PROJECT NUMBER 289706

COLLABORATIVE PROJECT

Assessing and Monitoring The Impacts of Genetically Modified Plants on Agro-ecosystems

Deliverable 3.2 Database of agricultural, economic and environmental factors for each of the 5 regions

Start date of the project: 01/12/2011

Duration: 48 months

Organisation name of lead contractor for this deliverable: Geoff Squire, THE JAMES HUTTON INSTITUTE LBG (UK)

<table>
<tr><td colspan="3">Project funded by the European Commission within the Seventh Framework Programme (2007-2013)</td></tr>
<tr><td colspan="3" align="center">Dissemination Level</td></tr>
<tr><td>PU</td><td>Public</td><td>x</td></tr>
<tr><td>PP</td><td>Restricted to other programme participants (including the Commission</td><td></td></tr>
<tr><td>RE</td><td>Restricted to a group specified by the consortium (including the Commission</td><td></td></tr>
<tr><td>CO</td><td>Confidential, only for members of the consortium (including the Commission Services)</td><td></td></tr>
</table>

Task 3.2: Collation and analysis of historical data on crop systems

- Deliverable 3.2: database of agricultural, economic and environmental factors for each of the five regions (M18).

1. Introduction

Aims

The aims of Task 3.2 are to compile data on long term trends in crop production and related factors, concentrating on the last 30 years. These data will define a baseline for current arable cropping and will set the context in which any new technology is tested or applied. More specifically, they will be combined with other information to address questions in the final synthesis of WP3 (T3.6) on -

(1) The type of impact that any innovation would have to exert to result in a change similar in size to the major trends that have occurred in the past 30 years.

(2) The type of impact would push the regional agroecosystems in a direction towards limits of concern for ecosystem health?

By defining existing trends and change, any substantial and potentially damaging long term effects of GM cropping should be distinguishable from minor effects that are unlikely to rise above the general background noise of agriculture.

The historical data on trends and variation collated in Task 3.2 therefore have several purposes. They will be used to derive indicators of ecosystem state and trajectory at regional and country scales (Task 3.4) and will provide the basis of scenarios and modelling when comparing states with and without GM crops (Task 3.3, 3.5, 3.6). The role of Task 3.2 within the wider AMIGA effort in WP3 and elsewhere is described more fully in *Annex 1 Theoretical Framework.*

Case studies

To ensure coverage of all agroclimatic zones considered in AMIGA, case studies were undertaken by partners for appropriate countries and local areas in the Atlantic, Boreal, Continental, Mediterranean and Balkan regions. Each case study summarises the changes in variables such as land use, crops, fertiliser and pesticide and provides links to original data commonly held in government statistical archives.

This report describes the methodology and approach to obtaining the case studies, a summary of the data available with examples of trends, and brief conclusions.

2. Methodology and approach

Types of data

Background information on change in land use, cropping practices and the returns of arable farming are assembled for representative crops and areas in each of the 5 regions – Atlantic, Boreal, Continental, Mediterranean and Balkan. The time period will be at least 30 years, i.e. beginning 1980. The data will consist of a set of priority variables that should be available for all regions, and additional variables that would provide further background and context but which may differ between regions. (The above is amended from Description of Work in the project proposal).

The priority variables will mostly be taken from annual statistics of government departments, agencies, or similar bodies, augmented by knowledge of cropping practices, and will consist of, for example:

- area of land under different types of agriculture and cropping;
- timing and operations of the cropping cycle for the main crops;
- inputs such as pesticides and fertiliser;
- data on pest incidence and targets for pest management;
- weather – solar radiation, temperature, rainfall, etc.;
- typical soils;
- typical cropping sequences (rotations);
- atmospheric deposition of N and other minerals;
- yield change for major crops: with contributions of plant breeding vs agronomy if available;
- economic data relating to crop gross margins, main input costs and output prices of key crops (linked to further data collection in the economics workpackage).

The context of the regions may be further defined in terms of additional variables using the results of surveys and research outputs in topics such as land use, soil variables e.g. carbon content, bulk density and biodiversity, e.g. weed incidence, long term botanical change and any regional protection goals.

Note on scale

There are already several schemes for classifying geographic and spatial information in European agricultural regions, but such information is rarely available at scales appropriate for the needs of WP3.2.

So which scales should WP3.2 aim for? It is necessary to identify the scale at which change has occurred and can be best represented. In scoping studies during the first month, WP3 considered the availability of information at the following scales:

1. European climatic region – e.g. boreal, atlantic, mediterranean.

2. Local region in which crop types, climate and agricultural practices are broadly the same (e.g. arable, or livestock and arable) – there will be several of these in each of scale 1.
3. Group of farms, county or local administrative area constituting a similar agriculture that has evolved in a similar way.
4. Single farm, set of fields or experimental farm
5. Single field or experimental site, GM or otherwise.

In each climatic region (Scale 1 above), there may be several examples of each of scales 2 to 5. A set of examples is given in Table 1.

Table 1. Example of five spatial scales over which information may be collated in W3.2, with examples based around the region of Eastern Scotland.

	location	name	land use / crops
1	European agro-climatic zone	Atlantic	farmland, forestry, moorland
2	Region (e.g. sub-national) or country	Eastern Scotland, UK	arable, horticulture, livestock
3	Farm groupings (500 km^2)	an area named the Carse of Gowrie, E Scotland	winter cereals, root crops, oilseeds
4	JHI experimental farm (200 ha)	arable farm at the east of the Carse of Gowrie	spring barley, winter wheat, potato, raspberry
5	crop trial site (10 ha)	Field X on the JHI experimental Farm	potato

For example, the change from spring to winter cereals that occurred from the 1970s, with the accompanying increase in fertiliser and pesticide use, is one of the largest changes in European agriculture, and may be best shown at about Scale 2 or 3 in Table 1. There may also be evidence of the change from spring to winter cropping at Scale 1 but the geographical differences within this scale are very large. There is too little representative data at the smaller scales 4 and 5 for analysis of time trends and inter-annual dynamics.

While ultimately, data may be collected at several scales in AMIGA, this collation of data in WP3.2 will most likely be targeted at the scale of the region or country - a defined entity of thousands of square kilometres, around Scale 2 in the table.

Sources of data

In general, the data on the types required are not available in any single compilation or database. They are most commonly presented as the results of national or regional agricultural censuses. Also the various types of information in the different regions may not have been collected and averaged over the same spatial and temporal scales. In some regions, the data are not available in electronic databases or files. This is particularly true for information before about 1980 in most countries. There may also be local peculiarities is data from some sources that careful interpretation and local knowledge of practices, conventions and language.

Therefore the aim was for representatives in each region to source and collate information, providing links to the most appropriate data and web sites, and summarise the main changes in crop systems for the variables available.

3. Data available and examples of change

Data available

The set of primary case studies provides the foundation of the database. Additional information and links to sources were also obtained from several other countries, where more comprehensive records were thought necessary for particular regions (e.g. east Europe, continental).

Each case study summarises the changes in variables such as land use, crops, fertiliser and pesticide and provides links to original data held in government statistical archives. An example of a case study is given in Annex 2.

Case studies

All documentation is held on the secure area of the AMIGA web site, organised as follows, with the contributing partner in parenthesis:

1. Italy – national and Emilia Romagna region (UNIBO)
2. France – national (UNIBO)
3. Spain – national (UNIBO)
4. Finland – national (UHEL)
5. Slovakia - national (SAU)
6. Bulgaria – national and regional, north-east (ABI)
7. UK – East Scotland region, but national data available (JHI)

Additional data and links

Information from three other countries was obtained to augment the above case studies. Data from Poland in particular are highly comprehensive and detailed.

8. Poland – national and all regions (JHI)
9. Romania – national (INCDSB)

10. Sweden – national (LSU)
11. Economic data – (UREAD)

Care in interpretation

Presenting and interprating the data requires some caution backed by knowledge of the mechanisms by which the original data were collected.

The primary difficulty, pertinent to all countries and regions, is that data on different variables (e.g. yield, fertiliser, pesticides, weather) were obtained from censuses and sampling schemes at different scales and times. For example, data on the area grown with different crops might be comprehensive, obtained from an annual census of all holdings, whereas data on yield per unit area were obtained from a stratified sub-set of farms and then data on fertiliser fom a different sub-set of farms. Also, for variables that were not collated annually, the year that the sample was taken was sometimes not the same across variables.

Additionally, in some instances, the categories in which data were collated by government agencies changed part way through a run of years. For example, the averaging scale might be changed or types of crop might be combined or split. Reliability and consistency in trends was also brought into question by some partners; for example, the provision of data on crop yield before and after 1989 in some countries of eastern Europe.

In general, however, the data allowed major trends in crop production to be identified and quantified.

Examples of change and trends

The data confirm that major change has occurred in several variables in all regions. Very few agricultural indicators have been conservative, with the possible exception of surface area under arable agriculture. The following are examples of change and trends.

Crop areas

- total cropped area generally stable except some transfer to forest where agriculture collapsed
- various major changes in areas for different crop species – often country specific , e.g. winter wheat replacing spring barley in the north west, increase in maize in the south
- oilseed rape – increase in sown area in many places, notably 16-fold increase in Slovakia, 20-fold in Finland, 23-fold in France.

Yield – output per unit area

- general rise of about 1% a year in yield during the 20th century in many countries

- cereal yield - levelled in most parts of Europe and for main crops (e.g. maize and wheat) in the mid-1990s after previous decades of increase
- wheat and maize, especially eastern Europe – technological improvements in the late 20th century caused yield rise.

Fertiliser input

- general trend of increase up to 1980s and 1990s then variously declining
- phosphorus fertiliser - continuous decline in usage over several decades; large 5- to 6-fold declines in Slovakia and Finland
- nitrogen fertiliser - major rise and then fall from the 1990s especially in grassland.

Demographic

- general decrease in the number and increase in the area of farms or holdings in most regions
- farm size, eastern Europe - large decrease in the average size of holdings after 1989 in eastern Europe, then subsequent increase during the last ten years
- agricultural workforce, - general decline, especially in eastern Europe, e.g. >5-fold decline over 20 years in Slovakia.

Conclusions and next steps

Agriculture has therefore experienced major changes in recent decades in factors would have had substantial impacts on in-field and wider ecological processes. Notable large changes have occurred in fertiliser applied to cropland, in yield per unit area, in the area sown with different crops and the advent of 'new' crops such as oilseed rape. Demographic changes in attributes such as farm size and number of holdings have occurred throughout but particularly in eastern Europe after 1990.

Such changes, commonly four- to five-fold over two or three decades, but sometimes much larger, should be considered the norm, and constitute a background in which any new technology is to be introduced. While some changes originated in new technology (e.g. food and feed quality oilseed rape), in many cases, the primary cause seems to be policy-related or economic, for example in the declines of nitrogen and phosphorus fertiliser. Some local influences may be attributable to weather-events, but in general, the warm years experienced in the last decade have had little impact on the main trends.

Availability of data

The data are now available to all AMIGA partners on the members' area of the AMIGA web site. The original sources in government web site and archives will not remain static, but are updated and augmented at least annually as new census data are incorporated. It is recommended that partners using the data always check the web links provided in case studies to ensure information they are using is up to date.

The case studies and all links will be uploaded to the central AMIGA database and GIS later in 2013. The results are being prepared for conference presentations and refereed papers.

Annex 1. Theoretical framework

1. Background and purpose

The various types of historical data collated in Task 3.2 are examples of indicators of the status of an agricultural system and of how it has changed over time. Task 3.2 has concentrated on regional-scale variables, such as fertiliser inputs and area of crops, because these are the ones for which information is likely to be available over a long run of years.

These regional scale measures are but one class of a set of indicators used in WP3. Other indicators include those measured at the field scale, for example agronomic inputs, crop yield and the populations of weeds and invertebrates, and those measured at the ‘patch’ scale, including microbial function and soil biophysical properties.

This document, based largely on a more general report on indicators in Task 3.4, shows how the regional scale, historical indicators measured in T3.2 will contribute to the later, more comprehensive analysis in Tasks 3.5 (limits of concern) and 3.6 (prediction of impact).

Aims and purpose of indicators within AMIGA

The general purpose of Task 3.4 is to develop a suite of indicators to:

- provide a common framework for characterising arable production systems;
- allow comparison of ecosystem function across different geographical regions or between different farming approaches;
- assess the impact of change, e.g. the introduction of new technologies, crop management practices or land use, on system processes.

More specifically, the suit of indicators is essential to questions addressed by the final task, T3.6 ‘Assessment of the degree of long term change due to introduction of GM cropping, 24 to 48 months’. The following questions to be addressed in T3.6 are adapted from the DOW.

> (1) What sorts of impact would any innovation, such as a GM crop, have to exert in each region or cropping system to cause a change similar to the major trends that have occurred in the past 30 years (e.g. changes due to the move from spring to winter cropping, or change in total nitrogen fertiliser usage)?
>
> (2) What sorts of impact would push the regional agroecosystems in a negative (or positive) direction and more specifically into, or farther into, limits of concern (or conversely, away from such limits)?
>
> (3) How do the possible long term effects of GM cropping compare, in terms of size and direction, with those identified in questions (1) and (2)?

The main thrust of the argument is not therefore on GMOs but on the systems to which they would be introduced. Any substantial and potentially damaging long term effects of GM cropping should thereby be distinguished from minor effects that are unlikely to rise above the general background trends and noise of agriculture.

Sensitivities and limits of concern

In order to be able to answer these questions, and particularly the second, it is necessary to define “limits of concern” or “safe ecological ranges” in which ecological systems and processes can operate in which they are sustainable, that is without suffering long term degradation. The concept of limits of concern is emerging in risk assessment studies and differentiates those effects of (say) a GM crop that simply alters a variable and those effects that move or keep a variable in an ecologically damaged or damaging state. The concept has not yet been widely applied in ERA for GM crops but will be explored in WP3 using limits definable from existing data and expert knowledge. In AMIGA, this work falls in T3.5 ‘Definition of sensitivities and limits of concern, 12 to 36 months’.

The concept is illustrated in Fig. 1. The line shows the progression of an ecological process through time or multivariate space represented by the green trace. This process might be represented by a trajectory in the input of nitrogen fertiliser or the changing state of a biophysical variable in soil, for example.

While the process remains within range A, it can operate indefinitely without harm. If it goes outside range A but remains within range B it still operates, but sub-optimally. Outside B, the process rapidly deteriorates to collapse. The process in the diagram is seen to move outside range A on several occasions and where an * is shown. At this point, work is needed to bring the process back within range A. In the agricultural context work might include, soil cultivation, changing the cropping pattern, introducing a new crop variety or altering the fertiliser regime.

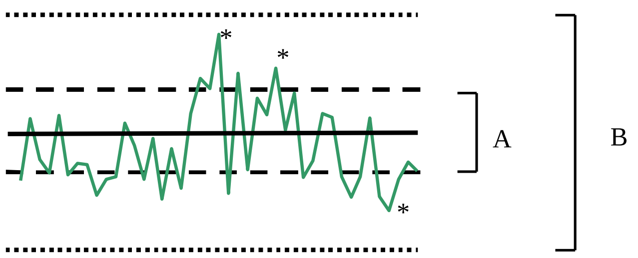


Fig. 1 Diagram to illustrate the concept of safe limits.

Examples

Soil condition can be defined by a range of variables including degree of compaction (maybe expressed as penetration resistance). A system is within range A if root growth and proliferation can operate optimally. Within range B, root penetration still occurs but is sub-optimal. Outside range B, the soil is either too hard to allow roots to penetrate (one limit) or too structureless and uncohesive, such that roots are not held by the soil because it is easily slaked and washed away.

A second example is that of the arable seedbank and weed flora, which has two potentially conflicting properties. First, it competes or otherwise interferes with crops; second, it supports the arable food web. One can envisage a range A, defined by species and abundance, in which the seedbank does not limit the crop and supports an active food web in which all major processes are optimal (comminution, pollination, etc.). Outside A, but within B, one or other of the processes is limited: let's say that below A in Fig. 1, the weeds species and abundance are such that they limit the crop, and above A, that they do not fully support a food web. Outside B, the seedbank is such that it is so weedy that crops are impossible or uneconomic to grow or the food web collapses. In this case there are two variables considered: they could be examined individually, but in this example they are combined.

A third example is given for a regional scale variable – nitrogen fertiliser. When supplies or stocks are low, they limit the growth and yield of crops. However, if applied in too high a dose, there is no further benefit to yield but the excess nitrogen pollutes waterways and contributes to greenhouse gas production (move to range B). If nitrogen is applied for a long time at a very high rate it would cause ecological collapse (movement outside B). Because information on the application rate is needed for long time periods, data are available from only very few individual farms. The main source of information for application of nitrogen fertiliser over long periods, for example of several decades, is the department responsible for compiling agricultural statistics in a national or regional government. This is one of the reasons why information from historical data collated at the regional scale is so useful.

Now, the difficulty with applying the approach in Fig. 1 is that of quantifying as precisely as possible the limits of A and B. Some such quantification will be attempted as part of AMIGA for some central processes such as seedbank and food web, soil condition and nutrient (fertiliser) balance. Moreover, the limits set for one production ecosystem may not be the same as those for another. Therefore in most instances, the quantification of A and B may have to be done though expert knowledge and opinion, supported by data being collated in other workpackages (e.g. 4, 7). The contribution of conditions and imperatives arising from economics and policy will be considered, working closely with WP10.

Defining required outputs or services provided by the ecosystem

The ecological variables and processes chosen for the analysis and the limits of the ranges A and B both need to be set in relation to what outputs are required of the ecosystem under consideration. These outputs are sometimes nested under the economic, social and environmental 'pillars of sustainability' but could as readily be nested under the four categories of 'ecosystem services' – supporting provisioning, regulating and cultural. It is likely that the latter will be chosen, since 'ecosystem services' are becoming increasingly the language of policy in this topic area.

The first thing to do therefore is to define - for each system into which GMOs might be introduced – the outputs or services that the system would need to sustain. This exercise is to a degree subjective and the result will differ between the various regions and ecosystems. But the main categories will be something like those indicative ones below.

Supporting

- soil condition – physical, chemical, biological
- food webs – plant, invertebrates, microbes
- energy and matter cycling – solar, fossil, carbon, nitrogen, phosphorus

Provisioning

- agricultural – the balance among crops, livestock, forestry
- agronomic and economic
- markets, food security, imports, exports

Regulating

- hydrological process – flood prevention, water storage
- pests and disease – prevention and control of invasions, epidemics

Cultural

- landscape and wildlife
- link between production and consumption
- sense of place and belonging

The main aim of this initial scoping report is now to identify the types of indicator that would inform the types of services and outputs in the list above and would help define the status of the system in relation to safe limits (as in Fig. 1).

2. The agroecosystem: indicators for different scales

A set of indicators at different scales

A set of indicators representing an agro-ecosystem is therefore being developed in WP3, mainly in Tasks 3.2, 3.3 and 3.4. These indicators will be selected to represent the key components of the system. They should be relatively easy to monitor and there should be an unambiguous, clearly defined, relation between each indicator and the ecosystem process that it represents. The suite of indicators should be generalised enough to represent any such system, but they can be pruned or augmented to suite a particular purpose.

The agro-ecosystem that we are attempting to characterise is illustrated generically in Fig. 2. The nested boxes represent spatial scale from the smallest scale of interactions between individual organisms at the centre, to the landscape or regional scale at the periphery. At each of these scales, there are a number of key processes or functions that determine the outputs from the system (ecosystem goods and services), and losses from the system that together impact on sustainability and system trade-offs. Ideally, the suite of ecological, environmental and economic indicators should be selected to represent these processes at each spatial scale. Some indicators are listed below, grouped according to spatial scale and process.

Patch scale

At a within-field, patch scale, the ecological interactions involve division and exchange of matter among organisms that determine their growth rates and survival. Services provided by these plants and animals that make up arable foodwebs include biological control of crop pests, pollination of crop and wild plant species and decomposition of organic matter. While such indicators are commonly measured at plot or even smaller micro-scales, they are usually amalgamated to provide an indicator at the field scale. In turn, these organisms are influenced by soil properties, and field and crop management, usually measured at the next spatial scale.

Examples of indicators of system function at the patch-scale

- soil biophysical structure, estimated as penetrometer resistance, soil bulk density, water holding capacity, aeration, root extension
- soil chemical content and pH – carbon, nitrogen, potassium, etc.
- soil microbial composition and function, e.g. nitrifiers, denitrifiers, decomposers
- litter decomposition rates (e.g. measured using litter bags)
- predation rate measured using bait cards
- pollination rate estimated from visitor frequency (see next scale)
- seedbank, weed flora and food web (see next scale)

Field scale

Individual organisms interacting at a patch-scale combine to produce a set of goods and services at the whole field (or forest compartment or hill-slope) scale. These services include soil formation, nutrient cycling, and primary production, the latter being used to provide food, fuel, fibre and other plant products e.g. pharmaceuticals. They also include biodiversity, where this is a tangible output, for example as a cultural service. Losses from the system usually measured at this scale include greenhouse gas emissions, nutrient leaching, soil erosion, pesticide run-off and fuel use. All of these processes are driven or influenced by management decisions that are made the field scale, including how intensively the crop is managed in terms of fertiliser and crop protection chemical inputs, field drainage, and machinery use affecting soil physical structure. In precision farming, a policy might be set at the field scale, but operations – such as the nutrients applied – might vary at the within-field scale.

Example of indicators of system function at the field scale

- carbon pools and fluxes – soil storage, intake by primary production, offtake, return to the soil, losses in water, to air
- nitrogen, phosphorus and potassium budgets – storage, inputs, GHG emissions, loss to water, offtake
- micronutrients (as above)
- plant biomass – development, cover, light interception, dry matter accumulation, conversion efficiency (g/MJ), nutrient use efficiency
- crop yield and quality – mass, constituents (variable depending on crop)
- total agrochemical inputs from sowing to harvest (fertiliser, herbicides and pesticides)
- fossil fuel usage in operations
- weed, pest and disease incidence, control measures and impacts
- estimated carbon footprint, water footprint

- wild plants – mass, abundance and composition (the latter defined by functional type, e.g. grass or broadleaf, or by aggressivity and competitiveness, and value to the food web
- invertebrate trophic groups - abundance of key arthropod groups (Carabids and spiders by pitfall traps, leafhoppers by vortis suction sampling and hoverflies by pan traps, other pollinators by transect walks)

Farm scale

Outputs and losses at the field scale aggregate at the farm level to produce a habitat mosaic of different field types, field boundaries and un-cropped habitats. The extent and type of these units and their spatial arrangement are influenced by management decisions particularly placement of crops across fields (homogenous or heterogeneous), blocking of fields containing similar crops, cropping sequence or rotation and land use (e.g. forestry, game conservation, arable, grass or amenity). Services produced at this scale, in addition to those accumulated additively from the previous scale, include control of flooding and erosion, pest and disease regulation through habitat structure and pollution control (e.g. through buffer zones) and visible or cultural biodiversity. Losses at the farm scale might include yield wastage, pollutants and fuel use, over and above that required for individual field management operations (e.g. transport between fields).

Examples of indicators at the farm scale:

- gross financial margins estimated from all input costs balanced against income from yield
- habitat structure measured as rank-abundance of different habitat types as a proportion of total area, or estimates of connectedness
- biodiversity of a key farm-scale indicator group, e.g. farmland birds, deer, bees and butterflies
- pollution (water, soil, air quality)

Landscape, regional and national scales

The properties of and outputs from a group of farms together produce a landscape or catchment with a particular set of properties relating to landscape connectivity, habitat mosaics, biodiversity, hydrology and pollution rates. Equally, decisions by farmer or landowners at the farm scale are influenced by the local market (processing plant availability, transport links, local demand, etc.) and policy decisions (availability of grants and subsidies, pesticide regulations, etc.) at a landscape, regional (i.e. sub-national) or national scale.

The information on indicators at these higher scales depends much on how regional and national authorities average their agricultural and environmental statistics.

Examples of indicators at the landscape scale and national scales

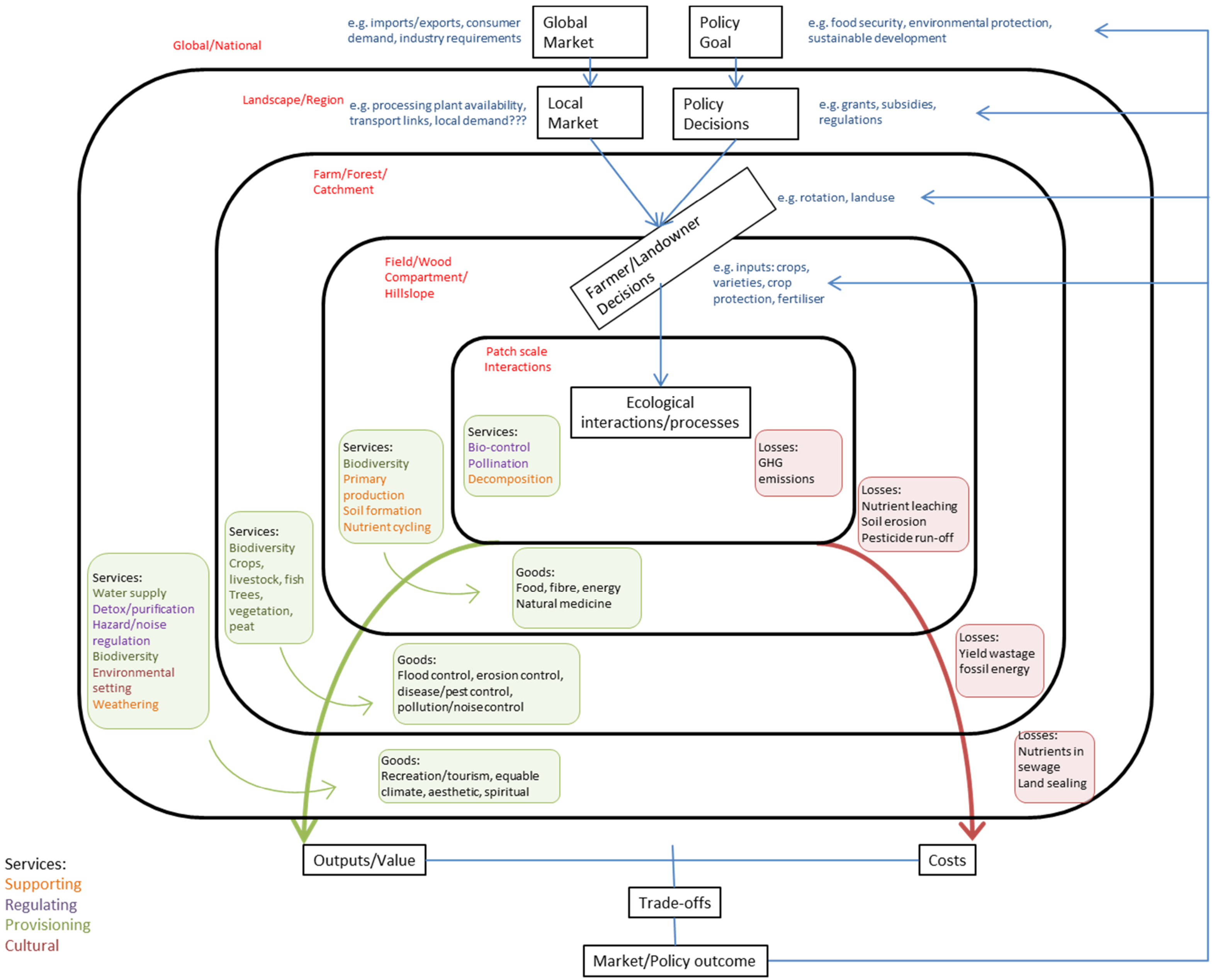
- land use (e.g. proportion of cropped/non-cropped area, proportion winter crops)
- landscape pattern and connectivity
- surveys of land use change (usually infrequently)
- national or sub-national statistics of fertiliser and soil amendments - mainly nitrogen, phosphate, potash, lime
- erosion rates from estimates of soil loss per hectare

- inventories of pollutants and atmospheric deposition
- total pesticide load from national statistics
- propensity of the landscape or country to invasions and epidemics
- imports and exports of the main commodities and energy sources

The above will be augmented by economic data relating to crop gross margins, main input costs and output prices of key crops e.g. from the Farm Accountancy Data Network - http://ec.europa.eu/agriculture/rica/index_en.cfm (linked to further data collection in the economics workpackage).

The establishment of a data set from which indicators can be derived at the regional/national scale is one of the main objectives of Task 3.2.

Fig. 2, next page, draft. Diagram of spatial scales (concentric boxes), ecosystem services, drivers, losses and indicators for characterising a system. (Best viewed at about 150% zoom.)


Global/National
e.g. imports/exports, consumer demand, industry requirements
Global Market
Policy Goal
e.g. food security, environmental protection, sustainable development
Landscape/Region
e.g. processing plant availability, transport links, local demand???
Local Market
Policy Decisions
e.g. grants, subsidies, regulations
Farm/Forest/ Catchment
Farmer/Landowner Decisions
e.g. rotation, landuse
Field/Wood Compartment/ Hillslope
e.g. inputs: crops, varieties, crop protection, fertiliser
Patch scale Interactions
Ecological interactions/processes
Services: Bio-control Pollination Decomposition
Losses: GHG emissions
Services: Biodiversity Primary production Soil formation Nutrient cycling
Losses: Nutrient leaching Soil erosion Pesticide run-off
Services: Biodiversity Crops, livestock, fish Trees, vegetation, peat
Goods: Food, fibre, energy Natural medicine
Services: Water supply Detox/purification Hazard/noise regulation Biodiversity Environmental setting Weathering
Goods: Flood control, erosion control, disease/pest control, pollution/noise control
Losses: Yield wastage fossil energy
Losses: Nutrients in sewage Land sealing
Goods: Recreation/tourism, equable climate, aesthetic, spiritual
Outputs/Value
Costs
Trade-offs
Market/Policy outcome
Services:
Supporting
Regulating
Provisioning
Cultural

3. Application of indicators within AMIGA

The approach to environmental risk assessment proposed in WP3 is system-centred and follows the line or argument – what outputs and services are needed, what are the underlying ecological and economic processes that could provide those services and what interventions are necessary to convert the present state of the system to one where the best balance off services is realised. Interventions in this sense will vary with scale, being, for example new varieties and agronomy at the field scale and agricultural policy at the national scale. A GM crop will then be judged to be compatible or not compatible with those interventions. However, most existing approaches to ERA have been GMO-centred, asking what the GM crop affects and whether the effect is substantive enough to merit adoption, prevention or monitoring.

The analysis in WP3, mainly in Tasks 3.5 and 3.6 (24 to 48 months) will illustrate both these approaches, showing where feasible, how limits of concern or ecological safe ranges, might be defined and used. The GM-centred approach (3.1 below) will be illustrated first mainly by reference to the case study of oilseed rape and GMHT oilseed rape in particular. The aim is to show how potential impacts of GMHT oilseed rape (it was not commercialised in Europe) compare with the impacts of other major agricultural change in the last 30-40 years – hence the need to collate data on and assess long term trends.

The system-centred approach (not presented here) will be first developed based on a case study of agriculture in a particular region and then extended to other AMIGA regions.

Example of an existing GM-centred approach

An example is here summarised – and will be developed further in AMIGA - of the rise of food-quality oilseed rape into European agriculture, and subsequently the proposed introduction of GMHT (food-quality) oilseed rape.

The following summary of the case is developed from that laid out in the EU SIGMEA project.

- Rapeseed (though the exact species is uncertain) has been grown in Europe for centuries, but a genetic difference incorporated into commercial varieties, together with a change in EU policy, lead to a major increase in the arable cover of oilseed rape from the 1970s, mainly in central and northern Europe.
- The increase in oilseed rape, to around 10% of the arable surface in some countries, changed the areas grown with some other crops by a similar amount (e.g. 10% less spring barley), but otherwise had at most, moderate impacts on the regional-scale and national-scale indicators. The winter varieties had similar inputs to the winter cereals (e.g. around 200 kg/ha N), while spring varieties had in some cases had only slightly lower inputs than spring cereals. In those regions where winter wheat and winter OSR became established together, then oilseed rape contributed to the intensification of arable farming in the 1970s to 1990s, but that intensification would have occurred without oilseed rape. These small global effects can be observed or inferred from statistics at the national and regional scales.
- Effects were probably more substantive at the field scale for certain processes such as exchanges in food webs. Being a broadleaf, flowering and seeding crop, oilseed rape provided opportunities for the biodiversity (living things) of the farmed landscape, such that weed

diversity and associated food webs were generally greater in OSR then in comparable cereals. The ecological benefits were observed from measurements at the field scale in studies such as the baseline and follow-on measures in the Farm Scale Evaluations. Modelling showed that the benefits in terms of species number probably increased when cumulated from the average field to all fields in a landscape, i.e. oilseed rape supported more species sub-nationally and probably nationally than cereals.

- Introducing GMHT oilseed rape in, say, 2000-2005, would have little impact of the national indicators because the area sown with oilseed rape, the fertiliser, the yield, the tillage system would change hardly at all or at most moderately (a few percent difference). Possibly there would be small effects on the national pesticide profile and residues, but they would be small since the pesticide profile would still be dominated by that of winter crops, potato and vegetables.
- Introducing GMHT oilseed rape would, however, have negative effects on two aspects of Fig. 2 – first, food webs and biodiversity, and second the need to ensure marketability of crop, in this case without GM impurity.
- Because of the ability to treat with herbicide late in the season, the arable food webs and their functional diversity would be reduced by a factor of 1.5 to 2. Since oilseed rape was the main opportunity in an arable sequence for food webs to function, this negative effects was more important than it would have been if other biodiversity-rich crops had also been present in the sequence
- Because of its long term seed persistence and propensity to spread, GMHT oilseed rape would cause economic problems for farmers or groups of farmers in their attempts to achieve coexistence with non-GM crops.
- The later analysis of how farming might need to respond to GMHT volunteers suggested greater ecological impacts would occur as a result of a change in rotation or orientation of fields. For example, not being able to use glyphosate to control glyphosate-resistant oilseed rape (if this type of GMHT were released)would probably reduce the options for deploying broadleaf break crops in a cropping sequence.
- Therefore on balance, introducing GMHT oilseed rape to northern Europe would bring little general benefit but would have several negative impacts.

The conclusion would probably not be the same if the above analyses and reasoning were applied to another GM crop. For example, current Bt (insect resistant) maize would have little effect on ecological processes, would cause few problems for coexistence and would probably lead to a reduction in the use of pesticide.

Limitations to the GMO-centred approach

The above analysis for oilseed rape lead to firm conclusions but was limited in scope, for the following reasons.

First, the balance of ecosystem services was not considered at the outset. For example, only a limited range of supporting services were examined (plants and food webs), the contribution to provisioning services was not fully taken into account (e.g. possibly higher yield, better economics) while regulating and cultural services were hardly looked at. In the event, as indicated above, effects on yield and agronomic inputs would have been mostly small, but that is incidental to the general argument.

Second, the limits of concern or safe ecological ranges were not set out in advance, largely because they were not known and the processes themselves were poorly understood. In the context of Fig. 1, it was thought that intensification had driven food webs well outside A and very near the limits of B. And the concern was that GMHT oilseed rape would further diminish the food webs (and send them beyond B). Once, however, the scope of the study had been established, the ecological indicators were then well defined in terms of plant and invertebrate species and trophic groups. Power analysis showed that differences of 1.5 to 2 times would be revealed by a stated level of replication. For coexistence, in contrast, one limit for impurity had already been defined (% impurity) and so all measurements and modelling concentrated on this limit.

The conclusions laid out in the SIGMEA project with respect to both ecological process and coexistence were based on a great deal of background knowledge of states and trends in agriculture and on some major coordinated experiments. It can be argued that one of the reasons why the assessment 'worked', and gave clear results and recommendations, was that the GMHT trait was unlikely to have little impact of any of the main supporting services, such as the biogeochemical cycles. It would not affect nitrogen additions, for example, nor would it have a widespread and permanent effect on tillage in wet, northern, heavy soils. So the analysis could concentrate on a relatively simple set of relations starting with effects on the weed flora and impurity in yield.

If GMHT oilseed rape had altered the N and P inputs, say, or caused a major change in tillage, then the analysis would have had to be much more comprehensive, and the impacts on functional biodiversity would have been small in comparison to those on biogeochemical cycles and soil structure.

4. Conclusion

This document, part of a wider report on indicators used in AMIGA and to be produced from Task 3.4, aims to illustrate the reason for compiling data on trends in agricultural statistics for different regions.

The data will be used to in major studies in AMIGA WP3 of GM-centred and system-centred approaches to assessing ecological risk.

In the final year of the project, in Task 3.6, the data will also be used to predict the potential long-term impacts, negative, neutral or positive, of introducing GM crops into agricultural systems.

This document is based on sections of an outline report written May 2013 on a theoretical framework fo use in AMIGA WP 3. Authors: Cathy Hawes and Geoff Squire, JHI.

Annex 2. Example of data collation for a case study

The following shows examples of data ands links to government records and archives obtained for an exemplar case study.

Example region: EAST OF SCOTLAND, UK

1. Summary

Region

East of Scotland UK is defined slightly differently by different data sources but consisting of an area of land typically <50 km inland from the coast along the eastern seaboard of the country (Table 1).

Table 1. Sources showing location maps of eastern part of Scotland. Note that the areas shown do not coincide directly with the Eastern Scotland region used here (see Fig. 1 below).

item	organisation	link
land use regions of Scotland	Pesticide Usage in Scotland (Scottish Government)	http://www.scotland.gov.uk/Publications/2011/10/27115016/5. With reference to the map at this link, the arable-grass areas of eastern Scotland are contained in Aberdeen, Angus, East Fife, Lothian, Tweed Valley and near coastal parts of Moray and Central Lowlands
climate of Eastern Scotland	Meteorological Office, UK	http://www.metoffice.gov.uk/climate/uk/es/

Type of agriculture

Lowland arable-grass consisting of mixed animal and crop farming, including

- Some farms with high intensity winter cereal production
- Some with winter and spring crop production
- Some with spring crop (barley) and grass ley
- Typically half the land in any year is cereal, one third grass (see pie chart, Fig. 2 below)

Products

- Cereal for alcohol and animal feed (some human food e.g. oats)
- Other crops – potato, oilseed rape, fruit
- Meat and some dairy

Main systematic changes in arable-grass cropping (mainly 1970 onwards)

- Move from spring-crop based, low input cropping to winter-crop high input in some parts of the region, with associated increase in fertiliser and pesticide (1960-1990)

- Increase in number of pesticide applications (e.g. one per year to three per year) associated with change to winter cropping; various changes in pesticide type over the period.
- Increase to dominance of some pesticide (e.g. glyphosate for weed control in the 1990s) independently of the above
- Increase of main fertiliser applications by 1.6 to 2 times as a result of change to winter cropping, peaking in the 1980s.
- After the 1980s, around two-fold declines in P and K on grass but much less change on arable (N fairly stable).
- (Note that the above changes are proportionately less than in the UK as a whole due to Eastern Scotland retaining large areas where spring barley is dominant.)
- Increase in yield of the main winter cereals from around 2 t/ha in 1920s to around 8 t/ha in the 1990s due to various improvements, but no further increase thereafter.
- Large number of warm years in 2000-2010 (7 of the warmest years in the last 100)
- Reduction in some air pollutants, especially sulphur (nitrogen deposition is about 5-10% of fertiliser input)
- Evidence from field survey of decline in soil and other ecosystem functions

Year to year variation

The region has moderate interannual dynamics in a range of variables. Examples include (with typical range of variation over several years):

- Area sown with arable crops (5%)
- Balance between spring cereal and winter cereal (10%)
- Yield of spring barley and winter wheat (10%)

Fig. 1 Arable land use areas (grey) in east Scotland extracted from land cover map.

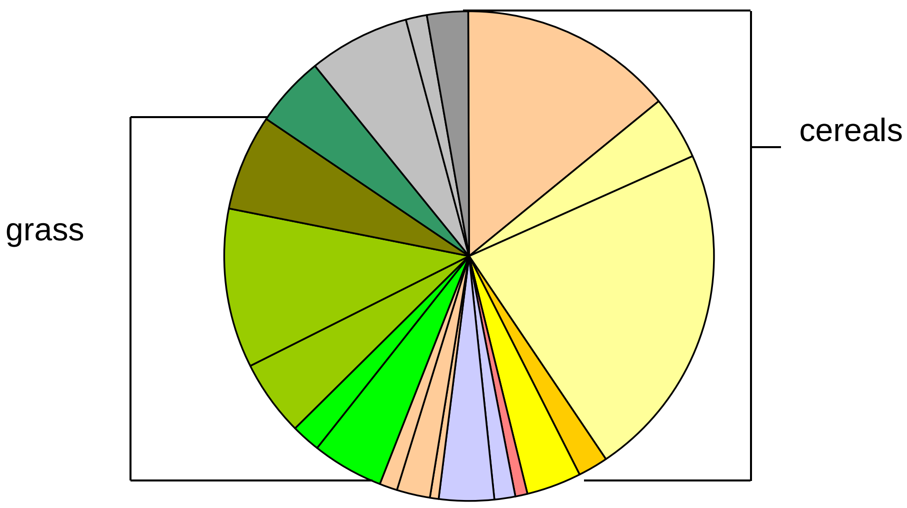


Fig. 2. Proportions of crops in the arable areas of east Scotland in 2005: cereals and grass as indicated, colours show different species or types of pasture; potato, oilseed rape and vegetables occur between them at the bottom; woodland, fallow and built-on land at top left.

2. Land use and crops

Agricultural census data

Data at Scales 2 and possibly 3 should be obtainable from national agricultural census records. The first type of data below is the most important. Other types in the list may be available.

- Areas of crops (e.g. winter wheat, spring barley, potato, winter oilseed rape, grass for grazing, grass for silage, coarse grazing)
- Livestock numbers
- Number of holdings e.g. separate farms
- People employed

Change in area of crops 1982-present

The main source of data is the annual census of agriculture carried out in June each year. Data are available in electronic file form from 1982 onwards (before that in scanned paper form).

Data are available at two scales. The first scale is either for the whole of Scotland or its agricultural regions produced as formal output by government departments and available on the www (e.g. Table 1)

Table 2. Sources for crop areas at national and regional scales.

item	organisation	link
areas of crops and livestock numbers 2001-11	all Scotland government statistics – annual June census	http://www.scotland.gov.uk/Publications/2011/09/27083355/31
regional distribution of arable crops 2010	Pesticide Use Survey, every two years approx	http://www.scotland.gov.uk/Publications/2011/10/27115016/20

Data at the second scale was obtained by a direct application to the government department for information on smaller areas within Eastern Scotland that were known to differ in major crops. These smaller areas (typically 500 km^2) are shown as red ovals on the map of agricultural census areas (parishes) in Fig. 3.

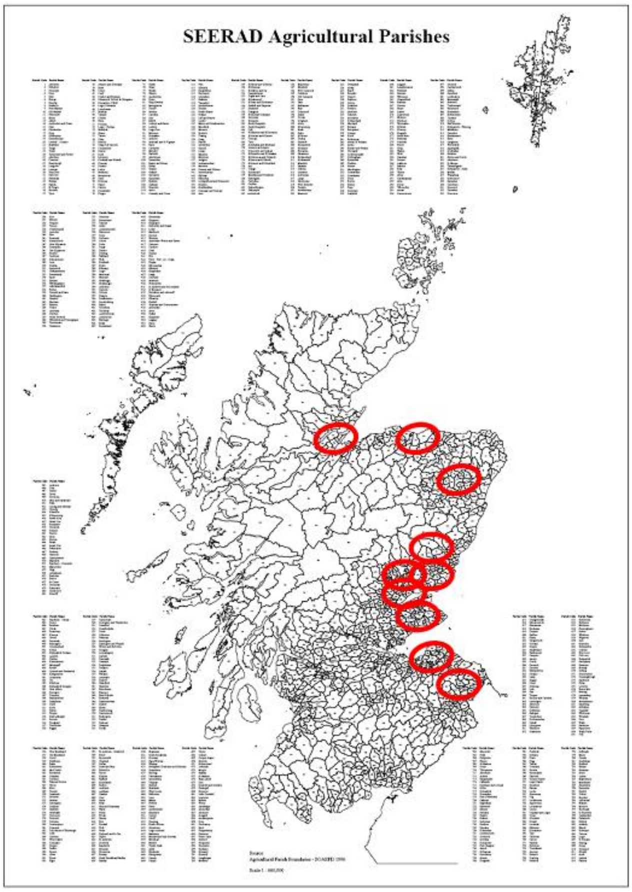


Fig. 3 Map of the agricultural parishes (areas defined within the polygons) on which the annual agricultural census is based. The red ovals indicate locations for which crop-areas were obtained.

Changes on this smaller scale are more instructive. Examples for two areas are given in Table 3. In one, the area of winter barley hardly changed over time; in the other barley decreased as wheat increased.

Table 3. Area of wheat (mainly winter) and spring barley (ha) in two of the localities in Fig. 3 over the period 1982 to 2005.

	locality 1	locality 1	locality 2	locality 2
year	wheat	s. barley	wheat	s.barley
1982	0	2383	781	3272.7
1983	192.1	2220.5	963.9	2953.5
1984	233	2283.9	1475.4	2607.8
1985	467.2	2110.1	1578.6	2018.8
1986	410.5	2286.7	1342.4	2770.9
1987	507.1	1912.7	1763.8	1891.4
1988	521.5	2094.5	1362	2207.3
1989	500	2074.4	1434.7	1974.2
1990	385.8	2021.1	1997.9	1210.1

1991	316.4	2103.5	1959.1	1177.1
1992	364.2	1940.5	2128	1037.1
1993	376.4	1542.7	1915.8	832.5
1994	337.4	1459.8	1931.9	792
1995	355.6	1793.4	1999.2	685.7
1996	355.4	1877.8	2077.6	764.1
1997	344.55	1900.31	2146.47	906.57
1998	324.52	1977.49	2242.54	885.92
1999	214.17	1939.57	1359.54	1723.37
2000	330.66	1705.1	2135.42	970.01
2001	263.55	1547.47	1169.93	1766.82
2002	257.77	1558.15	2056.28	1152.33
2003	287.39	1620.31	1751.69	1325.59
2004	328.93	1568.15	2071.65	1046.63
2005	264.27	1528.15	1882.83	1048.38

Yield of crops and other agricultural output

Yield, in tonnes per hectare, is usually estimated at regional or national scales by government statisticians or growers' groups from the returns of questionnaires to a limited number of farmers. Data may be available for one of the higher scales, such as Scale 2 and for individual farms and fields.

Main changes:

- Yield of the main cereals increased from 1920 to 1990 from 2 t/ha to around 8 t/ha
- After 1995, cereal yield have levelled in the UK as a whole and in East Scotland (both spring barley and winter wheat)
- Cereal yields in eastern Scotland are among the highest in the UK

Table 4. Sources of information for cereal yield.

Item	organisation	link
all Scotland cereal yield	government statistics, crop levy boards, agronomy groups – 1992 - 2011	http://www.scotland.gov.uk/Publications/2011/12/21141519/6

Fertiliser

Several major changes occurred mostly during the early part of the 20th century.

- Reduction of grain legumes in cropping systems (now generally less than 10% of the arable surface, including vegetables)
- Separation of much arable cropping from stock farming
- The result is that current crops are almost total reliance on industrially manufactured or mined fertiliser.

However there have been changes since the early 1980 when records for Scotland were included in the summaries of the trends in usage (see first row in Table 5).

- Not much change in nitrogen fertiliser input to arable land over the past 30 years.

- Phosphate (P) and potash (K) reached a high point in the 1980s; after that they changed differently in different parts of the UK; in England and Wales, P and K declined by 2- to 3-fold (a large change in comparison with other changes in this region); change was much less in Scotland in arable crops but that for P and K decreased about 2-fold in grass.

Table 5. Sources of information on fertiliser used in cropping systems

Item	organisation	link
survey of fertiliser usage	British Survey of Fertiliser Practice (for year 2010); government publication from Defra	http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-environ-fertiliserpractice-2010.pdf
fertiliser manual (RB209) published 2010	Government publication from www.defra.govv.uk (substantial document containing information on a range of topics to do with applied mineral nutrients	http://www.defra.gov.uk/publications/files/rb209-fertiliser-manual-110412.pdf
fertiliser data	summary stats from 'UK Agriculture' produced by 'Living Countryside'	http://www.ukagriculture.com/farming_today/fertiliser_data.cfm

Pesticide inputs

Like yield, these inputs are available for a sub-set of the total area, usually for crop type e.g. nitrogen applied to winter wheat in eastern Scotland (Scale 2) and also for individual farms or fields. Fertiliser and pesticide data are sometimes presented in the form of government reports, from which information has to be extracted.

There have been many changes in pesticides and more are to follow due to withdrawals. One of the largest that went unexamined was –

- The rise of glyphosate during the 1990s from virtually no usage to being the most widely applied herbicide.

Table 6. Summary of sources of information for pesticide use.

Item	organisation	link
pesticide usage	all Scotland, some regions, by crops, for 2010 (similar data every two years, but needs to be extracted from the report	http://www.sasa.gov.uk/sites/default/files/Arable%20Potato%20Store%202010.pdf

Other agronomic data

There are few requirements for farmers in the region to keep records of agronomic data, with exceptions such as pesticides. Agronomic date – particularly on timing of preparation, sowing, herbicide, fertiliser, harvest, etc. for the main crops – are available from some recent studies on a selection of farms (see table).

Table 7. Other agronomic data not covered in categories above.

Type of data	scale	location / ownership
all agronomic inputs and timings, crop sequence	individual field: more than 100 fields in cereals and break crops, one year only; through Eastern Scotland region	JHI agroecology group database – see Hawes et al., 2010 for examples
all agronomic inputs and timings	individual field: typical agronomy for all fields on five farms in part of the East of Scotland region	JHI agroecology group and EU SIGMEA project, see Sausse et al. 2012 for example of use

3. Meteorological and related data

Data are available at various spatial and temporal averaging scales. Daily data may be available at scales 4 and 5. Historical data extend back to 1910 for some stations in the region. For reference, the Met Office compute 30-year averages against which to compare current variation. They also provide spatial climate maps.

Variables include

- Solar radiation (e.g. by Kipp and Zonen) recently and sunshine hours historically
- various records of temperature (mean, max and min, air, soil)
- Precipitation
- Windspeed and direction

Table 8. Sources of information for meteorological data.

Item	organisation	link
met data	UK met office historic station data – example at link right shows five variables for individual stations scattered through the region	http://www.metoffice.gov.uk/climate/uk/stationdata/leucharsdata.txt (can easily be converted to xls)
met data (spatial average)	30-year regional averages, including Scale 2 in Table 1	http://www.metoffice.gov.uk/climate/uk/2011/december/averages.html
met data (daily)	daily variables at some locations; 15 min intervals at automatic weather stations for recent years	check metoffice.gov.uk or contact authors for detailed weather data

Main changes

- 7 of the warmest years of the past 100 years have occurred in the previous ten years – the impacts on crop production are uncertain
- Consequences for crop production of change in weather are unlikely to be as great as the changes identified in other factors.

Atmospheric deposition and pollutants

Pollution and atmospheric deposition: maps and some point data should be available from the larger scales; if not, it may be feasible to average or interpolate, for example, for Scales 2 to 4, deposition of N is fairly uniformly around 10 kg ka^{-1} a year for most parts of eastern Scotland and the Carse of Gowrie (Table 1)

Table 9. Sources of information for atmospheric deposition and related data.

atmospheric deposition - general	summary of deposition of air pollutants (1990s)	http://www.snh.org.uk/publications/on-line/advisorynotes/155/155.htm
atmospheric deposition and soil resources	2006 review of current status for a range of pollutants	http://www.scotland.gov.uk/Publications/2006/09/21115639/0 , particularly Chapter 7. Also available as pdf at http://www.scotland.gov.uk/Resource/Doc/149337/0039742.pdf

Large changes have occurred in several variables, including -

- Sulphur deposition has decreased due to practices introduced to reduce emissions from industry and home, leading to possible sulphur shortage for some crops.
- Ozone concentration from sources outside agriculture has probably increased though the effects on agriculture are uncertain

4. Other information

Other sources of information for the region, for example

- Government strategy on land use and associated maps
- Countryside survey, soil survey and land cover survey carried out at intervals by research organisations
- National Ecosystem Assessment – major UK study based on the Millennium Assessment
- Vegetation, biodiversity – mostly after long intervals, e.g. 40 years for flora atlas in UK

Changes in land cover and other variable are difficult to assess due to the infrequent coverage. However, large changes, probably greater than 2-fold, have occurred in the following:

- Farmland biodiversity, such as soil seedbanks, emerged vegetation in crop, associated invertebrate and bird food webs
- Soil carbon (though this has been changing through agriculture for centuries, latest data from recent survey)
- Soil physical status e.g. compaction (inferred from recent survey)

Table 10. Examples of data available on the www (see also Table 8)

Getting the best from our land – a land use strategy for Scotland	Government publication, 2011. Annex has maps of land use, and other variables	http://www.scotland.gov.uk/Publications/2011/03/17091927/0 (for downloadable pdf)
Countryside Survey (all UK)	Land use land cover and related data for the UK since 1978; last survey 2007	http://www.countrysidesurvey.org.uk/. Data available on request.
Soil survey, land cover, land suitability	Online documentation and maps; detailed maps available in paper form.	http://www.macaulay.ac.uk/explorescotland/lcs_mapformat.html

UK National Ecosystem Assessment	description and analysis of the UK's natural environment	http://uknea.unep-wcmc.org/ with downloadable summaries and technical reports as pdfs
New Atlas of the British and Irish Flora	Hardback book that replaced the 1962 atlas.	Authors: Preston, Pearman and Dines. Oxford University Press
Online Atlas of the British and Irish Flora	Botanical Society of the British Isles, etc.	http://www.brc.ac.uk/plantatlas/ http://www.bsbimaps.org.uk/atlas/main.php
Summary of biological atlases	Biological records Centre, UK	http://www.brc.ac.uk/atlases/main_atlases.htm