PROJECT NUMBER 289706

COLLABORATIVE PROJECT

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

Report: Indicators of Agro-Ecosystem Function

Deliverable 3.4: Synthesis paper on major changes in agricultural factors over the past 30 years

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Preamble

AMIGA Deliverable 3.4 is an outcome primarily of Task 3.2 (Collation and analysis of historical data on crop systems). Task 3.2 has two deliverables associated with it (D3.2 and D3.4). Deliverable 3.2 *Database of agricultural, economic and environmental factors for each of the five regions* consists of a set of case studies for countries in each of the Atlantic, Boreal, Continental, Mediterranean and Balkan agroclimatic regions. Each case study attempts to quantify the main changes in crop production that have occurred over the previous few decades. Deliverable 3.4 (Synthesis paper) consists of a peer-reviewed publication that summarises these changes but notably in relation to the potential for GM cropping itself to bring about change.

The present document – a Background Report - aims to provide more detailed information on the purpose and methodology behind D3.4 than can be included in a peer-reviewed paper.

Summary of concepts and approach in the study of Long Term Effects in the AMIGA Project

Agricultural biotechnology is expanding globally. In Europe, its adoption and spread have been restricted due to a range of concerns, some scientific, some political, yet import of GM crops grown elsewhere in the world continues. New technology, whether GM or otherwise, will continue to be introduced and to influence European cropping systems as it has since agriculture began. Historically, most innovations occurred without attempts to understand their long-term consequences. Notably, the recent intensification of arable systems that began in the 1970s released major limits to production, but caused damaging ecological effects that were not anticipated. There is a need therefore for a mechanism to consider possible long term effects of further change in cropping practice and central to that process is the definition of production systems that will sustain Europe into the future.

Types of long term effect

Long term effects of a change in crop and management are of two broad types, differentiated by whether they can be measured in contained experimental studies [1]. The first type can in principle be studied and revealed by experiments in growth room, glasshouse or field plot. The effect simply takes a long time to rise above the background trends and noise. The second type will not be revealed in controlled experimentation, no matter how long the experiment continues, and will remain unrealised until the GM crop is exposed to the complexity of the agricultural environment following extensive field trialling or the commercial growing of the crop. For example, the development of the Brassica complex of crops (*Brassica napus* and *B. rapa*), volunteers, ferals, wild relatives and their hybrids, having the potential for local evolution of populations with new properties, was not fully appreciated through small-scale experimentation prior to the great expansion of rapeseed in Europe from the 1970s [2, 3]. This second type of effect is very difficult to predict and is generally not anticipated. It is this second type that is the main focus of attention in AMIGA.

However, the long term effects of biotechnology are not yet addressable by reference to GM crops grown in Europe's agricultural environments, simply because they have not been grown for sufficient duration and in sufficiently complex landscapes for reliable answers to be forthcoming. The available means of assessing the scope for long term effects is through combining experimental knowledge of GM crops at small spatial and temporal scales, with experience of growing GM in other continents and, not least, with looking at existing trends and dynamics in agriculture that have resulted from previous technological change. The latter are particularly valuable since the various phases of intensification that were instigated during the 20th century have left their own trail of impacts that have lessons for present and future technological innovation [4].

The ecological comparator - is it safe

When assessing an environmental risk, the entity under consideration is usually compared against something whose role and impact are already known or partly known and judged to be safe. This approach, of comparing an innovation against a comparator that is *substantially equivalent* and has a known history of safe usage is the basis of risk assessment of GM products for use in food or feed [1]. For example, maize flour has been used for millennia and its nutritional effects are well known and appreciated; if a maize variety produced by recombinant technology is equivalent in food quality to a conventional maize, then the new type may be judged to be safe for food and feed.

However, a similar procedure (comparator of substantial equivalence) might not be the most appropriate way to assess a new crop or field practice. The comparator might well be something that is familiar and has a history, but it might not be ecologically safe. For example, modern, high-intensity farming, while having been around for decades, may not be a safe comparator since it is having deleterious effects on a number of ecological indicators [4,5,6]. If therefore a high-intensity cropping is used as a comparator for a new variety of cereal or potato, for example, and the innovation shown to be no different, the outcome could be the perpetuation of an unsafe practice.

It is proposed that three systems need to be compared therefore - the current practice, the current practice with the innovation and a state that is ecologically safe and sustainable. In much of environmental risk assessment, this third state is not usually considered explicitly.

The baseline and trajectory

The current practice, one of the comparators referred to above, is here termed the *baseline*. Because agricultural systems have momentum and memory, for example in soil, populations and food webs, the baseline is not simply the existing state in a given year or short run of years but consists of the changes that have occurred over time and that are likely to occur into the near future. Here, this trend over time is termed the *trajectory* of an agricultural system. The baseline is therefore a trajectory rather than a point in time.

The trajectory of cereal farming in Europe (wheat, barley and more recently maize with break crops such as oilseed rape and potato) began in the neolithic age a few thousand years ago. The subsequent trajectory replaced the original forest or grassland with managed disturbance. Very recently, in relation to the historical period of agriculture, the trajectory took a new direction as yields were raised through a combination of inexpensive, industrially made nitrogen fertiliser, phosphates and other plant nutrients imported through global trade, new highly effective chemicals for pest control, and advances in plant breeding and machinery. This recent part of the agricultural trajectory is potentially valuable as the baseline against which the new technology can be judged. For example, Fig. 1 shows the great rise in nitrogen application that occurred up to the late 1980s, a subsequent period of variability as inputs responded partly to nitrate directives, and a period of sustained decrease, in this instance mainly in managed grass. Comparable trends in yield, other fertilisers, the areas grown with different crops and pesticides applied provide a multidimensional trajectory of change for many European countries. Trends in such variables show great variation over a few decades, certainly four-fold and up to ten-fold in some instances. European agriculture has been highly dynamic over the past half-century.

How will such a trajectory continue? Though limited in scope, the data on cropped area, inputs and outputs generally offer a good indicator of where a system is heading. If nitrogen-rich cereals and oilseeds continue to be grown, very high inputs of nitrogen and pesticide will be inevitable. Moreover, there are no signs that the levelling of yield in cereals that occurred from the 1990s is only a temporary phenomenon. Without a further shift in the trajectory, adverse environmental impacts of modern arable cropping are likely to continue with little further rise in yield therefore. The route to a sustainable future requires that safe ecological states are identified.

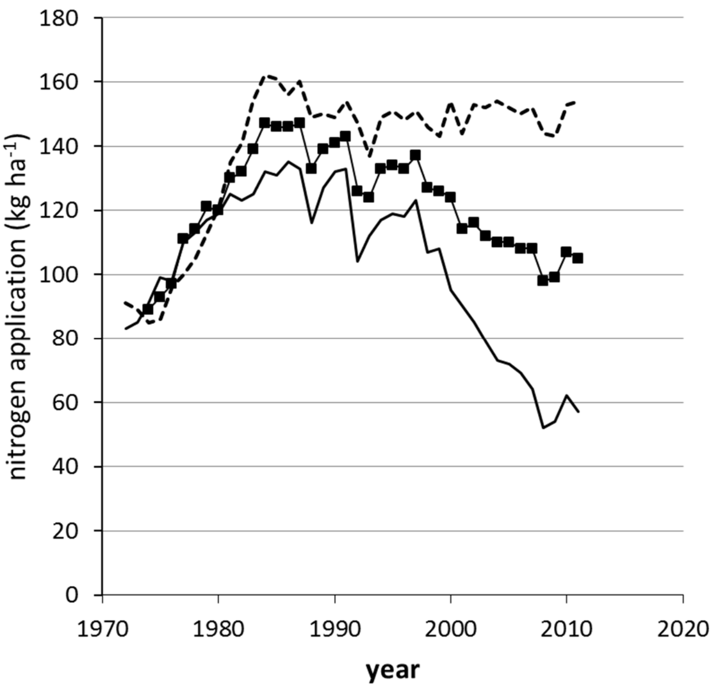

Fig. 1 Examples of trajectories in agricultural inputs (nitrogen, England and Wales) for all crops (symbols), grass (solid line) and tillage crops (dashed line). Declines in the late 1980s were related to nitrate directives and set aside. Source: Defra, UK

Towards defining safe ecological states

Cropland is some way removed from the original vegetation that it replaced, but there is no reason why it should not be sustainable. The activity 'growing cereals' has continued for many thousands of years: it is the growing of crops without regard for the condition of the field or the wider environment that will not be sustainable. It is therefore necessary to define 'safe ecological ranges' in which ecological systems and processes can continue without suffering long term malfunction or degradation. The concept is illustrated in Fig. 2. The jagged line shows the progression of an entity – e.g. an ecological process, a population of organisms - through time or multivariate space. 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 deteriorates to collapse. The hypothetical process in the diagram is seen to move outside range A on several occasions, and where an * is shown, 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.

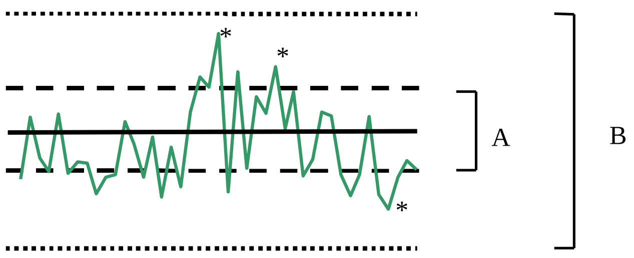

Fig. 2 Diagram to illustrate the concept of safe limits. After Squire et al. (in preparation).

Take soil cohesion for example. Careless management by allowing soil carbon to decline without replenishment or soil to be compacted or over-loosened allows the attribute to slip outside A where soil does not support root growth to the full. More slippage and it moves outside B, perhaps with catastrophic failure as when a farmed terrace becomes an erosion gulley. The scientific challenge is defining the limits of A. Information might simply not be available, or the limits set for one production ecosystem may not be the same as those for another. In some cases it might only be possible only to set the direction in which a process has to be moved.

In AMIGA, we are working towards setting such limits for a range of important ecological processes, including:

- energy and matter cycling (biogeochemical cycles)
- soil biophysical status
- soil microbial and faunal status
- wild plants, food webs and focal taxa
- pests and integrated pest management.

Here is one example. The seedbank of buried seeds gives rise to weed populations that both compete for energy and nutrients with the crop and support a range of beneficial functions such as pollination and pest biocontrol. Current knowledge is generally consistent with the view that seedbanks of less than 2000 m^{-2} (2000 seeds buried in the soil beneath 1 square metre of field surface) are unlikely to limit the crop but contain few species and will not support an active food web. Typically seedbanks between 2000 m^{-2} and 6000 m^{-2} (sometimes higher) can be managed so they do not compete with the crop yet support the food web (range A), whereas over 6000 m^{-2}, they may present a major problem for yield.

Multifunctionality and the chain of enquiry

In order to be able to achieve the comparisons just outlined, assessments may have to change the direction in which enquiries are made and in doing so to consider that production systems are multifunctional. The assessments to date have tended to begin with the new technology – for example a GM crop and its management – and assess its effect on populations and ecological processes that were thought to be directly affected by the new management (a direction here named *GM-led*). The direction of enquiry was predominantly from the innovation to the system via life form (crops, weeds, insects) and ecological process (Fig. 3). In a few cases, the assessments went further to consider the effects on broad outputs, defined in terms of ecosystem services for example, but most have tended to be fairly narrow in scope. Work on herbicide tolerant crops examines weeds and perhaps dependent invertebrates and that on insect-resistant crops concentrates on non-target arthropods. It is possible that being so focussed will emphasis small effects of a new technology and ignore null impacts on other major processes. The field trials on GMHT oilseed rape certainly found adverse effects on in-field food webs [7], but if a new system had altered, say, major fluxes in the nitrogen or phosphorus cycles (as were affected by the change in northern Europe to winter cropping in the 1907s), then the environmental impacts would have been substantial and wide ranging.

Broader issues began to be incorporated in subsequent work, such as that in the EU SIGMEA project [3], while ecological considerations became firmly embedded in the revised EFSA Guidelines of 2010 [1]. But a more explicit inclusion of ecosystem processes is fundamental to an alternative approach proposed here (named *system-led*). The approach first accepts that production systems are multifunctional – they might provide economic output, support for soil and food webs, regulation of disease, an attractive landscape. It defines the balance of outputs of a production system in terms of these high level descriptors (e.g. ecosystem services) then proceeds in the reverse direction. The ideal balance of services is first set, then the ecological processes that give rise to the services, then the combination of life forms (e.g. crops, weeds, invertebrates) that mediate the processes and finally the range of interventions (e.g. tillage, pest control, new crop variety) including the innovation that are thought best to deliver the services. This system-led approach is proactive, encompassing ecological design rather than simply risk assessment (Fig. 3).

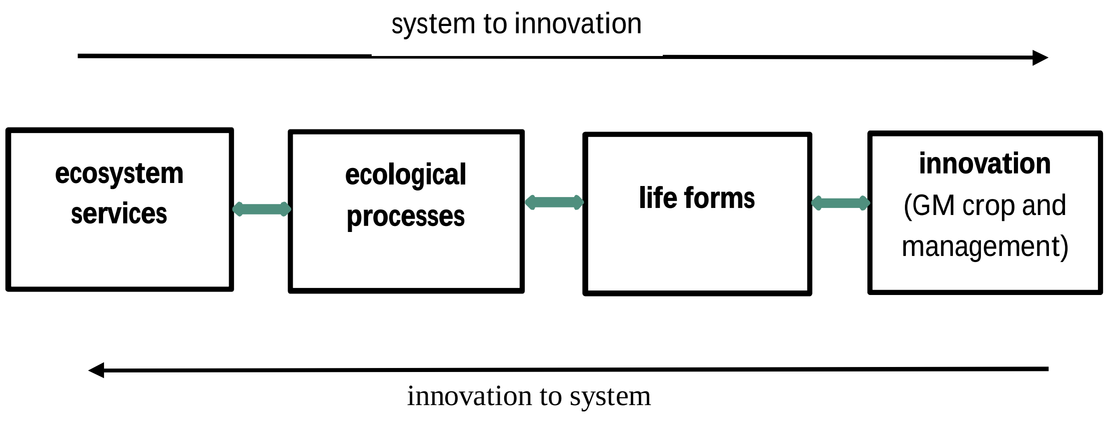

Fig. 3. Direction of enquiry: system-led, left to right; GM-led, right to left

Inevitably, a system-led assessment relies on a more comprehensive understanding of an ecosystem than the GM-led. It requires that the balance of services is set out in advance and that the ecological processes and life forms underpinning those services are identified and have safe limits set for each. While this setting of limits may be difficult for some processes and populations, the need for it should at least concentrate effort on what an ecologically safe system should be and the direction that things should be moved in if production is to be sustained.

The contribution of AMIGA WP3 on Long-term effects

The arguments above have returned the conclusions that -

a) some long term effects are those that arise out of complexity and cannot be adequately measured in short-term controlled experiments;
b) the baseline against which an innovation such as a GM crop is judged should be defined by a trajectory of change through time,
c) a comparator, additional to the baseline, has to be defined in terms of safe ecological ranges in the important variables and processes, and
d) assessment should proceed along the chain services-processes-life form-innovation (system-led).

To incorporate these ideas and thereby to complete the final task of work on *Long term effects* in AMIGA, the study will quantify the following for representative European agroclimatic regions: the baseline trajectory of agriculture over the previous 30-50 years; sustainable cropping systems for the region defined as far as possible by safe ecological ranges of the main variables; the type of change needed to deflect the baseline trajectory towards the safe ranges and the likely time scale for this change; the potential for the GM crops in question (e.g. insect-resistant maize or blight-resistant potato) to make contribute to a sustainable trajectory.

The centre of the argument on *Long term effects* is therefore adjusted from the GM crop to the system into which it would be introduced. By concentrating more on the system, any substantial and potentially damaging long term effects of a new technology should be distinguishable from minor effects that are unlikely to rise above the general background trends and noise of agriculture.

References

Identified by superscript numbers in the text

1 EFSA (2010) Guidance on the environmental risk assessment of genetically modified plants. EFSA Journal 2010;8(11) 1879 (111 pp.) (doi:10.2903/j.efsa.2010.1879)

2 Squire G R, Lecomte J, Husken A, Soukup J, Messean A (2013) Contributions of pollen and seed to impurity in crops – a comparison of maize, oilseed rape and beet. In: *Genetically modified and non-genetically modified food supply chains: coexistence and traceability,* First edition. Edited by Y Bertheau. Blackwell Publishing Ltd.

3 Final report of the EU SIGMEA project (2007) http://www6.inra.fr/sigmea

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5 Powlson DS, Gregory PJ, Whalley WR, Quinton JN, Hopkins DW, Whitmore PR, Hirsch PR, Goulding KWT (2011) Soil management in relation to sustainable agriculture and ecosystem services. *Food Policy* 36, 572-587.

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7 Hawes et al 2003 Hawes C, Haughton AJ, Osborne JL and 16 others (2003) Responses of plant and invertebrate trophic groups to contrasting herbicide regimes in the Farm Scale Evaluations of genetically-modified herbicide-tolerant crops. *Philosophical Transactions of the Royal Society of London B*. 358 (1439) 1899-1913.

Background Report providing supporting information

1. Introduction

1.1 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 cause 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.*

1.2 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 held, for example, in government statistical archives.

This report describes the methodology and approach to obtaining the case studies, a summary of the data available and examples of trends that will be described in the refereed paper.

2. Methodology and approach

2.1 Types of data

Background information on change in land use, cropping practices and the inputs to and outputs from arable farming are assembled for representative crops and areas in each of the 5 regions – Atlantic, Boreal, Continental, Mediterranean and Balkan. The time period covers at least 30 years, i.e. beginning 1980. The data 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 the *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 by 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.

2.2 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 platform
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

A major agricultural change, such as that from spring to winter cereals from the 1970s, with the accompanying increase in fertiliser and pesticide use, 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, while 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 was mostly targeted at the scale of the region or country - a defined entity of thousands of square kilometres, around Scale 2 in the table.

2.3 Sources of data

In general, the data 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 in data from some sources that need careful interpretation through local knowledge of practices, conventions and language.

Therefore the aim was for representatives in each region to source and collate information, provide 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

3.1 Data available

A 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 Members' 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)

and all complemented by …

11. Economic data – (UREAD)

3.2 Care in interpretation

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

Inconsistency in spatialscale and time

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, 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.

Change in census methodology

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.

3.3 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, e.g. 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.

4. Conclusions and next steps

Agriculture has experienced major changes in recent decades in factors that 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 appear to have had little impact on the main trends.

The data are now available to all AMIGA partners on the secure Members' Area of the AMIGA web site. The original sources in government web site and archives are unlikely to remain static, but can be updated and augmented annually or more frequently as new census data are incorporated. It is recommended that partners using the data always check the web links provided to ensure the information they are using is up to date.

Author's note on AMIGA Deliverable D3.4

Deliverable 3.4 consists of several parts uploaded as separate files to the members area of the AMIGA web server –

A. This summary paper, which is based on the following:

B. Refereed paper: Squire GR. Accounting for long term effects in the environmental risk assessment of GM crops (under review), file AMIGA_WP3_D3.4_LTE_principles.
C. Refereed paper: (multi-partner authorship). Defining the baseline and trajectory in agricultural production as a basis for estimating long term effects in environmental risk assessment (completion August 2014), file AMIGA_WP3_D3.4_LTE_baselines.
D. Report to provide additional material in support of the refereed papers included a worked case study, file AMIGA_WP3_D3.4_background_methods_report.