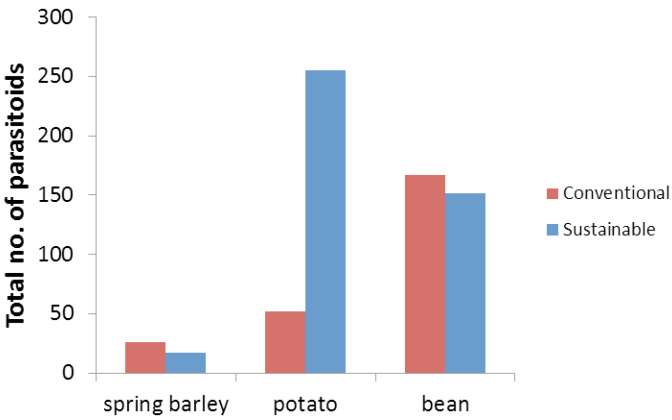



**Fig. 2: Parasitoid abundance varies between crop type and management treatment.**

## Results

- The common UK arable weed *Capsella bursa-pastoris* (Shepherd's purse) shows significant within-species variation (Fig. 1) linked to differences in functional traits (flowering time, seed size and dormancy and soil seedbank persistence) that allow survival in highly-disturbed arable fields.
- The abundance and diversity of arable weeds and associated invertebrates can respond positively to sustainable management (i.e. with reduced tillage and chemical inputs). There is potential for enhanced biocontrol of invertebrate crop pests, for example via parasitoids, although the effects varied with crop type (Fig. 2), soil and insect microbial diversity and abiotic stress. The proportion of generalist predatory carabid beetles was highest in wider field margins (>5 m) and those with woody vegetation.
- Overall, farming approach appeared to exert a selection pressure on the species composition of the arable weed seedbank, but these effects were scale-dependent. Farms that integrated sustainable and conventional practices tended to have a greater range of crop types and cropping practices and supported increased numbers of weed species compared to either conventional or organic farms.

## Conclusion

Increasing the diversity of cropping practices may offer a complementary approach to reducing agrochemical inputs for enhancing arable biodiversity across landscapes. Management to enhance the biodiversity of agricultural systems and associated ecosystem services requires an understanding of the different aspects of biodiversity (genetic, species, functional) and the impacts on ecological functions and services at multiple scales (field, farm, landscape).

Authors: Alison Karley, Cathy Hawes, Pete Iannetta, Graham Begg and Jenni Stockan *(James Hutton Institute)*

Contact: Alison Karley (alison.karley@hutton.ac.uk)

CHAPTER 9

# Integrated management practices for sustainable arable production systems

## Background

The human population is predicted to rise to 9 billion by 2050, requiring a 60% increase in global food production. Intensification of arable production has resulted in increases in yield, but only at heavy environmental cost. These trends have raised serious concerns about the long-term impacts of intensification on the sustainability of food production systems. **The aim of this research is to determine how to manage the cropping environment sustainably to maintain crop productivity whilst supporting ecosystem processes in the long-term.**

## Approach

Achieving sustainable agricultural production requires an understanding of system processes and how they interact with wider system functions over time. At the James Hutton Institute's Centre for Sustainable Cropping (CSC) at Balruddery Farm (Dundee, UK), we have developed a long-term, whole-systems approach for designing, implementing and testing an integrated cropping system, to enhance biodiversity and system functioning, whilst maintaining crop yield and reducing environmental footprint.

## Results

The CSC platform is a long-term experimental site and data will be made available on all the key measured indicators of arable ecosystems (Fig. 1) at the end of each rotation. However, there are already a number of emerging trends following introduction of the integrated cropping system:

- No effect, and sometimes a positive effect, of the integrated cropping system on yield of oilseed rape, barley, beans and potato (Fig. 2).
- A negative effect on productivity of winter sown cereals.
- Increased soil carbon and better soil physical structure resulting in reduced surface run-off and soil erosion.

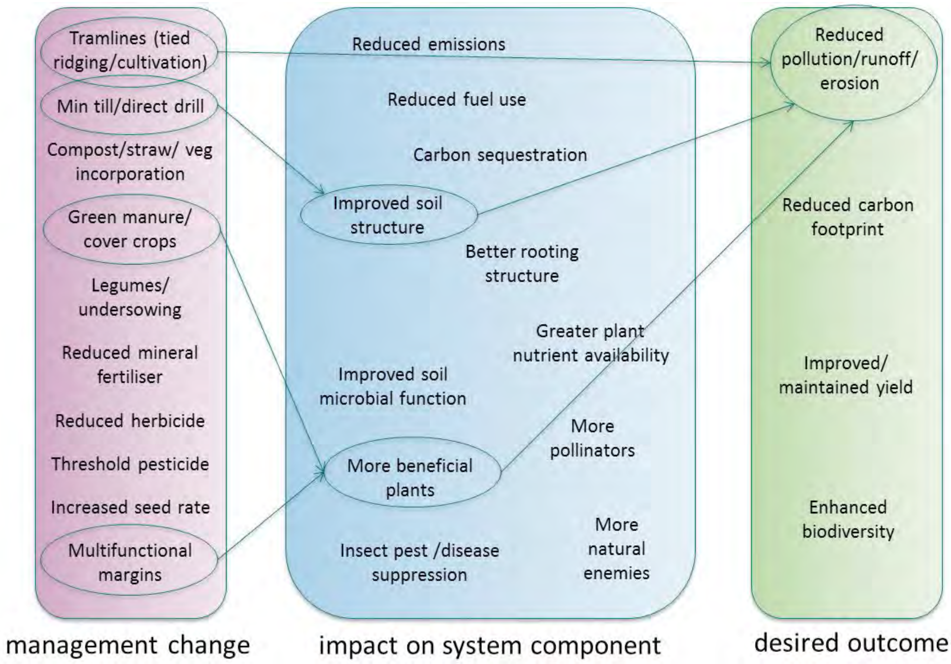



**Fig. 1: A systems approach for assessing the impact of sustainable management (purple box) on desired outcomes (green box), via impact on system components (blue box).**

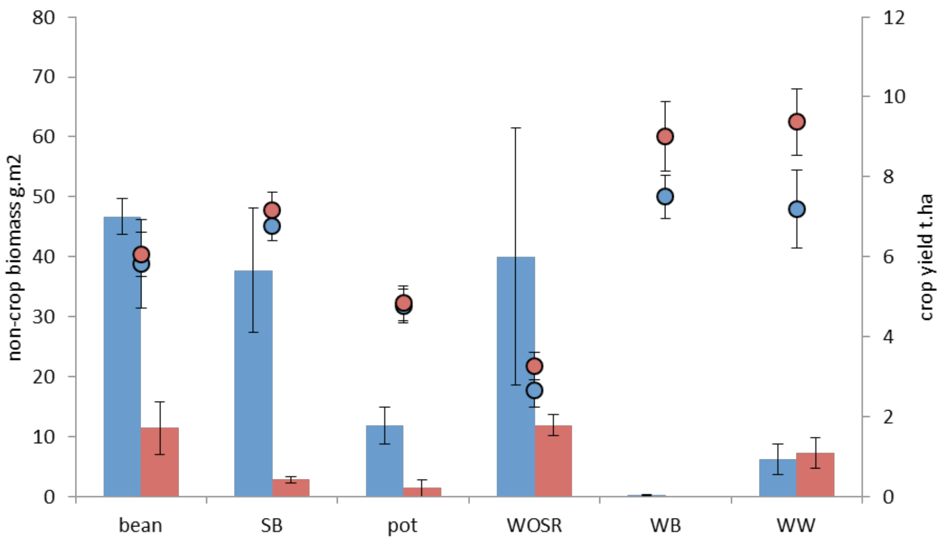



**Fig. 2: Effect of integrated (blue) and conventional (red) cropping systems on yield (circles) and dicotyledonous weed mass in July (bars) in fields of bean, spring barley (SB), potato (pot), winter oilseed rape (WOSR), winter barley (WB) and winter wheat (WW). Data are averages over five growing seasons.**

- Faster crop development in winter crops, due to improved soil conditions, better drainage and warmer temperatures.
- Increased weed biodiversity, providing more resources for insects and a more diverse arable foodweb, though non-inversion tillage also increases competitive grass weeds.
- Improved soil conditions and biodiversity resulting in enhanced system processes, e.g. carbon and nutrient turnover, measured as rate of litter decomposition.

## Conclusion

Some effects of integrated management on biodiversity and the cropped environment can be detected within a relatively short time period, but research over several seasons or rotations is needed for a realistic evaluation of success in achieving more sustainable production in the long term. Moreover, the assessment of impact must be based on the whole system to account for trade-offs between interacting components. In the long term, we predict an improvement in system function and resilience as internal regulation compensates for reductions in external inputs, optimising both food production and system health.

Author: Cathy Hawes, Graham Begg, Pete Iannetta, Alison Karley, Geoff Squire and Mark Young *(James Hutton Institute)*

Contact: Cathy Hawes (cathy.hawes@hutton.ac.uk)

CHAPTER 10

# Landscape engineering for durable pest control

## Background

Intensive agriculture relies on the widespread deployment of a few crops designed for optimal performance under a narrow range of conditions. Together with the loss of non-cropped habitats such as woodlands, wetlands and hedgerows, this has resulted in a reduction in the diversity and complexity of farm habitats. The control of pests, weeds, and diseases has been a traditional reason for the use of diverse cropping systems and its loss is likely to increase pest pressure and promote an over-reliance on pesticides. **The aim of this research was to assess whether more diverse cropping practices and deployment of non-crop habitats within the landscape offers the potential to rebalance agricultural food webs, disrupt pest life-cycles and conserve their natural enemies.**

## Approach

Landscape scale observations were combined with surveys of the natural enemies of crop pests to test the relationships with properties of focal fields and attributes of the surrounding landscape (Fig. 1). A modelling system for simulating interactions between a wide range of pests, crops and landscapes (AgBioscape) has been developed to examine the response of crop pests and their key natural enemies to landscape features including cropping patterns, the distribution of semi-natural habitats, and the use of field margins and other ecological focus areas supported by Scotland's Agri-environment - Climate Scheme.

## Results

- Generalist predators such as spiders responded to the composition of Scotland's arable-grass landscape (Fig. 2).
- Within fields, ground beetle, rove beetle and spider populations all benefitted from complex surrounding landscapes, in particular the proportion of broadleaved woodland and heath.

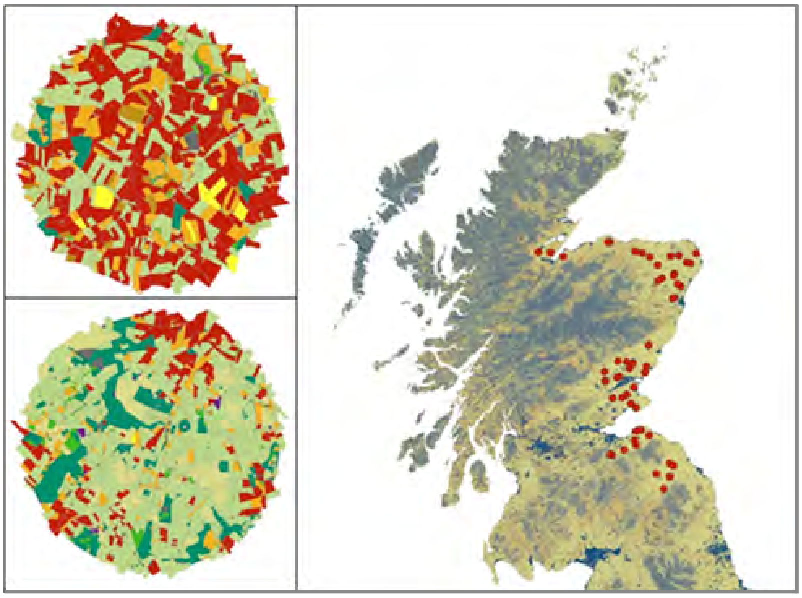


**Fig. 1: The location of study sites (right-hand panel) and two example field sites (left-hand panel) showing the distribution of crop and other land uses within a five kilometre radius of the central field.**

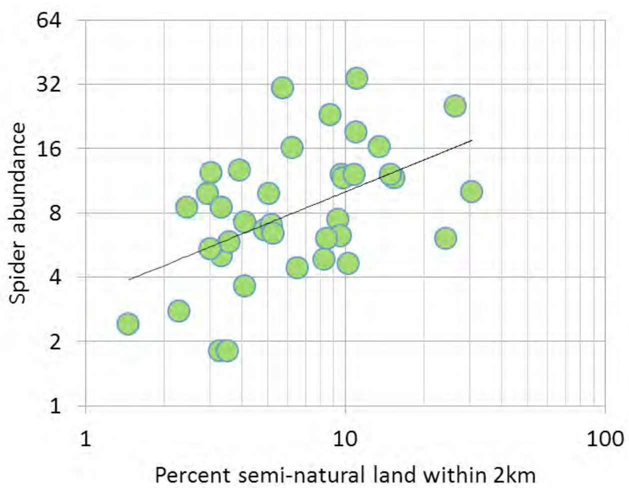



**Fig. 2: Impact of surrounding landscape features on spider abundance in arable fields.**

- Landscape cropping patterns also had a significant effect on predator populations: carabids were more abundant where winter oilseed rape predominated.
- AgBioscape model predictions indicated that adopting a control strategy across a landscape, using crop rotations combined with chemical control when threshold pest densities are exceeded, will successfully control insect pests, including rotation-resistant strains.
- AgBioscape modelling predicted that the introduction of beneficial habitats alone, while supporting parasitoid populations, does not provide effective pest control. However, higher levels of aphid parasitism occurred when parasitoid survival was increased, suggesting that supplementing crops with food resources (e.g. flowering intercrops) could promote biocontrol.

## Conclusion

These results establish that crop pests and their natural enemies are generally sensitive to their environment at multiple spatial scales. We infer that the majority of pests should be amenable to regulation by landscape engineering strategies. Cropped habitats and their management provide a flexible and effective route to achieving this and should be considered alongside prevailing semi-natural habitat amendment strategies such as conservation biocontrol.


Authors: Graham Begg, Nick Birch, Nora Quesada Pizarro and Richard Dye *(James Hutton Institute)*

Contact: Graham Begg (graham.begg@hutton.ac.uk)



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This synthesis focusses on a subset of the work on Biodiversity and Agricultural Sustainability and involved researchers from:

- The James Hutton Institute
- Scotland's Rural College

This booklet, and others in the same series, including Ecosystem Services, Grassland Biodiversity, Biodiversity and Upland Management, Woodland Biodiversity and Ecosystems, Peatlands and Soils: Environment, Health and Society are available online at www.hutton.ac.uk.

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