The Balruddery Sustainability Research Platform

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Summary

As part of CCT3, we propose to establish a research platform at Balruddery Farm for long-term studies on arable sustainability. The overall goal is to test whether or not potential solutions for sustainable agriculture arising from the current RERAD workpackages, actually result in improved arable biodiversity, resilience, crop productivity and yield stability at a commercial, field-scale over at least four rotation cycles (>20 years). To do this, we will design a sustainable cropping system based on existing research at SCRI that optimises inputs, yield, biodiversity and ecosystem processes. The effect of this 'sustainable' system on long-term trends in yield and system health will be tested by comparison with current commercial practice. The Sustainability Research Platform will provide a test-bed for new 'sustainable' crop varieties developed at SCRI. The performance of these new varieties, with traits for enhanced nutrient and water use efficiency, weed suppression, and pest and disease resistance, will be assessed under low input, sustainable management at a field-scale.

A contiguous block of five fields, covering 35ha, have been set aside for the experimental platform. These fields will be divided into twelve 2-3ha blocks, providing six replicates of the conventional and sustainable treatments over a five year rotation. The rotation will include potatoes, winter wheat, two years of spring barley and beans, and will be divided into two phases; one offset to the other by two years to provide some crop diversity across the area in any one year. The conventional treatment will reflect current commercial practice. The sustainable treatment will include reduced herbicide and pesticide inputs, inorganic fertiliser replaced by legumes, undersowing and green manures, and reduced tillage where appropriate. Both conventional and sustainable treatments will be flexible enough to track changes in commercial management practices and developments in sustainable technologies over time.

The general hypotheses are that 'sustainable' management, in combination with new crop varieties, will (i) maintain yield quality and yield stability at lower levels of agrochemical inputs, (ii) reduce GHG emissions and nutrient leaching from the system, and (iii) enhance soil quality and arable biodiversity. To test this we will measure the responses of the whole system to sustainable management over a range of different crop varieties throughout each growing season over the course of at least four rotation cycles. Measurements will be grouped into six research areas: carbon and nutrient dynamics, soil biophysics, community dynamics, pest and pathogen populations, crop yield and quality, and field margin biodiversity. Trade-offs between these components of the system will be assessed through empirical and mathematical modelling.

The platform will provide a resource for continued collaboration with SAC and MI scientists and a demonstration site for knowledge transfer, exchange and education activities, including specifically a resource for University undergraduate honours and Masters projects. In addition, links will be developed with existing long-term experimental platforms throughout Europe.

Contents

1. Background and rationale

Arable sustainability is defined here as the ability of a system to maintain stable levels of food production and quality in the long-term without the need for increasing inputs of non-renewable resources. In order to achieve this and maintain yields without escalating requirements for agro-chemical inputs to regulate the system, the within-field arable habitat must be able to support stable populations of a range of organisms that themselves regulate the key system processes (primary production, nutrient cycling, decomposition, predation and pollination). Management for arable sustainability must therefore allow a balance of different functional groups of plants and animals, together with crop varieties that can tolerate some weed, pest and disease pressure.

Existing RERAD-funded work programmes within SCRI focus on developing crops and crop management to enhance the sustainability of food production. Key issues include improved resource use efficiency (water, nutrients and light), durable pest and disease resistance, and management to optimise yield, ecosystem health and biodiversity.

These studies have been necessarily short-term and small-scale, aiming (i) to identify specific crop or system characteristics (e.g. screening collections for novel traits, or conducting surveys to identify indicators of resilient systems) and (ii) to determine mechanisms for specific processes (e.g. for enhance nutrient uptake, resistance to a particular disease or response to weed competition).

As we move towards the end of the existing work packages, there is a need to develop the capacity to test the results and hypotheses arising from this work within the context of the whole system and with a view to the cross cutting themes on biodiversity, climate change and sustainability. We need to test whether or not the crop varieties and management systems studied within the various workpackages, perform as expected in the context of the whole system at the field scale and over the course of a full rotation.

This proposal is to establish a unit within Balruddery Farm for long-term studies on arable sustainability to test whether or not our solutions for sustainable agriculture actually result in improved arable biodiversity, resilience, crop productivity and yield stability at a large (field)-scale over at least four rotation cycles (>20 years).

This unit will also provide a platform for new and innovative research projects outwith the existing RERAD research programmes, and an opportunity for linking to worldwide networks.

2. Aims and hypotheses

The sustainability platform will provide a broad framework for research on a wide range of system components from crop physiological stress responses to arable biodiversity and soil microbial function.

The general aims of the project are as follows:

- To design a sustainable cropping system that, over the course of a 5 year rotation, tests and demonstrates the optimisation of inputs (nutrients, herbicides and pesticides), yield (quality and quantity), biodiversity (soil microbes, plants and arthropods), and ecosystem processes (e.g. photosynthesis, carbon and nutrient transformations and fluxes, decomposition, community dynamics).

- To assess the effect of the sustainable system on long-term trends in yield and system health (biodiversity, weed, pest and pathogen population dynamics, soil water, carbon and nutrient status) relative to standard conventional practice.

- To provide a field-scale test-bed for new 'sustainable' crop varieties developed at SCRI for enhanced nutrient and water use efficiency, weed suppression, and pest and disease resistance.

- To provide a demonstration site for knowledge transfer, exchange and education activities, including specifically a resource for Dundee and St Andrews University undergraduate honours and Masters projects.

Opportunities for hypothesis testing are outlined in Figure 1 where the main components of the system are illustrated. Manipulated variables include crop variety, soil management, weed management and fertiliser inputs. These have a direct effect on the main components of arable systems including soil carbon and nutrients, pest, pathogen and weed populations, soil microbial communities and invertebrates. Changes in these components in turn impact on emergent system properties including crop productivity, GHG emissions, leaching and biodiversity.

It is expected that specific hypotheses and experiments would be generated by SCRI scientists and external collaborators, both within the context of existing RERAD funded research and through EU, RC, Defra and other externally funded research projects. Research areas and example hypotheses are described in section 5.

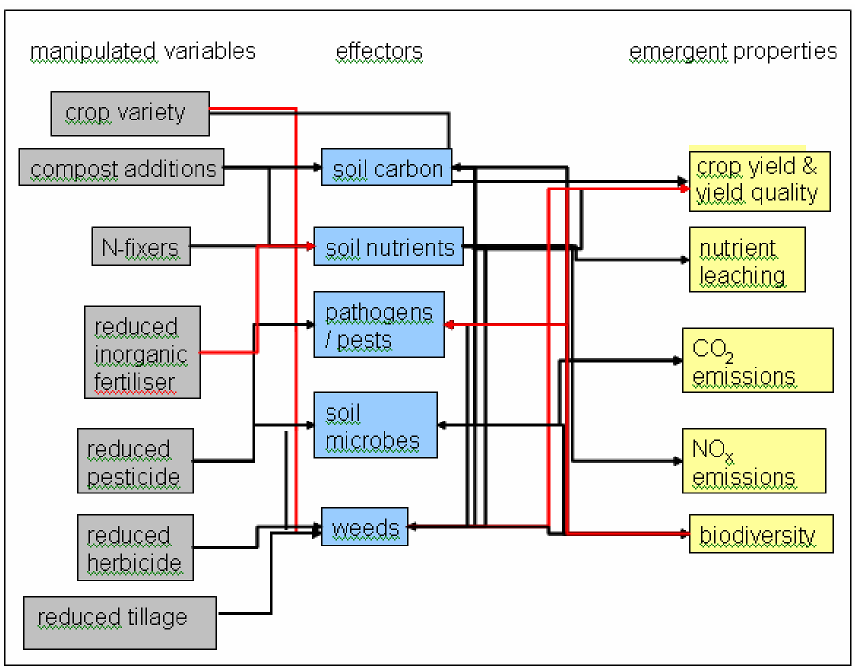


Figure 1. The main components of the arable system with potential, or likely, interactions between them that result in differences between conventionally managed and 'sustainably' managed arable ecosystems. Red lines indicate likely negative influences, black lines are

positive effects. The integrated, whole-system approach proposed here will allow investigation of the trade-offs between these positive and negative influences on emergent system properties, and identification of characteristics necessary to compensate yield under low input systems.

It is expected that specific hypotheses and experiments would be generated by SCRI scientists and external collaborators, both within the context of existing RERAD funded research and through EU, RC, Defra and other externally funded research projects. Research areas and example hypotheses are described in section 5.

3. Site

Balruddery Farm is a 118 ha arable farm located seven miles west of Dundee and between 70 and 160m above sea level on the lower slopes of the Sidlaw Hills. Road access is either via the A90 dual carriageway at Longforgan or through Fowlis village, which provide an access from the south and north respectively. The south entrance has a four tonne weight limited bridge. Both routes involve narrow lanes. There are 17 fields varying in size from 2.0 ha to 11 ha (Appendix 1). All except Ladyfield (2.7 ha) are within Angus, which is in Perthshire. The soil is a sandy loam, similar to Gourdie Farm, slightly shallow in depth on the eastern fringes adjacent to Balruddery Den. The farm is fairly typical of the area, with field boundaries being marked by drystone dykes with wooded den of the Balruddery Burn on the eastern boundary. There are mature tree lines and an old hedgerow along some of the dykes and two smaller watercourses that run west to east across the farm and feed into the West Den of Balruddery. The farm has previously grown oilseed rape, potatoes, barley, wheat and grass.

A contiguous block of approximately 40ha at the farm has been identified for the Sustainability Research Platform, comprising six fields (Den North, Den South, Estate, Kennels and Middle East) of a similar size (6.7 ha to 8.0 ha). Cropping histories for these fields are shown in Table 1.

	Road (1)	Middle East (2)	Den South (3)	Pylon (4)	Kennels (5)	Estate (6)
1998	w.rape	w.wheat	w.wheat	w.rape	w.wheat	w.rape
1999	w.wheat	s.barley	grass	w.wheat	s.barley	w.wheat
2000	s.barley	s.barley	grass	w.wheat	fallow	s.barley
2001	potato	fallow	grass	s.barley	w.rape	s.barley
2002	w.wheat	w.rape	s.barley	fallow	w.wheat	s.barley
2003	fallow	w.wheat	w.rape	w.rape	s.barley	s.barley
2004	w.rape	s.barley	w.wheat	w.wheat	s.barley	fallow
2005	w.wheat	s.barley	s.barley	w.wheat	s.barley	fallow
2006	fallow	s.barley	s.barley	fallow	fallow	w.wheat
2007	w.wheat	fallow	s.barley	w.wheat	w.rape	s.barley
2008	s.barley	peas	peas	s.barley	w.wheat	peas

Table 1. Cropping history for experimental fields

4. Design, treatments and crops

4.1 Design philosophy

Following a series of discussions with SCRI staff, a list was drawn up of all the variables that were considered to be important or necessary for sustainable crop management. This list could be divided into four main areas:

- crop varieties and soil properties for enhanced resource use efficiency;
- management for soil biophysical resilience;
- crop traits and herbicide use for maintaining viable weed populations below economic thresholds;
- durable pest and disease resistance and IPM strategies for reduced pesticide use.

Each one of these points could be expanded to include a wide variety of potential treatments and controls that, for a fully factorial design, would necessitate a much larger area than is available in order to maintain plots of sufficient size to represent commercial field-scale conditions.

There are two approaches that could solve this problem. The first is to select just one or two variables from the above list that we think are likely to be the most important in determining system sustainability. So, for example, we could just look at differences between alternative tillage regimes, pest management strategies, or nutrient inputs. However, this would turn the focus of the experiment to a single factorial tillage/pest/nutrient experiment and away from the original goal which was to test whole system responses to a fundamental change in approach to management. In addition, the design of the experiment should be sufficiently simple that it can be maintained in the long-term without becoming an overwhelming burden on the SCRI farm staff.

To satisfy both of these goals, the treatment structure needs to be a simple comparison of two treatments: conventional and sustainable management. Complementary plot and laboratory scale experiments using standard (multi-)factorial designs can be conducted along side the main experiment to unpack the underlying mechanisms for the observed responses. Note that many of these small-scale experiments are already being conducted as part of the current workpackage contributions to the Sustainability Cross-Cutting Theme.

4.2 Treatments

The conventional treatment is the standard management practice for each crop in terms of cultivation, inorganic fertiliser, herbicide, pesticide and fungicide applications (Appendix 2). The number of applications and their timing will reflect standard commercial practice for the region and will be sufficiently flexible to respond to weed, pest and disease issues as they arise and to track changes in standard practice over time.

The sustainable treatment is based on reduced inputs balanced against alternative management to attempt to compensate for resulting yield loss (Appendix 2).

a) *Pesticides.* Pesticides and fungicides will not be applied as a prophylactic but only as a last resort to prevent pest and disease population build up over time. Integrated pest and disease management strategies will be used to compensate for lower pesticide inputs, including natural biocontrol and the use of resistant crop varieties.

b) *Herbicides.* Herbicide applications will be reduced to allow the development of a weed understorey sufficient to support viable populations of non-target invertebrates (at least 1% of the total crop biomass). Herbicides will be applied only where (i) the total weed population has reached sufficient density to cause (>20%) yield loss, or (ii) to deal with a build-up of particularly competitive weeds such as *Galium aparine* and *Cirsium* spp.
c) *Fertilisers.* No inorganic fertiliser will be applied. To compensate, nutrients will be supplied in alternative forms including nitrogen-fixing by leguminous species (undersown cereals), ploughing in of overwintered green manures before a spring sown crop, and addition of municipal compost where tests indicate a depletion of soil nutrients.
d) *Tillage.* Conventional tillage will be replaced by minimum tillage where appropriate. Potential weed problems associated with min till will be reduced by ploughing once every five years for potato production.

As with the conventional management, the specification of the sustainable treatment will be flexible enough to track new developments in crop varieties, traits and management practices. Modifications of the "sustainable" management will be made as results are gathered, demonstrating either positive or negative impacts of each practice on system sustainability.

The differences between these management approaches will be quantified in terms of the responses of soil, weed, invertebrate, pathogen and crop components of the system as described in section 5.

4.3 Crop types, varieties and rotation

The rotation will comprise six different crops over six years: potato, winter barley, winter OSR, winter wheat, field beans and spring barley. With the exception of field beans, these crops represent the 5 most common crops with the greatest sown hectarage across Scotland (2007 data, Fig 2), and results should therefore be widely relevant and applicable to farming in Scotland. Field beans are included as a nitrogen fixer in the system even though this crop is less commonly sown.

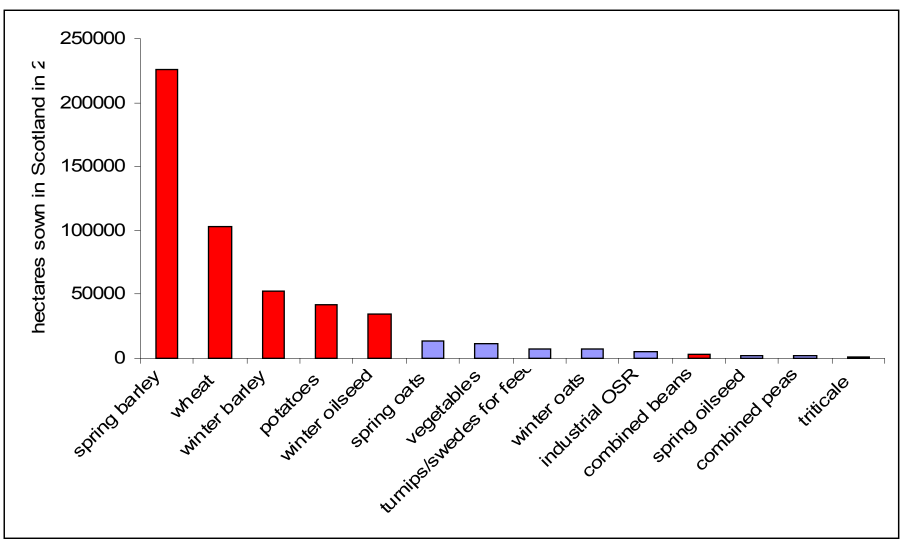


Figure 2. Ranked abundance of crop types grown in Scotland in 2007 (http://www.scotland.gov.uk/Publications/2007/10/agriccensus2007)

To increase nutrient input to the sustainable treatment, cereal crops will be undersown with clover, and spring crops may be preceded by a winter sowing of a green manure.

For each crop, three or four different varieties will be sown across both the sustainable and conventional treatments. One of these will be a standard commercial variety, the remaining two/three will be varieties selected for optimum performance under reduced input conditions (e.g. deep rooting, fast development to canopy closure or enhanced disease resistance). This will allow comparisons of the performance of different crop varieties under the two management regimes.

These varieties will remain unchanged for the duration of the five year rotation, but new varieties may be introduced into each subsequent rotation as new genotypes are developed.

4.4 Experimental design

Each of the six fields will be divided into half as shown in figure 2 and each half will be randomly assigned to either conventional or sustainable treatments. A permanent grass strip will be sown between each block to reduce edge effects and provide a consistent boundary around all treatments.

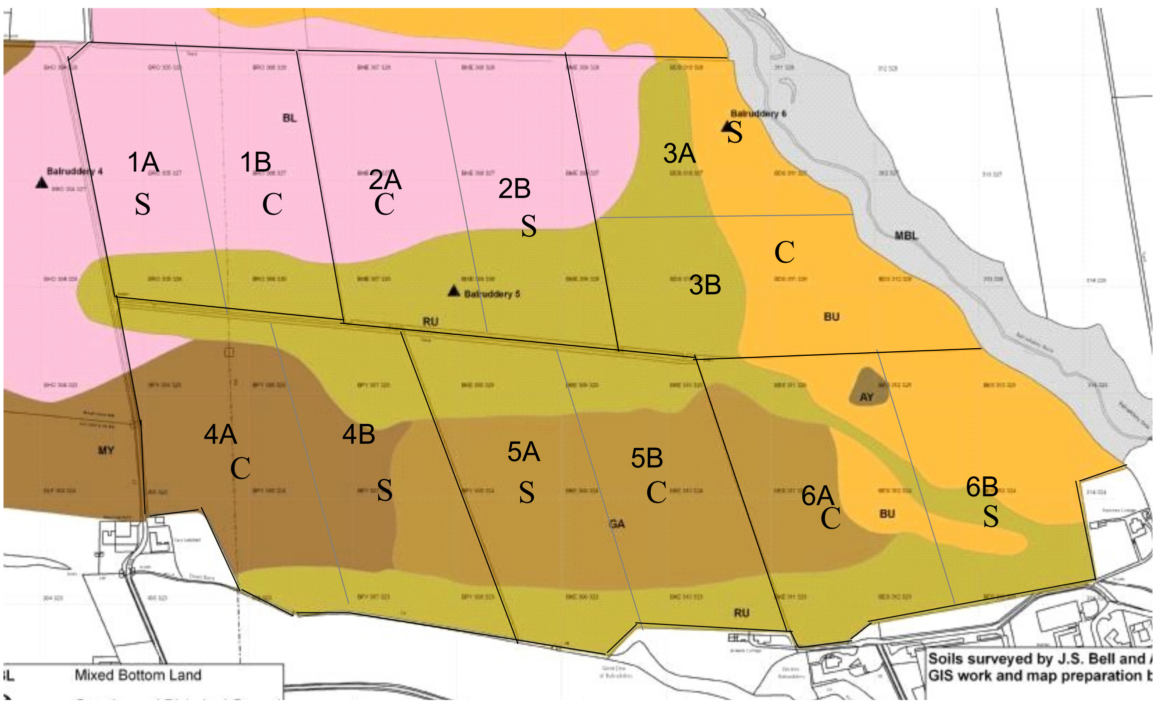


Figure 3. Field layout showing division of each field into two treatment halves (C = conventional; S = sustainable) according to soil type an aspect.

4.5 Statistical analysis

Power analysis based on this design is currently being carried out by BioSS. Details to follow (11 May 2009).

5. Research areas

Assessments of system responses to sustainable management and crop variety can be grouped into five main research areas listed below. This list is intended only as a rough guide and a basic minimum requirement: specific aims, resource requirements and protocols for sampling and analysis will be developed, generated and tested by the scientific staff with the appropriate expertise during the base-line sampling year (2009).

5.1 Carbon and nutrient dynamics

Aims
To quantify trends in carbon and nutrient dynamics under sustainable compared to conventional arable management over three to four iterations of a five year crop rotation.

Hypotheses
Sustainable management will result in increased soil carbon and nutrient retention, and reduced nutrient leaching and GHG emissions.

Methods
Carbon dynamics.

- CO_2 emissions will be measured at set points throughout each growing season using specifically designed cover boxes to allow gases to be sampled from a standard area of crop within each plot.
- Maize will be sown across all fields before the start of the experiment to provide a C4 pulse from which the C3:C4 ratio can be calculated to infer decomposition rates and soil carbon turnover at the beginning, middle and end of each field season.
- Total soil carbon will be estimated at the same time as C3:C4 ratios

Nitrogen and phosphate dynamics.

- NO_x emissions will be assessed at the same time as CO_2 using the same equipment.
- Nitrate and total organic and inorganic phosphate levels in soil water will be monitored periodically using cup lysimeters.
- Total soil N, total P and plant-available P (organic and inorganic fractions) will be measured along with soil carbon.
- Leaching into ground water may be possible by sampling run off into the burn and into the bore hole, but these will not be of a fine enough resolution to distinguish between the two treatments. A plot level setup may be possible using buried drain pipes (advice to be sought)

5.2 Soil biophysics

Aims
To assess the effect of sustainable management practices relative to conventional management on soil biophysical parameters.

Hypotheses

- Reduced tillage and agrochemical inputs under the sustainable management treatment will have a positive effect on soil physical and biological resilience, soil strength, bulk density, water holding capacity and texture.
- These soil biophysical responses to sustainable management will have positive knock-on effects to nutrient and carbon dynamics, plant growth, crop yield and biodiversity.

- Improved soil physical properties under sustainable management will result in reduced soil erosion (to be addressed as part of a new Defra-LINK project with EPI and Dundee University)

Methods

- Bulk soil samples will be collected at the beginning and end of each growing season to assess biological resistance and resilience to copper and heat stress, resistance to ex-situ root growth, water holding capacity, bulk density and texture. These samples will be the same as those used for the carbon and nutrient analyses in 5.1.
- Intact cores will be taken at the same time to assess soil physical resistance to stress.

5.3 Community dynamics

Aims

To determine the changes in function, composition and abundance of soil microbial communities, arable weeds and invertebrate assemblages under sustainable compared to conventional arable management.

Hypotheses

Sustainable management will result in:

- greater abundance and diversity of weeds with enhanced levels of functional redundancy resulting in greater resilience to environmental fluctuation and anthropogenic perturbation
- greater abundance and evenness of species in the soil seedbank with selection for a greater range of functional types under low input systems
- greater abundance, diversity, evenness and functional group representation of the macro-invertebrate fauna, and a shift towards the detritivore-based foodweb.
- increased microbial diversity and reduced fluctuation in soil microbial-based processes including decomposition and de/nitrification rates

Methods

- fluctuations in the taxonomic/functional composition and abundance of arable weeds will be monitored by sampling the soil seedbank every spring and conducting weed counts at three time points during each growing season to coincide with invertebrate, greenhouse gas and soil measurements
- fluctuations in the taxonomic/functional composition and abundance of epigeal and soil surface-active invertebrates will be monitored by pitfall trapping, vortis suction sampling and measurements of predation efficiency within the cropped area and in the field margins at three time points during the growing season
- fluctuations in soil microbial community diversity and function will be measured periodically through the season to coincide with vegetation and invertebrate assessments
- plant, invertebrate and microbial communities will be linked to measurements of system functions including nitrogen dynamics, decomposition rates and predation rates.

5.4 Pest and pathogen dynamics.

Aims

To assess the effect of reduced agrochemical inputs on the fluctuations in population density of insect pests and microbial or fungal pathogens associated with each crop, and to monitor the interaction between these pests, their natural enemies and potential non-crop host plants.

Hypotheses

- Under sustainable (lower input) management, initial fluctuations in pests and pathogens will be greater than under conventional management
- Initial fluctuations in population density will dampen down over time due to increases in natural enemy populations as the low input system stabilises.
- Diversity of cereal crop varieties within a field will reduce the build-up and spread of pathogens and cause an increase in crop yield sufficient to compensate for reduced fungicide application
- Increased diversity of weeds under sustainable management will result in greater populations of natural enemies and therefore reduced pest populations

Methods

- Above- and below- ground pests and pathogens will be monitored across all crops according to the protocol appropriate for each crop type/pest combination
- Invertebrate natural enemy populations will be monitored as part of 5.3.
- Predation efficiency will be quantified using insect bait cards in the cropped areas and field margins to monitor invertebrate predation rate within the sustainable and conventional treatments.
- Soil borne pathogens will be monitored annually using the same soil samples collected for seedbank and soil biophysical resilience

5.5 Primary productivity, crop physiology and yield

Aims

To quantify the effect of sustainable management on crop productivity and yield quality and identify the degree to which savings on agrochemical inputs are offset by yield reduction.

Hypotheses

- reduced inputs in the sustainable treatment cause a reduction in total yield and weed biomass
- lower weed biomass compensates for reduced herbicide application
- plant stress is higher under low input systems and correlates with reduced soil nutrient status, increased pest and pathogen attack and greater levels of weed competition
- low input systems have a negative impact on potato and cereal crop quality, measured as:
    - flavour compounds (umami, amino acid derived, terpene derived and fatty acid products), which may also be affected by soil K:N ratio
    - potato carotenoid content
    - concentration of nutritional components (iron, folate vitamin C, vitamin B6, starch composition and protein content)

Methods

- total vegetation biomass production will be assessed just before harvest for each crop type following standard vegetation sampling protocols, separating crop plant, and dicot and monocot weeds for dry weight apportionment
- bulk isotope analysis will be applied to determine C/H/N/O/S/P/K concentrations in crop and weed vegetation

- crop development (growth stage, height, cover and canopy light interception) and chemistry (e.g. N content) will be monitored at the same time as the weed vegetation surveys
- crop yield will be measured at harvest by the farm staff where this is practical, or on a small scale by science staff where the layout of cultivar strips make this impractical
- crop quality will be assessed by determination of key quality parameters e.g. potato dry matter, wheat and barley protein content
- plant stress will be assessed by direct measurement of antioxidant levels (e.g. ascorbate and glutathione), antioxidant enzymes, markers of oxidation and levels of reactive oxygen species.
- Complementary laboratory studies can also be used along side these measurements to determine the capacity of crops grown under low input or conventional methods to cope with different stresses (e.g. salt, water deficit, temperature and oxidative stress).

5.6 Field margins

Margin vegetation adjacent to the sustainable treatments will be sown with species-rich wildflower mixes to increase diversity in field margins for attracting natural enemies and pollinators. The change in distribution and abundance patterns of these insect groups will be monitored within the margins and into the cropped area across both treatments. These surveys will be related to results from the predation efficiency study in 5.4. (NB conservation headlands could also be introduced here, but we need to check that there is space within each block to do this).

5.7 Modelling

Aims

To identify the key trade-offs and compensatory responses between soil, plant, microbial and invertebrate components of the low input system and to estimate the likely economic implications relative to conventional management practices

The systems model design will be based on the schematic shown in Figure 1. The framework for this model will be developed in alongside the experimental work during 2009 in collaboration with a software engineer (University of Dundee, Applied Computing). Links will also be established here with existing systems modelling work at Macaulay and socio-economic modelling at SAC.

6. Methods and project management

Field sampling of soil, plants and invertebrates for the research areas outlined above will be conducted at a minimum of three permanent sampling locations in each of the 12 blocks at regular intervals throughout each growing season. Sampling will be organised centrally to optimise efficiency of sample collection, recording and storage. An outline field sampling calendar is shown in Appendix 3 which illustrates the co-ordination of sample collection for these different purposes.

Additional measurements of soil pH, soil and air temperature and meteorological data will be taken as covariates for each of the processes discussed.

A management group will be set-up to review progress and developments during the course of each season. This group will meet twice a year in conjunction with a wider science meeting, and will be responsible for making decisions regarding any recommended changes to the management of either the sustainable or conventional treatment or the crop varieties used. In addition to agronomic decisions, members of this group will be responsible for co-ordinating the sampling programme and managing the data processing and analysis across programmes and between collaborators.

The wider science meeting could be run as a workshop series to present results, discuss future developments and gather input and ideas from the international community.

7. KTE and opportunities for further developments

The platform will provide a base for scientific collaboration and a demonstration site for knowledge transfer, exchange and education activities, linking with the existing Living Field Study Centre, the LEAF Innovation Centre and the proposed Potato and Cereal Agronomy Centres at Balruddery Farm.

Schools – the SRP will be included as an extension of the existing Living Field Study Centre facilities based at Mylnefield, to provide a demonstration of the effects of different types of field management and crop varieties on wider biodiversity.

Universities – the experiment will form a resource for University undergraduate and postgraduate research projects providing both a wider historical and spatial context for specific small-scale experiments, and an opportunity for monitoring long-term system and population dynamics. Three SCRI-UoD PhD projects linked with the SRP are currently under review: “Modelling the socio-economics of sustainable agriculture in Scotland”; “Linking erosional processes with seedbank dynamics to inform sustainable cropping”; “How rhizosphere organisms affect parasitoid searching for aboveground crop pests”.

Growers - there is also a unique opportunity to engage with the UK farming community through LEAF (Linking Environment and Farming): LEAF members will be given the opportunity to suggest novel management practices that they consider are likely to enhance environmental sustainability but are perhaps not sufficiently tried and tested for them to risk applying in a commercial situation. These practices can be incorporated into the sustainable treatment and their effects on crop production and the environment can be reported back to the LEAF membership via e-briefs, the LEAF newsletter, SCRI open days and Open Farm Sunday.

Science community – existing collaborations with SAC, MI, Rothamsted and UK universities will be further developed through joint research projects on the site including studies of carbon and nutrient dynamics, soil biophysics, crop resource utilisation efficiency, biodiversity and economic modeling. Finally, this site will form part of a network of similar long-term experimental platforms throughout Europe through the proposed FP7 ANAEE design study, and through other EU funding opportunities including two further Framework 7 collaborative projects on ‘Water Use Efficiency and Drought Tolerance’, and ‘Legumes for the Environment and Farming’ currently in preparation between SCRI, SAC and >10 EU partners.

8. Infrastructure and resources

1. *Central database*. Given the long-term nature of the experiment and the large number of potential partners and collaborators, it is important that the collection, storage and archiving of samples and data are managed centrally. A database will be constructed to contain all field information, the type and timing of each management event, the location and date of

each sample collection, where those samples are stored, and the raw data itself. The database will be linked to a set of standardised sampling protocols which will contain detailed instructions, a standard layout for data collection and a format for sample labelling.

2. *Storage facilities.* Permanent cupboard, cold room and freezer and deep-freeze space will be needed for storage of archived soil, plant and insect samples. Temporary freezer space will also be required for storage of samples prior to processing.

3. *Dirty lab facilities at the farm.* Initial processing of samples would be most efficiently done on site to avoid repeated trips delivering bulky samples back to SCRI. A room setaside as part of the development of the steading buildings, equipped with a bench, sink, dissecting microscope, drying ovens and facilities for snap freezing of samples prior to analysis and archiving, would be useful.

4. *Vehicle.* It is anticipated that at least two people will require access to the farm on a weekly basis to take measurements and collect samples between March and September every year. It is recommended that a fieldwork vehicle is leased for the whole of this period.

5. *Farm machinery.* The grain drill and combine currently used for the commercially grown cereals at SCRI is in need of replacement and is already on a list for required capital equipment. SCRI does not own equipment for planting or harvesting legumes or potatoes at a field scale and these operations will therefore need to be contracted out. The field beans grown at Balruddery are already being managed by a contractor who may be willing to be sufficiently flexible to work around the requirements for this experiment. Potential contractors for the potato planting and harvesting (e.g. Taypack, Greenvale or a local LEAF farmer) will be approached early 2009.

9. Planning timetable - notes

Year -1 (2008)

- Finalise proposal and experimental design; establish management group

Year 0 (2009)

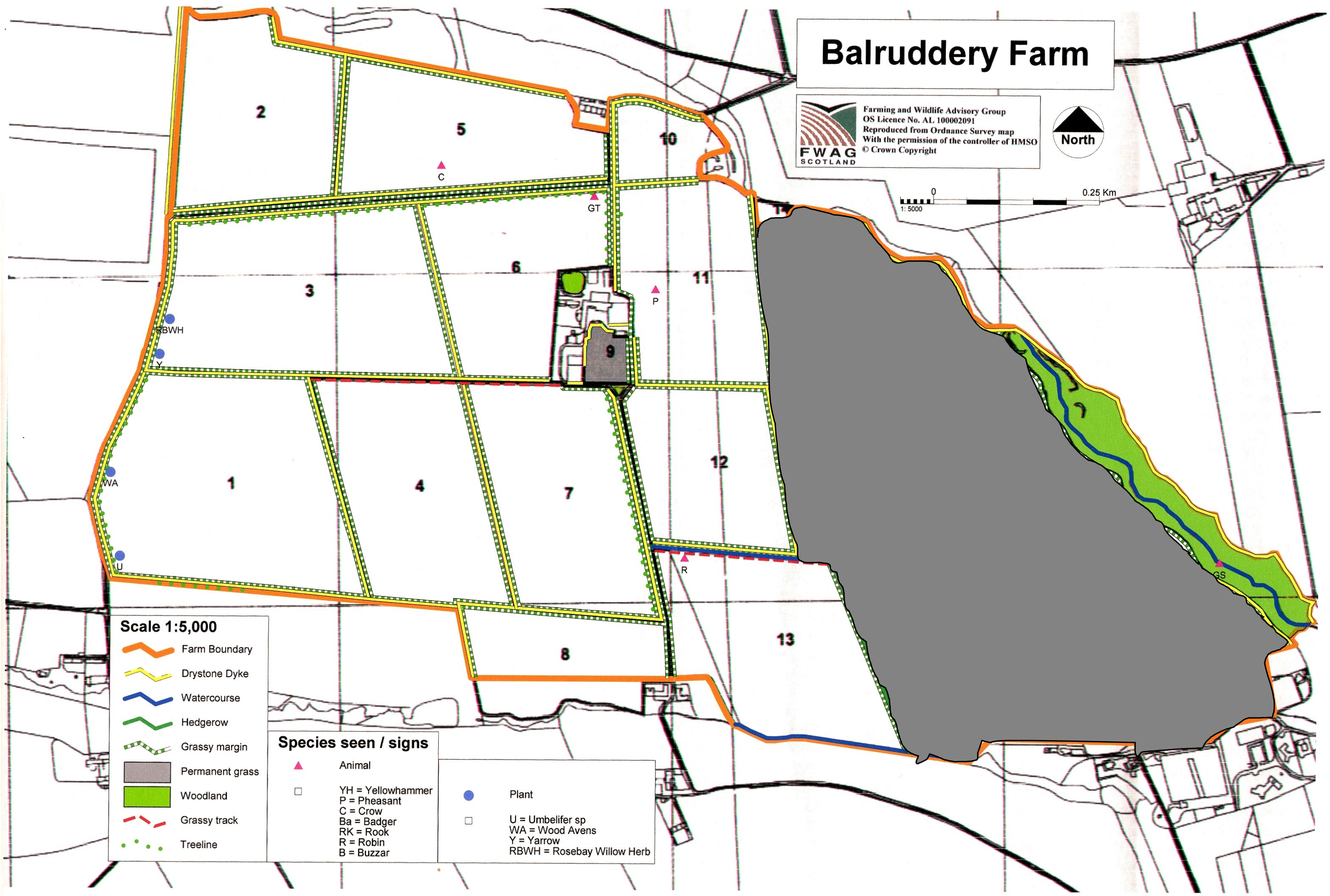
- Receive results of soil survey (Jan)
- Confirm field allocations (Feb)
- Install met station (Feb)
- Mark out blocks and permanent sample locations (March)
- Collect soil samples for chemistry, biophysical measurements and seedbank assessments (March)
- Confirm that maize will provide a sufficient C4 input (March)
- Sow all 5 fields to maize (April)
- GIS mapping/Digital Elevation model – to overlay yield map, nutrients etc (May-July)
- Installation and testing of essential instruments including gas chambers and lysimeters (May-July)
- Install and collect pitfall traps (May-June and Aug-Sept)
- Test field sampling protocols (May-Sept)
- Collect crop leaf samples for plant nutrient analysis (May-Aug)
- Plough in crop (Aug?)

- Sow winter wheat (Sept)
- Confirm field sampling, lab analysis and data/sample archiving protocols for 1st experimental year 2010

Year 1 (2010)

- Sow spring crops
- Carry out field sampling protocols
- 1st Annual review meeting – science meeting followed by management group meeting
- Distinguished Lecture in Plant Sciences – someone with experience in long-term experiments
- Launch in conjunction with LEAF open farm Sunday/PiP/CiP

Appendix 1. Balruddery field map



Appendix 2. Proposed crop management
[to be completed 2008/09]

Crop	Management operation	Conventional	Sustainable
Winter wheat	Pre-em herbicide		
	Post-em herbicide 1		
	Post-em herbicide 2		
	Dessicant		
	Fungicide 1		
	Fungicide 2		
	Insecticide 1		
	Insecticide 2		
	Molluscide		
	Fertiliser 1		
	Fertiliser 2		
	Fertiliser 3		
	Plough		
	Drill		
	Sow		
	Harvest		
Spring barley	Pre-em herbicide		
	Post-em herbicide 1		
	Post-em herbicide 2		
	Dessicant		
	Fungicide 1		
	Fungicide 2		
	Insecticide 1		
	Insecticide 2		
	Molluscide		
	Fertiliser 1		
	Fertiliser 2		
	Fertiliser 3		
	Plough		
	Drill		
	Sow		
	Harvest		
Potatoes	Pre-em herbicide		
	Post-em herbicide 1		
	Post-em herbicide 2		
	Dessicant		
	Fungicide 1		
	Fungicide 2		
	Insecticide 1		
	Insecticide 2		
	Molluscide		
	Fertiliser 1		
	Fertiliser 2		
	Fertiliser 3		
	Plough		
	Drill		
	Sow		
	Harvest		
Field Beans	Pre-em herbicide		
	Post-em herbicide 1		
	Post-em herbicide 2		
	Dessicant		
	Fungicide 1		
	Fungicide 2		
	Insecticide 1		
	Insecticide 2		
	Molluscide		
	Fertiliser 1		
	Fertiliser 2		
	Fertiliser 3		
	Plough		
	Drill		
	Sow		
	Harvest		

Appendix 3. Proposed field sampling calendar [to be completed 2008/09]

	F	F	M	M	A	A	M	M	J	J	J	J	A	A	S	S	O	O	N	N
Soil sampling for seedbank, chemistry, pH																				
Soil sampling for biophysical measurements; install/collect litter bags																				
Soil sampling for C/C3:C4, water, nutrients, stable isotopes, microbial diversity, pathogens																				
Soil water & leaching – lysimeters, soil moisture probes, soil temperature																				
GHG emissions (gas chambers on soil and whole plants)																				
Crop development, canopy cover & light interception measures																				
Weed counts + margin vegetation diversity assessments																				
Vortis sampling, crop pest and disease assessment (cropped area) + vortis sampling (margins)																				
Pitfall traps (cropped area and margins)																				
Yield, crop and weed biomass – samples for plant stress, chemistry and yield quality																				

Suggested field sampling calendar broken down into fortnightly intervals.

Where the same colour appears at the same time point, the intention is that this would constitute a single sample put to multiple uses (e.g. the soil collected at the end of March and September would be used for seedbank, chemistry, pH, biophysical measurements, carbon, water and nutrient analysis), or that the range of measurements are conducted at the same location and on the same field visit (e.g. the soil and gas C and N and temperature measurements in blue are all done at the same time).