Assessing Agricultural and Nitrate Pollution Control Policies with a Bio-economic Modelling Approach

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To my mother's eternal rest

Declaration

I hereby declare that this thesis has been composed by myself, that the work on which it is based is my own except where explicitly stated in the text, and that it has not been submitted for any other degree or professional qualification.

Ioanna Mouratiadou

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Abstract

Agricultural production and sustainable management of water resources are often in conflict. Focusing on the economy-agriculture-water resources links, two major policies are currently in place in the European Union: the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). Within these two policies, we are dealing with two conflicting goals in relation to agriculture: to minimise the adverse impacts of the sector on the water environment, and to maximise its economic return. Nitrogen fertiliser use is a particularly sensitive issue, given that it is one of the most significant factors determining farm productivity and agricultural diffuse pollution, and its impact on crop yields and pollution losses is determined by complex processes controlled by both natural and man-made factors. Clearly, analysing and modelling such a system requires understanding of both natural and social sciences. This thesis analyses the problem of nitrate water pollution from agricultural sources, with a focus on arable cropping systems. The impact of agricultural and water management policies on farmers' decision making and the resultant economic and nitrate pollution effects are investigated. The Lunan Water catchment in Scotland was used as a case study to i) explore the water quality and economic effects of the 2003 CAP Reform and the CAP Health Check, ii) assess the cost-effectiveness of economic and managerial measures against nitrate pollution, and iii) evaluate the effectiveness of the methodology used. The above goals were achieved by using a bio-economic modelling approach, which combines bio-physical and mathematical programming modelling. The results indicate that the decoupling of subsidies under the CAP reform resulted in minor changes regarding land use and subsequently economic and water quality indicators. The abolition of set-aside under the CAP Health Check increased farm incomes through the substitution of set-aside by profitable winter cereal crops. Even though these changes resulted in increased fertiliser use, the results indicate that this does not necessarily imply increased nitrate leaching due to rotational effects associated to the nature of nitrate losses. An analysis of the relative cost-effectiveness of measures demonstrated that similar leaching reductions can be incentivised through a number of economic instruments, such as per unit taxes on nitrogen fertiliser inputs and nitrate leaching, per hectare nitrate leaching standards and nitrogen fertiliser quotas, and subsidies and cross-compliance measures aiming at the reduction of fertiliser intensity. Taxes impose considerable costs on farmers without resulting in significant nitrate leaching reductions. On the other hand, subsidies impose the costs of environmental protection on the rest of the society, while cross-compliance can deliver water quality improvements at a lower cost compared to taxes. Cross-compliance instruments can either be used for the enforcement of measures at the farm level, such as nitrogen quotas, or measures at the field level, such as crop and soil specific reductions in fertiliser inputs. Further, the results indicate that considerable leaching reductions through changes in inputs can only be achieved at a significant cost. Thus, farm infrastructure measures and training and education of farmers, could further assist in achieving water quality objectives. The bio-economic modelling methodology used provided a consistent framework for water policy assessment in the agricultural sector, as it allowed integrating agronomic, environmental and economic information in a single framework. This was achieved at three spatial scales: the field scale capturing agronomic and environmental diversity, the farm scale that offers a better representation of farmers' actual behaviour, and the catchment scale that allows consideration of the aggregate policy impacts. The thesis also demonstrates the complexity of the issues involved, and highlights the challenges to be overcome.

List of Abbreviations

BSMs	Bio-physical Simulation Models
CAP	Common Agricultural Policy
CAR	Controlled Activity Regulations
DM	Database Module
DMF	Data Management Facility
ERSA	Economic Report on Scottish Agriculture
ESU	European Size Unit
EU	European Union
FMH	Farm Management Handbook
FSSIM-MP	Farm Systems Simulator Mathematical Programming
GAEC	Good Agricultural and Environmental Conditions
GAMS	General Algebraic Modeling System
HOST	Hydrology of Soil Types
IACS	Integrated Administration and Control System
ICM	Integration Code Module
JCD	June Agricultural and Horticultural Census Data
LCA	Land Capability for Agriculture
LMOs	Land Managers Options
LFA	Less Favoured Areas
MPMs	Mathematical Programming Model
NVZs	Nitrate Vulnerable Zones
N	Nitrogen
PAD	Percent Absolute Deviation
PMP	Positive Mathematical Programming
RBMP	River Basin Management Plan
RDCs	Rural Development Contracts
SEPA	Scottish Environment Protection Agency
SRDP	Scotland Rural Development Program 2007-2013
SSKIB	Scottish Soils Knowledge and Information Base

SFP	Single Farm Payment
SMRs	Statutory Management Requirements
SQL	Structured Query Language
WFD	Water Framework Directive

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1 General Introduction

1.1 Introduction

Agriculture and sustainable management of water resources are often in conflict. The excessive or inappropriate use of fertilisers, pesticides and livestock manure can result in water pollution through leaching and run-off. This can lead to eutrophication of rivers and lakes, high nitrogen fluxes to coastal waters, and increased nitrate concentrations in groundwater. These problems can create significant competition between farming and other water users, such as the urban water supply industry, and jeopardise environmental and socio-economic sustainability. Agriculture is perceived as the most significant and controversial water user in most European Union (EU) countries. While it is associated with both water quality environmental concerns and problems of poor water use management, its socio-economic significance and its sensitivity to a variety of external economic and bio-physical factors allows for special considerations regarding the implementation of environmental, and in particular water policy.

Policy design and implementation is a key driving force and a major influential factor of the perpetual and interdependent feedbacks between the economy-agriculture-environment complex. Focusing on the links of economy-agriculture-water resources, two major policies are currently in place in the EU: the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). Within these two policies, we are dealing with two conflicting goals in relation to agriculture: minimise the impacts of the sector on the water environment while maximising its economic return. Achieving these objectives requires a thorough assessment of the existing policy environment, the functioning of agricultural systems within this environment in socio-economic and natural terms, and the potential for policy improvement.

The assessment and design of effective and sustainable agricultural and water policies and measures is challenging in multiple ways. First, a multi-objective approach of policy decision making is necessary. Such an approach involves consideration of the trade-offs between socio-economic and environmental outcomes, which result from complex, interacting processes and competing goals (Letcher *et al.*, 2006). Secondly, the agricultural system is dominated by complex and interacting economic, agronomic, environmental and production processes. The bio-physical characteristics of the agricultural environment are an important determinant of the level and quality of agricultural production and they influence farmers' choices, with regard to both management practices and selection of crops. At the same time, the economic and environmental impacts of agricultural production are largely dependent on farm management decisions and their interactions with site-specific bio-physical characteristics, and they may vary substantially depending on natural and economic conditions. Finally, the selection of the most effective policy mix of regulation and economic incentives is complicated because action (at the farm level) and response (the environmental effect) do not normally coincide in time and space (Schöder *et al.*, 2004).

Nitrogen (N) use is a particularly sensitive issue, given that it is one of the most significant factors determining farm productivity and agricultural diffuse pollution. The impact of N use on crop yields and pollution losses is determined by complex processes controlled by both natural and man-made factors. Climate, soil types, crop types and rotations, and the amount, timing, application methods and types of fertiliser used all have a crucial influence on farm outputs and on the nature and rate of N losses. Clearly, analysing and modelling such a system requires understanding of both natural and social sciences.

In the above policy and conceptual contexts a number of questions arise: (i) *Can water resource problems be remediated without jeopardising the viability of the farming sector*; (ii) *Do the two policies (CAP and WFD) exploit potential synergies and diminish likely trade-offs emerging through the interactions of their impacts on agricultural systems*; (iii) *Are the measures aiming at water pollution reduction that are in place sufficient for achieving water quality objectives and if not what measures could be proposed*; (iv) *What are the costs imposed on the farming sector from different water pollution control measures and their associated effectiveness?*

(v) *Which methodology should be used in order to adequately represent agricultural systems and assess agricultural and water policies?*

This thesis explores these questions. It aims to analyse the problem of nitrate pollution from agricultural sources, with a focus on assessing how agricultural and nitrate pollution control policies along with the farmer's natural environment influence his/her choices, and how in turn these choices impact on the natural environment. The following section discusses the scope for integration in disciplines, scales, and policies for agricultural and water policy analysis and some of the challenges involved. These issues underpin the broader scope of the research. Section 1.4 outlines the basic principles of bio-economic modelling that forms the core of the methodology that has been used in the research. Section 1.5 specifies the objectives of the research and outlines the structure of the thesis.

1.2 The Scope for Integration in Agricultural and Water Policy Analysis

1.2.1 Integration across Disciplines

Water resource management is an inherently complex, multi-scale and multi-disciplinary process comprising of the understanding and analysis of many interdependent components. Each of these components is the focus of a number of different disciplines, such as socio-economics, agronomy, ecology, hydrology, soil science, politics, etc. and hence an approach that crosses disciplinary borders is needed in order to provide constructive input to policy making. The recognition that the relationship between the ecosystem and the economic system is complex, has given way to the development of scientific approaches that study the relationship between the economic and ecological systems and aim at providing knowledge for a sustainable management of this relationship. These scientific approaches are thought by Baumgärtner *et al.* (2008) to comprise the field of *Ecological Economics*. Such approaches are interdisciplinary in nature, where interdisciplinarity refers to the cooperation of many scientific disciplines, in order to analyse the relationship between the economic and natural systems (*ibid*).

Indeed, the importance of interdisciplinary research, particularly when informing policy in the management of socio-ecological systems, is recognised by both social and environmental scientists (e.g. Mascia *et al.*, 2003; Lawton, 2007). Interdisciplinary research, in order to be successful, requires that separate disciplines gain a common understanding of the problem at hand, identify the scales of relevant system subcomponents, the underlying phenomena or processes, and the important variables involved (Dollar *et al.*, 2007). As a consequence, new research questions, new approaches to problems, new theories, and new generalisations are produced (Pickett *et al.*, 1999). These can be seen as different forms of knowledge or constructions of reality that have resulted from the interplay between human intellect and empirical experience (Baumgärtner *et al.*, 2008).

This thesis adopts an interdisciplinary approach, drawing from the premise that economic systems form sub-components of the broader natural system and therefore an analysis of any of the two types of systems cannot be achieved in isolation from the other, if the aim is to gain a better understanding of the economy-environment interactions and propose answers to problems with real life applicability. Fig. 1.1 demonstrates the complex economy-environment interactions that occur at the level of agricultural systems, using the example of nitrate pollution. Farmers adjust their production decisions (e.g. tillage, fertilisation, sowing) in order to optimally combine inputs based on natural capital (e.g. soil, solar energy, rainfall) and inputs from human-made capital (e.g. fertilisers, pesticides, irrigation water). This process yields desired outputs, namely agricultural products, and undesired emissions to the environment (van der Werf & Petit, 2002). These interrelated natural and economic processes give rise to the need for an interdisciplinary approach informing policy design.

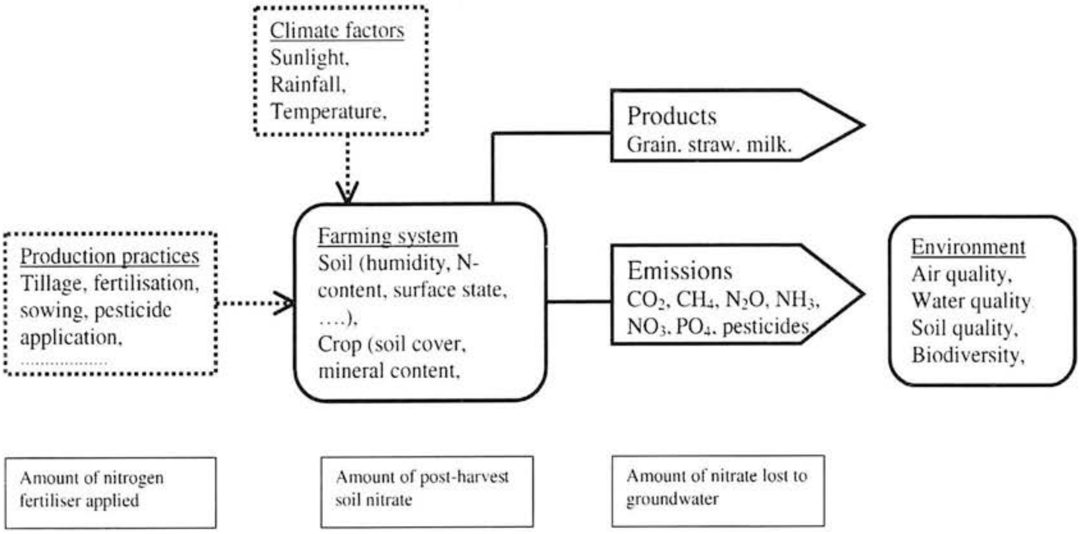

Fig. 1.1 Scheme of a farming system

Source: van der Werf & Petit (2002)

1.2.2 Integration across Systems and Scales

A challenge that often appears in the analysis of integrated environmental-economic systems is how to combine heterogeneous information and systems boundaries in a consistent manner. Integration of scales is seen as a major research challenge by many authors (Bouman *et al.*, 1999; Vatn *et al.*, 2006), and the selection of the appropriate spatial and temporal scales of analysis for integrated ecological-economic modelling is subject to a number of considerations. Firstly, the wide arrays of agronomic/environmental and economic processes, between which the causal relationships have to be established, operate at different spatial and temporal scales. Crop production and emission losses take place at the field level on a daily basis. Farmers make their main cropping decisions at the farm level on a seasonal or yearly basis, while some management decisions, such as fertilisation, are made on a daily or weekly basis. Pollutant transport into water bodies operates at the catchment level on a daily basis.

Secondly, while the integration of bio-physical and economic models should ideally occur at a highly disaggregated level so as to capture bio-physical and economic behaviour heterogeneity, policy making is interested in larger units of analysis, as for example the river basin, the regional or the national level, and in the long-term effects of environmental and agricultural policy regulations. These large scale and long term effects are effectively the result of the accumulation in time and aggregation in space of the effects that occur at smaller units of analysis. As Rossing *et al.* (2007) state, policy goals implicitly or explicitly express pertinent temporal and spatial scales and organisation levels, and thus affect the definition of the systems to be assessed.

Thirdly, data and statistics are fairly 'mono-disciplinary' in terms of their content and boundaries. Data on environmental parameters are collected with respect to the boundaries of the natural environment, while economic parameters adhere to economic and administrative structures. Data describing the natural environment do not have any links to the economic activities that occur in the respective environment, while data on economic units, such as farms, do not provide any information on the physical environment within which the farm operates.

In essence the problem is threefold: i) what is the best level of integration of the ecological and economic relationships; ii) how can these relationships be then upscaled or aggregated to greater levels so as to provide meaningful information to policy makers; iii) how can limitations of existing data be overcome in order to achieve integration of scales? Therefore, important considerations in the design and implementation of integrated models are: i) the resolution and the extent of the spatial and temporal dimensions[1] for the bio-physical and economic models, ii) the classifications used to capture ecological and economic heterogeneity at that level of resolution, and iii) the methods of upscaling/aggregating from the resolution to the extent level. These issues will be extensively explored in the following chapters of this thesis.

1.2.3 Integration across Policies

An integrated approach to policy making that pays greater attention to the interactions between agricultural and environmental policies has significant benefits. As explained by Leathers & Quiggin (1991), policy interactions occur mainly through their effects on the level of agricultural production inputs such as fertilisers, pesticides, and irrigation water. For example an environmental policy that aims at the

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[1] The resolution of a model refers to the smallest unit of analysis, while the extent of the model refers to the total area or period to which the model is applied (Valvidia, 2006).

reduction of a certain input would influence agricultural output and therefore the results of any relevant agricultural policy. On the other hand, an agricultural policy changing crop production would impact on input use, and consequently on the effectiveness of certain environmental policies (*ibid*).

The introduction of the WFD has increased the importance of water resource issues, and hence the importance of reducing diffuse pollution from agriculture. This should be expected to have a direct impact on the use of fertilisers and follow-up consequences on agricultural productivity and yields. On the other hand, the agricultural sector operates within a background of agricultural policy reform which will in turn affect the effectiveness of water policy measures in three main ways. Firstly, the composition, levels, and production techniques of agricultural output are changing as a result of the decoupling of subsidies and production levels. The 2003 CAP Reform introduced a Single Farm Payment (SFP) based on historical payments, as opposed to payments according to production levels, with the objective of directing farmers from a subsidy-oriented to a market-oriented approach. The CAP Health Check led to the abolition of set-aside obligations. Secondly, the imposition of cross compliance measures, such as those to protect water in Nitrate Vulnerable Zones (NVZs), can significantly reduce the pressures of agriculture on the water environment and enhance compliance with the WFD. Cross compliance measures refer to a number of Statutory Management Requirements (SMRs) with which farmers need to comply in order to receive the financial support. Finally, agri-environmental measures under the Rural Development Programmes can provide additional incentives for achieving water quality objectives. Clearly, understanding input use and farmers' reactions to agricultural and environmental policies (in our case the WFD and the CAP) is important in evaluating their effectiveness as well as in examining the interactions between them (Isik, 2002).

1.3 Previous Research in the Scottish Context

The assessment of water policy measures and their cost-effectiveness in Scotland has been the subject of a number of studies, the majority of which belong to the grey-literature. A thorough review of such studies has been recently carried out by Lago (2009). This review considered the type and scope of the studies, the types of farms that were assessed, the number and types of measures, the types of costs included in the calculation of the cost estimates of the different measures, the pollutants covered, the consideration of the baseline levels of farm nutrient loads, and their suitability for cost-effectiveness analysis. Lago (2009) concludes that i) the majority of studies reviewed have some degree of inconsistency in the units of costs and effectiveness presented across measures; ii) there is no clear description of the costs involved and often a total cost figure for a whole farm or the whole agricultural sector is presented; and iii) effectiveness and cost units are not consistent within or across studies (e.g. £/farm, £/ha or £/m^3).

In addition to the above, some major weaknesses of most of these studies are that: i) farmers' behaviour in relation to the selection of crops and management practices is taken as given, and thus their reactions and the environmental repercussions arising from changes due to the implementation of water or agricultural policy are not assessed; ii) the assessment of the costs and effectiveness of some of the measures is based on figures that have been derived using poorly-documented assumptions and methodologies, not allowing a thorough assessment of the approach used; and iii) economic incentive measures, such as taxes or voluntary agri-environmental schemes are not usually assessed.

1.4 The Use of Bio-economic Modelling for Policy Analysis

Exploring the questions posed in this thesis, with the aim of overcoming limitations of previous studies, requires an approach that considers farmers' reactions to policy change, takes into account both the socio-economic and environmental outcomes of agricultural production, and allows the comprehensive representation of the complexity of the agricultural system. Bio-economic modelling appears to be an approach that satisfies all three conditions.

Bio-economic models facilitate the integration of socio-economic and agro-ecological information into economic modelling by using bio-physical simulation models (BSMs) to establish agronomic and environmental pollution relationships which serve as an input to the economic model. BSMs deal with the effects of weather, the bio-physical characteristics of the agricultural environment, the inputs of production, the management practices, and their interactions on agricultural productivity and yields. The data generated by such models enter as input to the economic model in the form of production/pollution functions or technical/environmental coefficients. The economic model describes farmers' production and management decisions, which are optimised subject to a set of explicitly defined technical, agronomic, economic and institutional constraints. The economic model simulates alternative environmental or economic policies following an optimisation process, the outcomes of which provide information on the effects of the policy on economic, agronomic/technical, and environmental parameters. A diagrammatic representation of a bio-economic model is given in Fig. 1.2.

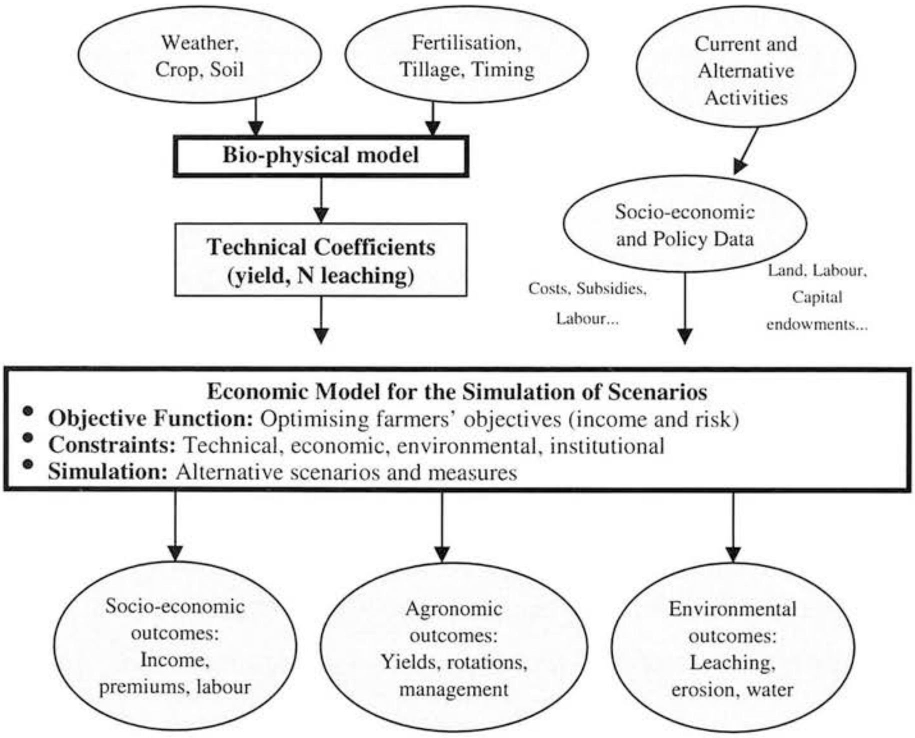


Fig. 1.2 Scheme of a bio-economic model

Bio-economic models have been used to answer a diverse range of research questions where the interplay between economic and environmental outcomes is important. For example, Mimouni *et al.* (2000) used bio-economic modelling to generate the trade-off curves between economic and environmental objectives in a representative farm in Tunisia; Flichman (1997) to analyse the impacts of CAP on technological, production and environmental patterns; Belhouchette *et al.* (2004) to study the sustainability of agricultural systems in Tunisia; Pacini *et al.* (2004a; 2004b) to assess the impact of the Agenda 2000 reform and to design efficient agri-environmental schemes looking at the performance of organic and conventional farming systems; Martínez (2006) and Martínez & Albiac (2006) to evaluate the cost-efficiency of several pollution control policy measures to abate N pollution.

1.5 Research Objectives and Thesis Outline

The preceding sections analysed the policy and conceptual rationales and contexts of the research, and briefly presented the core features of the applied methodology. Following from that, the specific policy and methodological objectives of the research are outlined as follows:

Policy Objectives

1) Convey the key features of the Scottish policy scene related to water and agricultural policy;
2) Explore the water quality and economic effects of the 2003 CAP Reform and the 2008 CAP Health Check;
3) Explore the interplay between water and agricultural policy in the Scottish context;
4) Assess the cost-effectiveness of economic incentive and managerial measures against water pollution from nitrates;
5) Consider the potential of combining measures under both WFD and CAP for enhancing the sustainability of agricultural production regarding water resources;
6) Analyse the trade-offs between socio-economic and environmental outcomes of agricultural production in a Scottish context.

Methodological Objectives

1) Review approaches in integrated assessment and modelling of agricultural systems;
2) Develop, apply, and present an integrated assessment bio-economic modelling methodology to assess agricultural and nitrate pollution control policies;
3) Assess the usefulness of different water pollution indicators in informing policy making;
4) Evaluate the benefits and limitations of the methodological approach, in order to draw conclusions on its overall suitability and applicability for policy assessment and for the selection of cost-effective measures against water pollution from nitrates.

These objectives will be investigated by applying bio-economic modelling in a representative case study catchment in Scotland. Farmers' decision making has been modelled with an extended version of the Farm Systems Simulator Mathematical Programming (FSSIM-MP) model (Louhichi *et al.*, 2010a; 2010b), namely FSSIM-REG. FSSIM-MP was developed under the EU FP6 Project SEAMLESS (van Ittersum *et al.*, 2008), and the research carried out for this thesis took place while the model was being developed. The estimation of nitrate leaching associated with the agricultural activities has been assessed using the bio-physical model Coupled Heat and Mass Transfer Model for Soil-Plant-Atmosphere Systems (COUP) (Jansson & Karlberg, 2004).

The thesis consists of two main parts. The first part deals with the policy and the theoretical contexts of the research. The second part concerns the empirical part of the work.

Part I contains chapters two and three. Chapter 2 presents the key features of the Scottish policy scene in terms of agricultural and water policies, thus providing the policy context for this work. The policies analysed include the WFD, the CAP, the Scotland Rural Development Programme 2007-2013 (SRDP), and the Nitrates

Directive. Chapter 3 reviews and discusses approaches regarding integration across systems, scales, and policies, and the specifications of economic and bio-physical models. The latter relate to economic approaches for predicting and understanding behaviour, objective function specifications, farm typologies, model calibration approaches, data management and integration procedures for economic models, water pollution indicators, bio-physical simulation modelling of cropping systems, soil typologies, and policy instruments and measures.

Part II is an exposition of the methodology, the results produced and the implications of the research. It contains Chapters 4, 5, 6 and 7. Chapter 4 presents the case study area used in this study, namely the Lunan Water Catchment, in terms of its natural characteristics, the status of the water resources, the related pressures exercised by agriculture, and the land use and farm type trends. Chapter 5 presents the methodology in relation to i) integration across systems and scales, ii) selection, overview and specification of the economic component (FSSIM-REG), iii) selection, overview and specification of the bio-physical component (COUP), iv) data management and integration procedures, v) system and data specification, and vi) modelling scenarios. Chapter 6 presents the results of the research. These include yield and nitrate leaching estimates for each of the agricultural activities modelled with COUP, the economic and environmental impacts of CAP and nitrate pollution control policies, the cost-effectiveness of measures against nitrate pollution, the relationship between water quality indicators, and the land use, intensity changes, and supply responses induced by the scenarios modelled with FSSIM-REG. Chapter 7 discusses the applied methodology and results, and concludes with the key messages of this work and recommendations for further research.

2 Setting the Policy Scene

2.1 Introduction

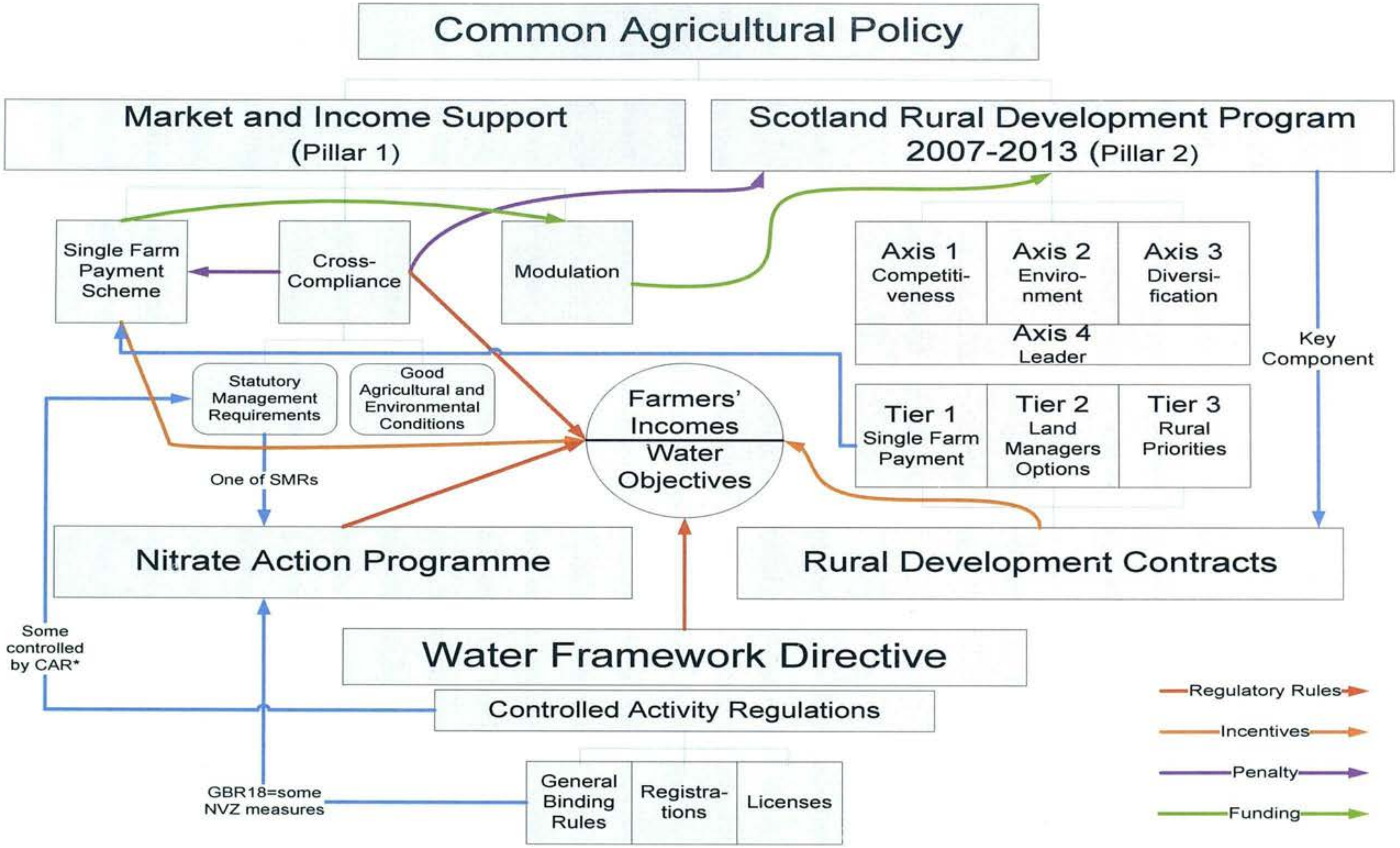
As identified in Chapter 1, the agricultural sector is affected by a number of policy regulations aiming at influencing agricultural production and management decisions and consequently related environmental attributes, such as water quality. The socio-economic and water quality impacts of each of these policies and their combined effects are not straightforward. This chapter outlines the main policies impinging on agricultural decision making. It aims to disentangle the Scottish policy scene focusing on its water related dimensions and to identify potential synergies or trade-offs between the policies regarding the implementation of the WFD. The policies that have been analysed, using mainly Scottish governmental bibliography, include the WFD, the CAP and the SRDP, and the Nitrates Directive. A diagrammatic representation of the main policy features is provided in Fig. 2.1.

2.2 The Water Framework Directive

In the year 2000, the European Commission introduced Directive 2000/60/EC *Establishing a Framework for Community Action in the Field of Water Policy* (European Parliament, 2000) more commonly known as the *Water Framework Directive*. The WFD is widely referred to as the most significant water legislation ever to emerge in Europe, as it connects the existing fragmented legislation for different aspects of water conservation and protection, thus establishing a common framework for the management of the water environment within which Member States will work to achieve its objectives. The Member States had the responsibility to transpose the Directive into their own legislation and to implement it in a way that the objectives of the Directive are met.

The main objectives of the WFD can be summarised as follows:

- Expand the scope of water protection to all water resources (surface waters and groundwater);



*Controlled Activity Regulations (CAR)

Fig. 2.1 Scheme of Scottish policy

- Achieve *good status* of water resources by a certain deadline (good ecological and chemical status for surface waters, good chemical and quantitative status for groundwater);
- Adopt integrated river basin management, managing water resources at the river basin scale;
- Use a *combined approach* of emission limit values and quality standards, and phase out specific dangerous/hazardous substances;
- Use economic instruments, methods and tools to develop sustainable water management policies;
- Get the citizens more closely involved through active involvement and participation of stakeholders and the public;
- Streamline water related legislation.

The Directive sets a stringent timetable for implementation that spells out the main steps to be followed towards achieving its objectives. One of the most important milestones was the establishment of River Basin Management Plans (RBMP) by 2009, which would be providing detailed information on how the objectives set for the river basin will be reached according to the Programme of Measures. In Scotland, waters fall within two river basin districts: the *Scotland River Basin District* and the *Solway Tweed River Basin District*. Most of Scotland is within the Scotland River Basin District, but the major river catchments that cross the border with England are included in the Solway Tweed River Basin District[2]. In accordance with the approach emphasised by the WFD, the Programme of Measures should provide the lowest-cost measures to achieve the environmental requirements. This may include actions such as i) measures to manage pressures arising from specific activities such as agriculture, forestry and industry, ii) environmental permitting systems or abstraction and discharge control regimes, iii) measures of water demand management, iv) economic incentive measures such as taxes on fertilisers (Interwies *et al.*, 2006), v) river restoration strategies, etc. Specific provisions on economic incentive measures are outlined in Article 9, where the Directive requires Member States to consider the

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[2] http://www.sepa.org.uk/water/river_basin_planning.aspx

full costs of water services, to ensure that pricing policies act as an incentive for more efficient water use and that the different water users, including agriculture, contribute adequately to the recovery of costs of water services, and to embody the *Polluter Pays Principle* (European Parliament, 2000).

Indeed, the Scotland RBMP was published in 2009 (SEPA, 2009) and the agricultural sector has been identified as one of the target sectors for the Programme of Measures, as it is one of the sectors that give rise to significant pressures in most water bodies. In Scotland, the Scottish Environment Protection Agency (SEPA) has estimated that 40% of water bodies in Scotland are at risk of not meeting the *good status* requirement of the WFD (Scottish Government, 2008a; Scottish Executive, 2008a). Diffuse pollution and abstraction have been identified as some of the key pressures (Scottish Government, 2008a) and therefore reductions in the quantities of pollutants and abstraction of water are some of the key actions that have been prioritised in order to achieve the objectives of the WFD (SEPA, 2009). Specifically SEPA's *Significant water management issues in the Scotland river basin district* report (SEPA, 2008a) states that:

> *"**Diffuse pollution** from agriculture is a significant issue for **groundwater, rivers, lochs, transitional and coastal waters**...nearly half of those water bodies at risk...are affected by diffuse pollution from agriculture. In rivers, diffuse agricultural pollution is now the single most important pollution pressure."*

The three intervention mechanisms that have been employed in the Scotland RBMP and the Programme of Measures are i) legislative framework, ii) economic incentives and support, and iii) promotion via education and advice.

The major tool for legislative intervention is the *Water Environment (Controlled Activities) (Scotland) Regulations 2005* (Scottish Government, 2008a; SEPA, 2009). These regulatory controls came into force on April 2006, and their final further expansion and amendment was through the *Water Environment (Controlled Activities) (Scotland) Amendment Regulations 2007* and the *Water Environment (Diffuse Pollution) (Scotland) Regulations 2008*, which came into force on April 2008 (SEPA, 2008b). There are three types of CAR authorisation (*ibid*):

- *General Binding Rules*: They constitute the lowest level of control. Activities complying with the General Binding Rules do not require an application to be made to SEPA, as compliance is automatically considered to be authorisation. There are no associated charges;
- *Registrations*: They allow for the registration of potentially environmental harmful activities, after an application to SEPA. Application fees for registrations apply;
- *Licenses*: They are applicable to activities that pose a higher risk, by allowing for site-specific conditions to be set in order to protect the water environment. There is an application fee and potentially subsistence annual charges. There are simple and complex licenses for which different charges apply (SEPA, 2008b).

The role of economic incentives and the scope for policy integration via the employment of voluntary measures under the SRDP has been recognised within the RBMP (SEPA, 2009) which proposes the following examples of intervention: i) Rural Development Contracts (RDCs) under the SRDP, such as buffer strips and creation of wetlands, ii) funding from Scottish Water to reduce pressures from water abstraction, and iii) funding from Scottish Government to provide support for restoration projects (SEPA, 2009).

Finally, education and advice involve actions such as organising and facilitating advisory groups, collaborating on research, consulting on new legislation and guidance, publishing good practice guidance, providing one-to-one advice to involved parties, supporting voluntary groups that deliver education and advice, and facilitating discussion between water users (SEPA, 2009).

SEPA's (2009) outline of the planned measures for reducing agricultural diffuse pollution and abstraction of water are shown in Table 2.1

Table 2.1 Summary of planned water management measures in Scotland

Improvement required	Examples of on-the-ground actions	Mechanisms to encourage and ensure action
Diffuse Pollution		
Reduced nutrient inputs to the water environment	**Control at source** Manage nutrient (fertiliser) use to minimise losses to the water environment; Implement in-field measures to minimise soil erosion and compaction; Separate clean and dirty water at farm steadings. **Intercept and store/treat** Install buffer zones, including woodland planting and wetlands; Capture polluted run-off from steadings (e.g. in constructed farm wetlands); Install new slurry storage systems.	**Legislative** CAR; Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2003. The Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations (2008) **Economic** SRDP; Cross-compliance and Good Agricultural and Environmental Condition (GAEC) (Cross-Compliance) (Scotland) Regulations 2004 **Education and advice** National awareness raising campaign; Work with farmers in priority catchments; Trial catchment projects; Demonstration farms
Reduced pesticide inputs to the water environment	**Control at source** Test and maintain pesticide sprayers; Apply Integrated Crop Management techniques to reduce pesticide losses to the water environment. **Intercept and store/treat** Install buffer strips, biobeds.	**Legislative** CAR; Legislation on the sale and use of pesticides, including: Food and Environment Protection Act 1985 Part III, Plant Protection Products (Scotland) Regulations 2005; Control of Pesticides Regulations 1986 **Economic** SRDP; Cross-compliance and GAEC **Education and advice** Development and promotion of guidance; Delivery of on-site advice; Voluntary Initiative for Pesticides 42, Sheep Dip Pollution Reduction Programme 43

Reduced inputs of organic waste (organic matter, faecal pathogens, and ammonia) to the water environment	**Control at source** Control access of livestock to surface waters; Manage waste stores to minimise losses to water environment; Prevent pollution hotspots developing at heavily used areas (gates, tracks, feeders etc); Manage steading runoff (e.g. clean and dirty water separation); **Intercept and store/treat** Capture polluted runoff from steadings (e.g. in constructed farm wetlands); Install new slurry storage systems.	**Legislative** CAR; Bathing Water Regulations 2008. Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003 **Economic** SRDP; Cross-compliance and GAEC. **Education and advice** National awareness raising campaign; Work with farmers in priority catchments; Trial catchment projects; Demonstration farms; Trial catchment projects; Demonstration farms
Water Abstraction		
Reduced water abstraction impacts on water flows and levels	**Reduce demand** Improve water use efficiency (e.g. better match irrigation levels to crop needs); Manage soil to increase its water holding capacity; Sow crops/varieties with lower water needs **Change timing of abstraction** Stagger timing of abstractions in river catchments with multiple abstractions; Abstract water into constructed ponds during wet weather and use the stored water for irrigation during dry weather **Use alternative source** Obtain water from other sources (e.g. groundwater), integrate use of various sources	**Legislative** CAR **Economic** SRDP funding for storage ponds **Education and advice** Guidance and advice on reducing demand, constructing storage ponds etc

Source: SEPA (2009)

2.3 The Common Agricultural Policy

The CAP has for long been subject to criticisms of distorting the markets and directing farmers towards a subsidy rather than a market oriented behaviour. The 2003 Fischler Reform of the CAP aimed to address such criticisms by significantly strengthening the decoupling process, which began with the MacSharry reforms in 1992 and was expanded with Agenda 2000. The main element of the MacSharry and Agenda 2000 reforms was the substantial reduction of the supported price of agricultural commodities compensated by increased direct support area and headage payments (Scottish Parliament, 1999). The 2003 Reform extended this by introducing a decoupled system of payments per farm, consequently "completing the shift from product to producer support" (Commission of the European Communities, 2002). Along with promoting the socio-economic sustainability of agricultural systems, the Reform takes into consideration the need to improve the wider environmental benefits that agriculture can deliver through the use of agricultural support expenditure. The Scottish Executive[3] embraced this rationale by stating that the aim of the CAP Reform was to promote sustainable, market-focused agricultural systems throughout Europe[4]. The key features of the Reform can be summarised as follows:

- *Decoupling*: decoupling with the introduction of the SFP to break the link between the levels of agricultural production and support payments and to meet World Trade Organisation requirements (Scottish Government, 2008b);
- *Cross-compliance*: a number of SMRs were introduced in order for farmers' receipt of support payments to be conditional on achieving environmental objectives (*ibid*);
- *Modulation*: modulation and distinction between Pillar 1 (direct support payments) and Pillar 2 (payments under the SRDP).

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[3] Now the Scottish Government.

[4] http://www.scotland.gov.uk/Topics/Agriculture/Agricultural-Policy/CAPRef

The 2003 CAP Reform was reviewed through the CAP Health Check[5] in 2008. The Health Check resulted in a number of adjustments for the 2009 to 2012 CAP period. The main changes introduced relate to the abolition of set-aside obligations and changes in modulation rates and cross-compliance measures (Scottish Government, 2008b).

2.3.1 Direct Support Payments for the Arable Sector

Under Agenda 2000, the payments to farmers were coupled to the agricultural production of their farms. For the arable sector, payments were made under the Arable Area Payment Scheme. The compensation rate per hectare was estimated by multiplying the regional yield by the compensation rate for each crop category. The regional yield for Scotland for areas outwith the Less Favoured Areas (LFA) was set at 5.67 tonnes/ha. Each year, the compensation rates were converted into pounds using the effective euro exchange rate (for example 0.643937£/€ for 2002; Chadwick 2002). Thus a premium rate per hectare was estimated every year for each crop group. These payments were then reduced for the overshooting of regional base areas and modulation. Regarding overshooting, when the regional base area, equal to 551,592 hectares in Scotland, was exceeded payments to all claimants in the region were scaled back according to a penalty reduction that was defined in relation to the overshooting of the base area. For example, in 2000 the base area was overshot by 2.25% giving a penalty reduction of 2.2% (Chadwick, 2001). Modulation is effectively transferring money from the SFP (Pillar 1) to the funding of the Rural Development Programmes (Pillar 2). Further details on modulation are provided in Section 2.3.3. Additionally, producers were obliged to set-aside 10% of the total claimable area, i.e. area of cereals, linseeds, flax, hemp, oilseeds, proteins and set-aside, in order to receive the payments.

In Scotland the Reform was brought into effect on 1 January 2005. The model chosen was the historic SFP Scheme under which each farmer was granted entitlements per hectare relating to the reference amounts and the reference areas that gave rise to the direct payments in the reference period 2000-2003. The standard

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[5] http://ec.europa.eu/agriculture/healthcheck/index_en.htm

entitlements corresponded to arable and grassland, while the set-aside entitlements corresponded to land that was put to set-aside. The value of the entitlements was equal to the reference amount divided by the reference area. The reference area was: i) in the case of arable schemes, the average of eligible hectares that gave rise to arable payments, i.e. area of cereals, linseeds, flax, hemp, oilseeds, proteins, and set-aside land in excess of the 10% requirement; ii) in the case of set-aside, the 10% of the total claimable area (Scottish Executive, 2005a). The reference amount was calculated on the basis of average claims made during the reference period, using 2002 payment rates (Chadwick, 2006). Specifically, the reference amount was equal to: i) in the case of arable payments, the average eligible areas claimed multiplied by the 2002 payment rates; ii) in the case of set-side, the land that gave rise to set-aside payments multiplied by the 2002 set-aside premium rates. The total number of entitlements equated to the average reference area. Payments were adjusted for the overshoot of the base area and the national reserve. The overshoot corresponded to an average 3.13% reduction over the three years (Scottish Executive, 2005a). The national reserve, which aimed to help producers who would be seriously disadvantaged by the Reform, was equal to 4.2% of all entitlement allocations (Scottish Government, 2008b). Payments were also subject to deductions due to voluntary and compulsory modulation as described in section 2.3.3. For an entitlement to be activated, it had to be matched with an eligible hectare of agricultural land, i.e. arable or forage area for the standard entitlements and land managed under the set-aside rules for set-aside entitlements. Land under permanent and horticultural crops was not eligible as of June 2007, but has been made eligible thereafter (Scottish Government, 2007c). The set-aside obligation continued to be in force[6]. The only payments that remained coupled were the protein crop premium (55.57 €/ha) and the energy crops premium (45 €/ha) under the Protein and Energy Support Schemes. Producers could claim both the SFP and the coupled payments for the areas used to grow these crops (*ibid*).

Under the CAP Health Check, set-aside has been abolished. The change took effect from 2008 onwards. Set-aside entitlements in effect became standard entitlements

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[6] http://www.scotland.gov.uk/Publications/2004/09/19897/42633

and can thus be activated on land subject to the same eligibility conditions as any other entitlement (Scottish Government, 2008b).

2.3.2 Cross-compliance

For farmers to receive their full payment, they have to conform to a number of SMRs and to the minimum standards of GAEC, as defined by the individual Member States. The Scottish cross-compliance measures were published in 2005 (Scottish Executive, 2005b). These consisted of 15 SMRs and 18 GEAC measures. A *Supplement to the Cross Compliance Notes for Guidance* (Scottish Executive, 2007a) and a number of other modifications[7] were issued thereafter. Additionally, the addition of two GAECs in relation to water resources (establishment of buffer strips along water courses, respect of authorisation procedures for using water for irrigation) was considered under the CAP Health Check (Scottish Government, 2008b)[8]. The GAEC measures are grouped under the headings of i) soil erosion, ii) soil organic matter, iii) soil structure, and iv) minimum level of maintenance. The SMRs and GAEC measures that are of direct relevance to water resources, as described by the Scottish Executive (2005b; 2007a), are shown in Table 2.2.

If a farmer fails to comply with the SMRs and the GAEC measures he/she will be penalised with reductions of the overall amount of his/her direct payments in the year that the non-compliance was found (Scottish Executive, 2005b). A negligent failure to comply is equivalent to payment reductions ranging between 1% and 5%. In cases of intentional non-compliance, the payments can be reduced from 15% to 100% and may result in exclusion from any payments for the following year (*ibid*). From 2007, cross-compliance applies also to schemes that are part of SRDP (Scottish Government, 2007a).

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[7] http://www.scotland.gov.uk/Topics/farmingrural/Agriculture/grants/Schemes/CComplianceupdates

[8] The details related to these GAECs, and whether they have been enforced or not is not clear from the information published in the Scottish Government website.

Table 2.2 Cross-Compliance measures potentially related to water quality

Measure	Description
Statutory Management Requirements	
SMR 2* - Protection of groundwater against pollution	Farmers need to ensure that they have an authorisation from SEPA in order to dispose List I or List II substances, such as waste sheep dip and pesticide washings to land, in accordance with CAR.
SMR 3 - The use of sewage sludge in agriculture	"Sludge producers…and the farmers applying sludge on their land must follow the Sludge… Regulations 1989."
SMR 4 - Protection of water in Nitrate Vulnerable Zones	"Farmers with land in NVZs must follow the rules set out in the Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2003…detailed in the "Guidelines for Farmers in Nitrate Vulnerable Zones" (2003) …."
Good Agricultural and Environmental Conditions	
GAEC 1 - Post-harvest management of land	"All cropped land over the following winter must, where soil conditions after harvest allow, have either crop cover, grass cover, stubble cover, ploughed surface or a roughly cultivated surface."
GAEC 2 - Wind erosion	"…reduce the risk of soil loss in the spring by maintaining a crop cover, using coarse seedbeds, shelter belts, nurse crops, or take other appropriate measures…"
GAEC 3 - Soil capping	"…you must form a coarse seedbed or break any cap that forms to avoid erosion."
GAEC 4 - Erosion caused by livestock	"…prevent the erosion of land and in particular banks of watercourses, at watering points and feeding areas from overgrazing…"
GAEC 5 - Maintenance of functional field drainage systems	"…maintain functional field drainage systems…unless environmental gain can be achieved by not maintaining field drainage systems."
GAEC 6 - Muirburn Code	"…follow the latest edition of the Muirburn Code."
GAEC 7 - Arable crop rotation standards	"Use suitable break crops in an arable rotation" and "Optimise the use of organic materials by basing the rate of application on soil and crop needs."
GAEC 8 - Arable stubble management	"Incorporate livestock manures within 2 weeks after spreading on stubbles."
GAEC 9 - Appropriate machinery use	"Do not carry out any cultivations if water is standing on the surface or the soil is saturated".
GAEC 19* - Abstraction of water for irrigation	Farmers need to comply with the CAR and depending on the amount of water abstracted they need to follow the relevant General Binding Rule, or obtain a registration or license.

* Measure has been updated or added after the first publication of the cross-compliance measures by the Scottish Executive (2005b)

Source: Scottish Executive (2005b; 2007a); http://www.scotland.gov.uk/Topics/farmingrural/Agriculture/grants/Schemes/CComplianceupdates

2.3.3 Modulation and Rural Development Programmes

The concept of modulation is not new, but under the Reform it has been made compulsory. Previously it was up to Member States to decide whether or not to apply it. In Scotland, both compulsory and voluntary modulations are being used. The initially planned modulation rates were modified after the CAP Health Check. The yearly rates are shown in Table 2.3. The first €5000 of SFP is exempt from compulsory modulation[9].

Table 2.3 Modulation rates in Scotland

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Compuls.	0%	0%	0%	0%	3%	4%	5%	5%	7%	8%	9%	10%
Voluntary	2.5%	3%	3.5%	3.5%	3.5%	4.5%	5%	8%	6.5%	6%	5%	4%

Source: http://www.defra.gov.uk/foodfarm/farmmanage/singlepay/furtherinfo/modulation.htm; Scottish Executive (2007b); Meat & Livestock Commission's Planning & Forecasting Group (2002);

The modulation funds are spread across the three Axes of the SRDP. The majority of the funds (70%) of the total rural development budget, including voluntary modulation, are devoted to Axis 2 (Scottish Executive, 2007b), which is the Axis for *Improving the environment and countryside* (Scottish Executive, 2008a). The rest of the funds will be distributed between Axis 1 on *Improving the competitiveness of the agricultural and forestry sector* and Axis 3 on *The quality of life in rural areas and diversification of the rural economy* (*ibid*), at 16% and 11% respectively (Scottish Executive, 2007b).

The RDCs, previously known as Land Management Contracts, are one of the three key components of the SRDP, along with the Less Favoured Area Support Scheme and LEADER (Scottish Executive, 2008a). The RDCs are seen as the main vehicle for the delivery of support to rural land managers (Clayden, 2006), and as an opportunity for an integrated approach to land management and rural development (Schwarz *et al.*, 2007; Clayden, 2006). They combine social, economic and environmental measures under a single *contract* of assistance and can incorporate

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[9] http://www.scotland.gov.uk/Publications/2008/06/11125012/9

measures from all 3 main Axes of the SRDP (Scottish Executive, 2008a). They offer three different levels for incentivising environmental public goods (Clayden, 2006):

- Tier 1 consists of the SFP and the Cross-compliance measures. It is a basic standard that all recipients must meet (*ibid*). The payments are derived from Pillar 1, and are not part of the SRDP funding (Scottish Executive, 2008a);
- Tier 2 is a menu scheme of different measures aiming to deliver widespread benefits of economic, social and environmental improvement. It was introduced in 2005 as the Land Management Contract Menu Scheme, and developed into RDCs-Land Managers Options (LMOs). It includes a range of widely applicable agri-environmental measures that go beyond those delivered by Cross-compliance and other EU and national legislation (*ibid*). Land managers can choose from this menu of 21 measures and receive support up to the value of their LMO allowance, through a non-competitive allowance-based delivery mechanism (*ibid*);
- Tier 3 was introduced in 2007 as RDCs-Rural Priorities. It is a competitive scheme tailored to regional priority objectives of economic, social, and environmental enhancement (Scottish Executive, 2006; Scottish Executive, 2008a). It comprises 75 measures and sub-measures (Scottish Executive, 2008a).

The accomplishment of each of the measures gives a right to the payment rate of the relevant measure. The payment rates do not include incentive elements but only income foregone, additional costs incurred by recipients in implementing the measure and, where appropriate, transaction costs (*ibid*). The SRDP measures that are relevant to water quality as outlined by the Scottish Executive (2008a) and the Scottish Government (2008c) are shown in Table 2.4. Water quality objectives are of importance within the framework of the SRDP and RDCs. *Improved water quality* is one of the three outcomes of Axis 2 measures. Also, the Scottish Executive (2008a) states "*LMOs...will contribute to the implementation of national, EU and international obligations including...the Water Framework Directive.*". In September 2010, the Scottish Government identified the reduction of diffuse pollution as a new *National Target*, out of the six *National Targets*. Contribution towards these targets is meant to greatly assist the assessment of applications under Rural Priorities.

Table 2.4 Scotland Rural Development Program 2007-2013 related to water management

Measure	Summary of Objective/Actions	Axis (Measure code)	Scheme
Nutrient Management Plan	Optimise the amount of nutrients applied by matching organic and inorganic fertiliser to crop requirements.	1 (3)	LMOs Rural Priorities
Management of Grass Margins and Beetlebanks in Arable Fields	The creation of grass strips in or around arable fields to benefit biodiversity and water quality by reducing soil erosion and nutrient run-off.	1 (14)	LMOs
Soil and Water Management Programme	Assessment of risks from erosion, compaction, structural degradation, loss of organic matter and contamination; adoption of management to address the issues, identification of improvement.	1 (4)	Rural Priorities
Manure/Slurry Storage and Treatment	Improve manure storage, handling and application facilities and/or manure treatment.	1 (6, 7)	Rural Priorities
Provision and Upgrading of Infrastructure related to Access to Farm and Forest Land, Energy Supplies and Water Management	Invest so as to improve viability, increase market orientation and/or achieve other benefits such as reductions in diffuse water pollution (e.g. storage reservoirs or other infrastructural elements to improve efficiency and/or sustainability).	1 (14)	Rural Priorities
Treat Run-off of Pollutants - Biobeds and/or Farm Wetlands	Creation of biobeds or farm wetlands.	1 (15,16)	Rural Priorities
Conversion and Maintenance of Organic Farming	Convert to organic farming and/or maintain organic farming.	2 (1)	Rural Priorities
Water Margins and Enhanced Riparian Buffer Areas	Protect water margins from erosion and diffuse pollution, by encouraging the development of waterside vegetation and riparian buffer areas	2 (21)	Rural Priorities
Arable reversion to grassland	Reduce diffuse pollutions and soil erosion by changing previously arable land to permanent grassland, ungrazed or with low stocking rates and with zero or low fertiliser input.	2 (40)	Rural Priorities
Livestock Tracks, Gates and River Crossing	Improvements in changing the location of tracks, gateways and river crossings.	2 (42)	Rural Priorities

Source: Scottish Executive (2008a); Scottish Government (2008c); http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Options

2.4 The Nitrates Directive

Council Directive (91/676/EEC) *concerning the Protection of Waters against Pollution Caused by Nitrates from Agricultural Sources* was adopted by the EU in 1991 with the aim of reducing existing and preventing of future water pollution from inorganic and organic N sources, taking into account regional particularities across the EU. The Member States were responsible for identifying the areas of surface waters and groundwaters within their territory that were severely affected by nitrate pollution and designate the areas draining into them as NVZs. Severely affected water bodies were those where nitrate concentrations in water were approaching or had reached 50mg NO_3/l (Scottish Executive, 2006). Subsequently action programmes needed to be established laying down regulations with which farmers operating within NVZs had to comply to reduce the impact of farming practices on the water environment. These action programmes and the NVZ designations need to be reviewed and if necessary revised every four years.

In Scotland, 14% of the land was designated under NVZs in 2002 (*ibid*). This consists of four NVZ zones affecting around 12,000 farms of various types and sizes (Barnes *et al.*, 2007). These are i) Lower Nithsdale, ii) Lothians and the Borders, iii) Strathmore and Fife, and iv) Aberdeenshire, Moray Banff and Buchan (Scottish Executive, 2006). The Scottish NVZ designations were reviewed in 2004-05, and it was concluded that there was no strong reason for amending the present NVZ boundaries (*ibid*).

The action programme was established in 2003 and is laid down in the *Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2003* (The Stationery Office, 2003) and explicitly set out in the *Guidelines for Farmers in Nitrate Vulnerable Zones* (Scottish Executive, 2003). In 2006, the Scottish government consulted stakeholders on a number of modifications to the 2003 Action Programme (Scottish Executive, 2006). The consultation was published on 16 November 2006 and comments on it were invited by 15 February 2007 (Scottish Executive, 2007c). An analysis of the responses was published in September 2007

(Scottish Government, 2007b). The final revision of the Action Programme was carried out in 2008 leading to the *Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2008* (The Stationery Office, 2008) that came into force on 1 January 2009. These regulations are described in the *Guidelines for Farmers in Nitrate Vulnerable Zones* (Scottish Executive, 2008b).

The measures prescribed by the regulations can be broadly classified into five categories: i) restrictions on the quantity of applied N, ii) restrictions on the timing of N applications, iii) manure storage requirements, iv) record-keeping requirements, and v) other restrictions on application. Table 2.5 depicts i) the individual measures of the 2003 Action Programme described by Scottish Executive (2003); ii) the modifications proposed in the consultation and an indication of whether the majority of respondents to the consultation agreed or disagreed with the proposed amendments indicated by the Scottish Executive (2006); iii) amendments/additions introduced by the 2008 Action Programme described by Scottish Executive (2008b).

It is interesting to note that the summary of the views expressed in the consultation was introduced as follows (Scottish Executive, 2006):

> "*The farming sector...felt that other proposals had been made without due weight having been given to the* ***cost to farmers****....the environmental sector respondents were generally supportive of measures that were tighter than present ones where they considered there...would ensure a smoother transition to future requirements under the terms of the* ***Water Framework Directive****. Some of these respondents considered that more assessment should have been made of the* ***benefits to the environment****...from reducing nitrogen levels in the water.*"

This clearly demonstrates the requirement of reconsideration of both costs and benefits of any potential measures. It also implies that there was unease as to whether the previous measures would have been sufficient under the WFD requirements. Scottish Government also states "*In selecting these measures or actions we are to take into account their effectiveness and their cost in relation to other possible preventative measures.*" (*ibid*), highlighting the need for a comprehensive cost-effectiveness analysis informing the suggestion and selection of measures.

2.5 Conclusions

The analysis demonstrates that the farming sector poses significant challenges in achieving the WFD objectives. Interestingly, the Scottish government is in the process of setting up an integrative policy environment where the different policies are combined in order to achieve synergistic effects. This is one of the initial propositions of this thesis and it is noteworthy that the most recent policy developments are moving in this direction. However, significant challenges still remain in terms of policy assessment and future policy design. As identified in Chapter 1, this requires a methodology that is able to provide an integrated assessment of both the costs in terms of farmers' incomes and the improvements in terms of water quality. The following chapter reviews methods of integrated assessment that can be applied to assess the impacts of policies in relation to agriculture and the water environment.

Table 2.5 Previous, proposed and current measures under the NVZ Regulations

Action programme for Nitrate Vulnerable Zones (Scotland) Regulations 2003	**Action programme for Nitrate Vulnerable Zones: Proposed Amendments**	**Action programme for Nitrate Vulnerable Zones (Scotland) Regulations 2008**
Restrictions on the Quantity of N		
Organic and inorganic nitrogen application must not exceed crop requirements, and must take into account i) crop uptake and soil supply from organic matter, crop residues and manures; ii) soil conditions, soil type, and slope; iii) climatic conditions, rainfall and irrigation; iv) land use, agricultural practices, crop rotations.	Introduce a statutory mechanism for assessing N fertiliser crop requirement, including a revision of the standard reference figures for the N content of livestock excreta and the calculation system (A). Limit the amount of N that can be applied to each crop, averaged over the whole farm.	This amendment was accepted, and a new Nmax procedure for calculating maximum permitted N was introduced. Calculations need to be made in accordance with standard tables and a defined procedure, prior to making applications of fertilisers. Compliance is assessed at a crop type rather than an individual field level.
Applications of organic manure (including grazing deposition) must not exceed 250kg/ha for grassland, and 170kg/ha on other land, averaged over the whole area in any 12 month period. A field limit of 250kg/ha applies to all individual fields (excluding grazing deposition).	Reduce the limit of 250 kg/ha for grassland to 170 kg/ha. (D)	This amendment has been put into action, and now the 170kg/ha loading limit for livestock manure applies to all land within NVZs
Restrictions on the Timing of Applications		
Closed periods for inorganic fertiliser: Grassland: 15/09 – 15/02 Other Land:1/09-15/02(20/02 in Aberdeen NVZ)	Extend the application limit to the end of September for oilseed rape, other brassicas and catch crops used as fodder.	Application to winter oilseed rape, and a maximum 100kg/ha application to other brassicas is permitted during the closed period.
Closed periods for slurry, poultry manure or liquid sewage sludge on sandy/shallow soils: Grassland or autumn sown crop: 1/10-1/11 Other Land: 1/08 – 1/11	Extend the closed periods and make them applicable to all soil types, choosing between a) distinguishing between soil types (A) and b) not distinguishing (D). Include more manures and fertiliser types (A). Restrict the amount of organic manure applied before and after the closed period (A). Leave a period of three weeks between each application of manure to a field.	Closed periods for manures with high N content have been extended and apply to all soil types: Sandy/shallow soil, grassland: 01/09-31/12 Sandy/shallow soil, other land: 01/08-31/12 Other soils, grassland: 15/10-15/01 Other soils, other land: 01/10-15/01 Quantitative restrictions also apply 4 weeks prior to the closed period and until 14/02.

Storage Requirements		
Sufficient **storing capacity** to hold any slurry/poultry manure that cannot be applied to land due to closed periods. **Field middens** should be at least 10m away from surface waters and 50m away from wells or boreholes.	Add explicit directions on the calculation of sufficient storage capacity (A), using the revised guidelines to assess storage capacity (D), specifying the types of manures to be stored in field middens (D), etc.	Minimum storage requirements for manure types have been specified: 26 weeks for pig slurry and poultry manure, 22 weeks for cattle slurry. Solid manures can be stored in temporary field heaps for up to 12 months.
Record-keeping Requirements		
Fertiliser and Manure Plan including expected manure, storage capacity and land for spreading manure, assessment of available N, and assessment of crop requirements.	Obligatory preparation of the Fertiliser and Manure Plan according to the revised guidelines for farmers in NVZs (A). Include a risk assessment plan (A)	All applications of N fertiliser must be recorded according to the defined procedures and a risk assessment plan for organic manures needs to be produced.
Farm records on a) farm area, b) quantities, type and dates of application of chemical and organic fertilisers for each field, c) the number and type of livestock on the farm, d) the quantity and type of manure moved off and onto the farm	Additional information on soil type, amount and types of fertilisers, etc (D).	Farm on a) farm area, b) area, soil type, crop, quantity, types, dates of application of chemical and organic fertilisers for each field c) number, type, length of time livestock kept on farm, d) quantity, type of manure moved off or onto farm
Other Restrictions on Application		
Accurate application and testing of **spreading equipment**.	Prohibit some type of equipment for slurry spreading (D).	Slurry cannot be applied using a high trajectory splash-plate spreader, unless the application is made on land where arable crops are growing.
No application to uncropped areas, hedges, watercourses, steep sloping fields, waterlogged, flooded, covered with snow, or frozen land.	Prohibit application of manure to bare ground (D).	If manure is applied to bare ground during July, August, or September, crop must be sown within 6 weeks of the first application.
Organic manure should not be applied to land less than 10m from a **watercourse**, or within 50m of a well or borehole.	Chemical fertilisers should not be applied within 2 meters of inland or coastal waters (A).	This amendment has been put into action.
Vegetable residues should be incorporated into the soil when an autumn sown crop is established before 1/10, or left untouched until 1/12.		

(A): Agree; (D): Disagree

Source: Scottish Executive (2003; 2006; 2007c; 2008b)

3 Methods, Models and Reviews of Integrated Impact Assessment

3.1 Introduction

The increasing importance of the assessment of environmental and agricultural policies has led to the development of a very broad range of modelling techniques. Even though this implies that a single model classification and the coverage of all possible modelling approaches is not a straightforward task, it is essential to consider the key characteristics of models and modelling frameworks that can be applied to analyse water policy measures in relation to agriculture. Letcher & Bromley (2006) identified a number of key model characteristics for integrated water resource management, including treatment of time and space and whether the models used are data based or process based. Other issues of importance are the level of integration between different modelling components, and the specifications of economic and ecological models. Finally, in addition to the specific characteristics of modelling frameworks and models adopted, the way a model has been applied is of interest. For example, the defined farm types and soil types, the considered indicators, and the assessed measures and policies are all important in determining the outcomes of any modelling application. This chapter reviews and discusses these issues with illustrations from previous studies.

3.2 Systems, Scales and Policy Integration

3.2.1 Systems Integration

Integrative models are a means to express the performance of a formulated system in terms of a set of defined indicators (Rossing *et al.*, 2007). The integration of ecological and economic modelling can be achieved through a number of approaches with different degrees of coupling between the components of the analysis representing the economic and ecological systems. The different model components can be loosely integrated, with some of the models generating information which is used as input in the other model components, or tightly integrated allowing feedback between the sub-models. From a technical point of view, model coupling is usually characterised as *loose* when the outputs of models are linked externally to the original models, perhaps manually, and referred to as *tight* where the different modelling components are engineered to share inputs and outputs (Letcher & Bromley, 2006).

Models aimed at the integration of natural science and economic analysis have been effectively classified by Vatn *et al.* (2006) into three basic categories: a) "analyses that are dominantly economic, but where rather simple or indirect environmental indicators are attached to the economic analyses", b) "analyses that are still dominantly economic, but where the estimation of environmental indicators is more sophisticated", and c) analyses where the structure of integration of economic and natural science models takes into account the interactions between farmers' actions and the dynamics of the natural systems.

In the first category of models, the bio-physical factors related to productivity and environmental damages are represented by using simple or indirect indicators that are often linked to the levels of production of outputs or consumption of inputs (Flichman, 2002). For example some studies use fertiliser input as a proxy for pollution from agricultural sources (e.g. Bartolini *et al.*,2007; Blanco, 2006; Gómez-Limón & Riesgo 2004a; 2004b) and others estimate the effect of N surplus at farm or sector level (e.g. Dietz *et al.*, 1991; Vermersch *et al.*, 1993; van Calker *et al.*, 2004).

The second category of models uses field experiment data or natural science models to establish agronomic and environmental pollution relationships as a function of agronomic practices, soil conditions etc. (Vatn *et al.*, 2006), which are then used as an input to the economic model. An increasing number of such studies exist. Some examples include Mimouni *et al.* (2000), Flichman (1997), Belhouchette *et al.* (2004), and Martínez & Albiac (2006).

Finally, the models pertaining to the third category allow for feedback between the economic model and the models that simulate natural processes. The way different models are integrated and the system interactions that are taken into account vary substantially between models. For example ECECMOD (Vatn *et al.*, 2006), analysing the effect of policies that target agricultural pollution, allows for feedbacks between farmers' choices, the agronomic system, and soil processes. The NELUP framework (O'Callaghan, 1995) links economic, hydrological, and ecological models to examine the effects of land use change.

Although the third approach allows a closer representation of the actual feedback between the bio-physical and socio-economic systems, its operationalisation is not a trivial task. That probably explains the very small number of models with explicit links and feedbacks between the models representing the natural and the economic systems. As Vatn *et al.* (2003) suggest one would like to model all processes simultaneously and explicitly, but this is hindered by limited understanding of some processes and danger of over-complex and opaque models.

3.2.2 Integration across Spatial Scales

Chapter 1 identified a number of important considerations regarding spatial and temporal scales in the design and implementation of integrated models (resolution, extent, classifications and methods of aggregation of ecological and economic relationships). In agronomic and environmental processes the main unit of operation and analysis is usually the field. On the other hand, the spatial resolution of the economic agent plays a role that goes beyond the strict representation of space, as we are dealing with management units as opposed to spatial units, with the farm being the main management unit of the agricultural system (Payraudeau & van der Werf, 2005). That is why it is often argued that the farm-level approach is appropriate i) for primary policy analysis, since it is the real unit of operation and the level at which the actual decisions about cropping patterns, production intensity, etc. are made (Falconer & Hodge, 2001; Kostrowicki, 1977) and ii) for environmental assessment methods, as illustrated by the multiplicity of methods proposed at the farm level scale (Payraudeau & van der Werf, 2005).

Typical approaches for achieving assessment at the farm level are i) assessing the farm as a whole, often using a nitrogen balance approach, and ii) synthesising results from individual fields (*ibid*). Examples of the first approach (e.g. van Calker *et al.*, 2004; Vermersch *et al.*, 1993) typically focus on one or few representative farms and it is often assumed that only one soil type covers the whole farm (e.g. van Calker *et al.*, 2004, Rossing *et al.*, 1997). Alternatively, the synthesis of individual fields into farms can be incorporated in the definition of the farm type, by using the criterion of the availability of the area/number of fields of each land category of the individual farms (e.g. Bouman *et al.*, 1999). The second approach provides a more realistic systems representation as space is divided into homogenous units, the different processes are modelled at the appropriate level, and then up-scaled through aggregation procedures. Additionally farmers tend to change production practices on different fields over time and a farm gate nutrient budget approach seems to disregard this aspect. However, the challenge of aggregating fields to the farm level is associated with high data intensity, as it requires information on the endowments of land units of differing characteristics for individual farms. Although this might be feasible for studies looking at a small number of representative farms, this is hardly ever the case when looking at geographic areas of greater extend. Additionally, the classification to be used for the establishment of homogenous land units is not straightforward as it often depends on the sensitivity of the environmental outputs to different natural factors such as soil texture, slope, etc.

The next level of upscaling/aggregation takes place between the farm and the regional/catchment/river-basin level. As discussed in Chapter 1, analysis at this level is more appealing to policy makers who are interested to the aggregate results of policies. As in reality every farm is unique in terms of its resource endowments, its decision-making problems and thus its production and management pattern, ideally one would like to model separately each individual farm in an area under study and then aggregate the outcomes at the regional/catchment/river basin scale. However, such an attempt requires a prohibitively large amount of data and computational power, especially when the economic model is linked to other models, and hence is hardly ever feasible in practice. Consequently, typically farms are modelled in some aggregate manner by either modelling a single large aggregate farm representing all farms and their resources in the study area, or by separating the farms of the study area into smaller groups of farms, developing a model for each group, and multiplying the results in accordance to the frequency of each farm type in the area (Moxey *et al.*, 1995). The first approach is associated with unrealistic assumptions, as farm boundaries, resource ownership and farmers' behavioural heterogeneity in relation to their resources and production patterns are totally ignored. In both approaches however the combination of small heterogeneous farm units into larger units of analysis is the source of aggregation problems, which create biases in the supply outcomes of the relevant optimisation problems. The main source of these biases is that each real farm deviates from the aggregate or the average farm that is modelled in terms of resource availability. As resource mobility is overstated by allowing farms to combine resources in proportions that are not available to them directly, the aggregation biases are always in an upward direction (Hazell & Norton, 1986). Hazell & Norton (1986) and Barker & Stanton (1965) show this with simple examples for the aggregate farm and the average farm, respectively. The degree of bias can be reduced by increasing the number of farms to represent the population of all the farms (Barker & Stanton, 1965) and by adopting the criteria used for their classification to minimise the variation within classes. Thus the approach of using a well-grounded farm typology seems more promising that modelling a whole case study area as if it was a single farm. The classifications used to capture decision making heterogeneity between farmers are discussed in section 3.3.3.

3.2.3 Integration across Temporal Scales

As identified in Chapter 1, temporal integration and respective modelling choices are challenging due to the multiplicity of the temporal scales of the different processes to be modelled, and because policy decision-making is interested in the long term effects of policies. A thorough typology of treatment of time in economic models is provided in Blanco Fonseca & Flichman (2002):

- *Static Models*: In static models time is not taken explicitly into account. The optimal value of the objective function is calculated for a given moment, time is not included in the model's structure, and decision variables do not depend on time.
- *Inter-temporal optimisation models*: These models take into account all periods included in the planning horizon of a decision-making problem. Optimisation is performed over a discounted flow of returns, where temporal

preference is taken into account. They can be deterministic, where complete and perfect information about the future is assumed, or stochastic, where knowledge of the future is given in terms of probabilities of different states of the system.

- *Recursive models*: Recursive models are also dynamic models, but ones where optimisation is performed for each period separately, rather than over the entire planning horizon of a decision problem. In these models the results of each decision period have an influence on the decisions to be taken in the following decision period, i.e. the results of one simulation are used as the starting point for the next simulation (Belhouchette *et al.*, 2004).

The key advantages of dynamic models are that they are able to analyse problems where certain decisions have consequences for future periods or where the transition over time of a system from one state to another is explored (Blanco Fonseca & Flichman, 2002). In the sphere of natural and resource economics this can be the case when natural resources need to be analysed as stocks and flows of natural capital the status of which has a direct impact on the provided utility throughout time. An example is deterioration of yields due to increased soil salinity or depletion of soil organic matter. Additionally, such models are useful for analysing investment and credit decisions.

Where there are no such problems, the use of dynamic programming merely adds superfluous modelling complications as these models are associated with greater complexity, model size, data requirements, and simulation time. That is why static models appear to be more popular for bio-economic modelling applications. In fact, in a review of bio-economic models, Janssen & van Ittersum (2007) commented that most bio-economic models do not explicitly take into account time and tend to simulate a period with a single time step. In the case of water pollution from agriculture, the key factors that have a critical effect over time on farmers' decision making and the associated pollutant losses are rotational effects, as the previous crop in a rotation impacts on the levels of fertilisers to be applied and the losses arising. However, given that there are ways in which static models can be used to model the environmental effects of some farming practices (*ibid*), using a simpler or implicit representation of time compared to an explicit dynamic model might be a more efficient way to approach the problem of rotational effects on water pollution.

3.2.4 Policy Integration

As discussed in Chapter 1, the identification of potential synergies or trade-offs between policies regarding the implementation of the WFD are important, and hence greater attention is required to the interplay between water quality measures and CAP scenarios (Bartolini *et al.*, 2007). A variety of studies have already attempted to assess the socio-economic and environmental implications of alternative water policy options (e.g. Bartolini *et al.*, 2007; Blanco, 2006; Martínez & Albiac, 2006; Mejías *et al.* 2004; Gómez-Limón & Riesgo, 2004a; 2004b). However, there are a very limited number of studies (e.g. Bartolini *et al.*, 2007; Mejías *et al.*, 2006, Bazzani, 2005) that take into account the interactions of the WFD with CAP, and these studies either focus on water quantity rather than water quality problems or use simple or indirect indicators for the integration of agronomic and environmental effects.

3.3 Economic Component

3.3.1 Predicting and Understanding Behaviour

Economists have long experience of using models to predict the behaviour of socio-economic agents at the micro, meso and macro scales. An interesting summary of economic approaches for predicting and understanding human behaviour is provided by Cooke *et al.* (2009). Although their review was aimed at readers from an ecology background, it is also useful for economists as it is based on a review of papers on integrated models focusing on agricultural systems. The three main approaches that Cooke *et al.* (2009) have distinguished are those that: i) "assume humans are rational optimisers" (rational optimisation), ii) "calculate the likelihood of a behaviour by evaluating an individual's motivations, the strength of belief that the behaviour will make a difference and the opinions of others on the consequences of the behavioural change" (socio-psychological approaches), and iii) "describe macro-scale behaviour using phenomenological relationships" (aggregated models) (*ibid*). Cooke *et al.* (2009) further subdivide the models in the first category into mathematical programming models (where the decisions of individuals are independent), game theory models (where individual decisions depend on the decisions of others), and techniques from the field of bounded rationality such as heuristics (where the assumption that knowledge is freely available and that decision-makers use this knowledge to reach a set of choices is relaxed). Socio-psychological approaches, such as the Theory of Planned Behaviour, instead of assuming the occurrences of objective optima, quantify behaviour as a product of beliefs, values or other psychological factors. Finally, aggregated models, such as models of macro-economic analysis, disregard individual-level detail and describe phenomena at a higher level (*ibid*).

The framework of rational optimisation, using mathematical programming models (MPMs) based on the assumption of a utility maximising behaviour, has been widely used for agricultural economics policy analysis. An optimisation-based MPM selects the optimal allocation of farm resources to a large number of alternative agricultural activities described by an input-output matrix in terms of its inputs and its emissions (Stoorvogel, 1995). Optimisation of a specified objective function is applied, subject to technical, agronomic, economic and policy constraints which limit the selection of possible activities. For each of the policy scenarios modelled, the parameters or constraints representing the scenario are altered, invoking changes in land use and the economic and environmental outcomes of the optimisation. The comparison of those outcomes with a base scenario facilitates the ex-ante impact assessment of policies and consequently their design. The key advantage of MPMs is that they can explicitly model complex policy or technological constraints under which behavioural functions cannot be obtained easily or at all (Heckelei & Wolff, 2003).

Socio-psychological approaches could be particularly useful in cases where there is suspicion or evidence that apparently rational decisions are not preferred by some farmers for cultural, psychological or institutional reasons. For example, if the introduction of an economically advantageous agri-environmental measure is not widely adopted, then a socio-psychological approach would help to identify the barriers to otherwise economically efficient behaviour. Also it can be potentially useful in cases where costs and benefits are difficulty to quantify in a utility framework. Methodologies of socio-psychological approaches and those based on a rational optimisation framework should be seen as complementary rather than substitutes. Different decisions are driven by different motivations for different actors. Some of these motivations can be accounted for by an optimisation framework, while others can only be effectively identified by socio-psychological approaches.

Macroeconomic models can often be MPMs, as mathematical programming has been shown to be a particularly useful tool for simulating the effect of new policies upon a sector (McCarl & Spreen, 1980). Other macroeconomic approaches include input-output analysis, general equilibrium modelling, and econometric approaches. For an extensive review of macroeconomic approaches see Blitzer *et al.* (1975). Even though aggregated models at the regional, national and international scales provide important insights into the economy-wide effects of production systems, inter-sectoral linkages, and sectoral structure analysis, they are not particularly suited for analysing aspects of water pollution from agricultural sources that have largely local effects. A major limitation is that they mask ecological and behavioural heterogeneity by discarding or disregarding detail in the outcomes produced by highly heterogeneous agents (e.g. farmers with varying production orientations, resource endowments, risk perceptions, etc.) and occurring through processes that take place at a much finer spatial resolution (e.g. the field). As Fischer *et al.* (2005) state "aggregation produces deceivingly small numbers".

3.3.2 Objective Function Specifications

In a rational optimisation framework using mathematical programming approaches, the objective function is the driving force of the model outcomes. Objective functions can incorporate multiple goals relating to economic, environmental, agronomic and social issues. In a review of bio-economic farm models, Janssen & van Ittersum (2007) found that out of the 42 reviewed, 23 model the farmer as a simple profit maximiser, five account for profit maximisation minus some risk factor, five look at expected utility (e.g. measuring utility through interviews or by including long-term goals), and nine use a multi-criteria approach.

An objective function based on multiple and often conflicting environmental, economic, and social criteria is closer to a representation of society's goals, as these are pursued by policy-makers, rather than farmers' goals which are usually more focused on production-related outcomes. An advantage of an approach simulating multiple objectives is that it can be more easily used in interaction with farmers, policy makers, and other stakeholders involved in the planning process for identifying objectives and their importance to stakeholder groups. Additionally, it allows the exploration of normative system solutions, which maximise the objectives describing societal welfare. The main shortcoming of such an approach is that unless the weights for the different criteria associated with each of the goals are explicit in the objective function so that they can be altered to represent farmers' objectives, then it does not allow assessment of the potential adoption of policy instruments, when, as is often the case, farmers' objectives and the objectives of society diverge.

Vatn *et al.* (1999) effectively contextualise the above problem in the case of water pollution. They suggest that the solution of the optimal level of policy instruments for achieving water pollution objectives is in essence a principal-agent problem, where the principal (policy maker) incentivises the agent (farmer) to adopt production practices that satisfy the demands of society. The operationalisation of such a problem is not trivial as its complexity will often make it difficult to determine optimal levels of policy control variables. As the authors conclude, an alternative approach that does not necessarily reduce information quality, while it increases transparency and allows for preservation of higher resolution in the environmental space, is to use a cost-effectiveness criterion which measures the costs for obtaining certain levels of emission reductions. Effectively, here the optimisation problem of the principal is omitted and instead information is generated for him through scenario modelling (*ibid*).

The next important consideration is defining the actual farmers' objectives that are to be represented by the objective function of the model. As shown by Janssen & van Ittersum (2007), the profit maximisation objective seems to be one of the most commonly used. It also is one of the most commonly criticised as not capturing the major driving forces of farmers' decision making and the full range of goals and complexity of farmers' behaviour and motivation (e.g. Austin *et al.*, 1998; Wallace & Moss, 2002; Dent *et al.*, 1995). Nevertheless, a profit maximisation criterion is easier to handle analytically, hence avoiding further complications in very complex model structures (Vatn *et al.*, 1999).

A more complex preference structure can be represented by the incorporation of risk aversion in the model objective function. Farmers face two main sources of uncertainty that are significant sources of farm income variability: production and output prices (Isik, 2002). Ignoring risk and its aversion might lead to misleading inferences (Roe & Graham-Tomasi, 1986) and results that bear little relation to the decisions that farmers actually make (Hazell & Norton, 1986). A very thorough analysis of the implications of production and output price uncertainty for evaluating the effectiveness of market-based policies and examining the interaction between environmental and agricultural policies can be found in Isik (2002).

A number of approaches for the incorporation of attitude to risk in MPMs have been developed over the years. The majority of studies focus on non-embedded risk (Hardaker *et al.*, 1991; Dorward, 1999), where it is assumed that agricultural activities have known resource requirements, but have uncertain returns due to uncertainty about physical yields or output prices (Dorward, 1999). Models dealing with embedded risk allow a sequence of decisions to be made in the light of new information in the course of the decision making process (*ibid*), and thus are often recursive and/or stochastic. These models often assume that along with the uncertainty confined to the objective function coefficients which is also assumed by non-embedded risk approaches, the constraint coefficients are also stochastic (Hardaker *et al.*, 1991). Hazell & Norton (1986) and Hardaker *et al.* (1991) provide thorough reviews of the most commonly applied risk methods. Embedded risk problems and models are much more complex that non-embedded risk approaches and their use is justifiable only in cases where there is considerable uncertainty regarding the associated constraint coefficients.

3.3.3 Farm Typology

The advantages of using a farm typology in integrated modelling studies have been presented in section 3.2.2. The choice of the criteria for the development of a farm typology should be based on the principle of obtaining the maximum amount of heterogeneity between the different farm types, while attaining the maximum degree of homogeneity within each of the farm types (Köbrich *et al.*, 2003), so as to eliminate or minimise potential aggregation bias in the outcomes of the optimisation process.

As emphasised by Day (1963) and as summarised by Hazell & Norton (1986), the elimination of aggregation bias can be achieved when the criteria used for the classification ensure the satisfaction of the following conditions:

1) *Technological homogeneity*: This requires the same technology in each activity between each of the farms and the aggregate farm, with technology being expressed as resource requirements/use in the matrix of resource constraints. According to Hazell & Norton (1986) this means that farms need to have the same type of resources and constraints, the same production possibilities, the same levels of technology, and the same levels of managerial ability.
2) *Pecunious proportionality*: This requires proportionality of the input-output matrixes or the price expectations of individual farmers to each other and the average farm (Day, 1963). In other words, it demands that the expectations of individual farmers about unit activity returns are proportional to average expectations (Hazell & Norton, 1986).
3) *Institutional proportionality*: This means that the constraint vectors (including fixed, quasi-fixed, and behavioural and policy constraints) of individual farms are proportional to the constraints of the average or aggregate farm. This is strictly necessary for the binding constraints of the model solution (Hazell & Norton, 1986).

A number of authors have tried to provide less demanding conditions, for the *minimisation* as opposed to the *elimination* of aggregation bias. A number of these approaches were reviewed by Hazell & Norton (1986), who also provided some rules of thumb for the selection of the aggregation criteria: i) *Similar Proportions in Resource Endowments*: This most often means similar land-to-labour ratios, i.e. classifying farms by class size; ii) *Similar Yields*: This means looking out for differences in climate, soils, elevation, etc., which alone (even apart from the technology employed) create significant yield differences; and iii) *Similar Technologies*: This rule implies separating farms according to predominant crops.

There are several methods, both qualitative and quantitative, for the creation of farm typologies. Quantitative approaches, such as cluster analysis, seem to be particularly useful in cases where a farm typology has to be derived from scratch, as for example in developing countries (Köbrich *et al.*, 2003). Qualitative approaches establish thresholds for the classification criteria, which are either decided *ad hoc* or chosen from the available literature (e.g. Gassman *et al.*, 2002). There are also cases where predefined farm typologies are used, such as the Farm Accountancy Data Network (FADN)[10] or other national or regional typologies which focus on the main land use activities and/or the economic return associated with each of these activities (e.g. Godard *et al.*, 2008).

The most typically used criteria for the classification of farms seem to be land use and size. In the case of cropping farms, size is usually expressed in relation to land and/or labour availability (e.g. Rossing *et al.*, 1997). Also, a number of studies focus on the availability and proportionality of resource endowments and the associated constraints (e.g. Jansen & Stoorvogel, 1998; Bouman *et al.*, 1999). In this case one of the criteria used for the classification is the land/labour ratio for each of the farms, which is often combined with other criteria such as dominant crop group (e.g. Jansen & Stoorvogel, 1998), farm size in terms of area (e.g. Jansen & Stoorvogel, 1998; Bouman *et al.*, 1999), or availability of land units of differing quality (e.g. Bouman *et al.*, 1999). Environmental criteria can also be taken into account, such as thresholds for separating farms with nitrogen surplus from ones within the acceptable nitrogen limits (e.g. Vermersch *et al.*, 1993).

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[10] http://ec.europa.eu/agriculture/rica/concept_en.cfm

3.3.4 Calibration

Calibration can be defined as a way to find the best values for parameters which characterise a given model in order to minimise the difference between model outputs and the actual situation (Santillana & Serrano, 2005). A review of calibration approaches has been recently carried out by Louhichi, Flichman & Mouratiadou (2009). The results of the report, supplemented by information in a recent publication of Kanellopoulos *et al.* (2010), will be summarised in this section. The full version of the report can be found in Annex I.

Linear programming models tend to select agricultural activities with the highest average returns until resources (e.g. land, water, capital) are exhausted. The predicted crop mix is usually less diverse than that observed in reality. The reason for this overspecialisation is that the number of nonzero activities in a linear programming framework is upper bounded by the number of resource constraints (Heckelei, 2002). Since in practice the number of model constraints has to be kept small to reduce complexity and data requirements, overspecialised solutions occur (Kanellopoulos *et al.*, 2010). A number of calibration approaches have been proposed in response to this problem. These approaches can be broadly classified into *approximate* and *exact* calibration methods.

Approximate calibration approaches seek to fit model predictions to observed data allowing a residual deviation between simulated and actual data. They include i) the traditional calibration methods which require more complicated constraint structures to reproduce the observed cropping pattern, such as the imposition of rotational constraints or step function over multiple activities (Meister *et al.*, 1978), and the imposition of upper and lower boundary constraints on certain activities in a recursive procedure (Day, 1961); ii) methods which are based on the addition of risk and uncertainty to the linear programming model such as MOTAD, Target MOTAD, Mean-Variance, and Safety first (Hazell & Norton, 1986); and iii) multi-criteria approaches, such as weighted goal programming and Min-Max goal programming.

The obvious disadvantage of the approaches adding calibration constraints is that the constraints which determine the optimal solution for the base year also affect significantly the policy simulation runs of other scenarios. As a consequence, the solution of the model under policy runs is largely restricted by the base year solution constraints. Additionally, approximate calibration approaches, even though they reduce the calibration problem, cannot calibrate the model exactly and thus substantial calibration problems remain in many cases. The definition of objective and robust thresholds for the evaluation of the fit of predictions and overall model performance is also a problem. Finally, the calibration procedure is generally manual, and thus fits that may be obtained by eye and intuition then play a role in choosing appropriate calibrated parameter sets (Jackson *et al.*, 2004).

On the other hand, *exact* calibration approaches aim at the exact reproduction of the observed situation by the model using formally specified procedures. The first exact calibration approach was proposed by Howitt (1995) under the name *Positive Mathematical Programming* (PMP). The approach stipulates that a divergence between model's predictions and observed reality of a base period means that either some technical constraints or cost (or yield) specifications or both are not taken into account in the model formulation. Consequently, these need to be included in the objective function via a nonlinear cost (or production) function (Gohin & Chantreuil, 1999). Thus, a decreasing marginal gross margin function, justified by increasing variable costs per unit of production due to inadequate machinery and management capacity and decreasing yields due to land heterogeneity (Howitt, 1995), can be used to ensure that the base year activity levels are reproduced (Kanellopoulos *et al.*, 2010).

Several expanded frameworks of the PMP methodology have been developed in order to overcome some of the criticisms of the original version. These include: i) approaches developed for estimating the parameter values of the non-linear functions (Hemling *et al.*, 2001; Paris & Howitt, 1998; Judez *et al.*, 2001); ii) approaches used to solve the problem of the exclusion of crops that are not present in the base year (self-selection problem) (Paris & Arfini, 2000); iii) approaches dealing with the problems of zero marginal product (cost) for one of the calibrating constraints (Gohin & Chantreuil, 1999; Paris & Howitt, 2001; Röhm & Dabbert, 2003); iv) approaches to overcome the inclusion of greater competitiveness among close competitive activities whose requirements for limiting resources are more similar compared to other activities (Röhm & Dabbert, 2003); v) approaches for solving the issues of fixed technology coefficients, and the use of data based on many observations (Paris & Howitt, 2001); and vi) approaches to overcome the underestimation of the value of limiting resources and the assumption of constant marginal gross margin of the non-preferable activity (Kanellopoulos *et al.*, 2010). The principal advantage of PMP approaches is that they achieve automatic and exact calibration based on information on the observed behaviour of economic agents. Additionally, they have lower data requirements, and they adhere to a generic procedure that is easily applicable to different regions and farm types (*ibid*).

3.3.5 Data Management and Integration Procedures

Databases and data integration procedures are increasingly important in MPM applications, especially in the case of generic models that have been designed to assess numerous scenarios. The manual introduction of data either directly in the model or in text files is particularly error prone, difficult, and user hostile, and therefore infeasible for large models or multiple scenario simulations. Most studies provide little information on the data management and data integration procedures used for the economic model, which is an indication of limited model reusability. Nevertheless, a number of alternative approaches are nowadays available regarding data management and data integration into economic modelling. Given the multiplicity of modelling software, the focus in the present work will be on the approaches that are available for MPMs written in General Algebraic Modeling System (GAMS)[11].

Typical data management approaches for MPMs written in GAMS involve the use of MS Excel, MS Access, and My Structured Query Language (SQL). My SQL is a well-established and free-of-charge database management system, but it requires

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[11] http://www.gams.com/

greater user knowledge than MS Access or MS Excel. Although MS Excel is a very widespread tool, it lacks the data management properties of a specialised database product. These include i) easier and faster data control, ii) possibility of using structured procedures for database population, iii) maintenance of data integrity, and iv) possibility of linking the database tool to other external databases and/or models. MS Access is a user-friendly, easily accessible database management system, offering the above capabilities.

Additionally, the use of MS Access, as opposed to MS Excel, is advantageous for the retrieval of the data and their writing into text files, as the operation of the system is faster, and more generic and re-usable. Specifically, GAMS offers the xls2gms and mdb2gms utilities, operating with MS Excel and MS Access respectively[12]. The loading of files into GAMS is significantly faster when using MS Access and the mdb2gms utility, compared to using MS Excel and xls2gms (L. Carroll, pers. comm., 14/11/07). The system is also more generic and re-usable, since in xls2gms one has to specify the range of cells to be imported for each specific application. On the other hand, mdb2gms uses the same code for data retrieval in any application.

Further information on data management and integration procedures for economic models written in GAMS can be found in a recent report by Mouratiadou *et al.* (2009a) appended as Annex II.

3.4 Ecological Component

3.4.1 Water Pollution Indicators

Indicators are a means of translating policy goals into measurable, calculable or communicable quantities, and can represent the proxies or the actual quantities of interest (Rossing *et al.*, 2007). Linking indicators to threshold values and a monitoring system can be useful in the setting of either legislative standards or economic incentive systems to allocate premiums or fees to farmers (Schröder *et al.*, 2004). A number of indicators for the assessment of water pollution from agriculture from both cropping and livestock sources, in relation to the Nitrates Directive and the

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[12] http://interfaces.gams-software.com/doku.php

WFD, have been analysed and schematically represented, as shown in Fig. 3.1, by Schröder *et al.* (2004). The authors provide a thorough review of each of the indicators shown in the scheme and identify four key criteria for the selection of indicators for policy analysis:

1) *Effectiveness*: an indicator should be effective, in the sense that it should be related to the intended objective;
2) *Integrality*: it may be convenient that an indicator is the sum total of other objectives, so that the total number of indicators can be minimised;
3) *Responsiveness and attributability to actions of individuals*: this will allow individuals to notice the impact of their actions, such as adjustments in management, and the factors for which they can be held responsible;
4) *Efficiency*: the costs of carrying out a sufficient accurate measurement of the indicator should be as low as possible (*ibid*).

Clearly, the scoring of each of the water pollution indicators against these four criteria differs, as does the weighting of the importance of the criteria between different members of society. As the authors (*ibid*) report, the effectiveness of the indicators in Fig. 3.1 will decrease as we move from top to bottom. In other words, the further an indicator is positioned from the ultimate goal, i.e. state of health and welfare, the less certain the achievement of this goal becomes. On the other hand, the integrality, in terms of representing several objectives, and the attributability and responsiveness of an indicator to actions of individuals increase from top to bottom. Finally, the efficiency of indicators is hard to estimate, but it generally depends on the required resolution and thus the amount of pooling of samples that can and should be done (*ibid*).

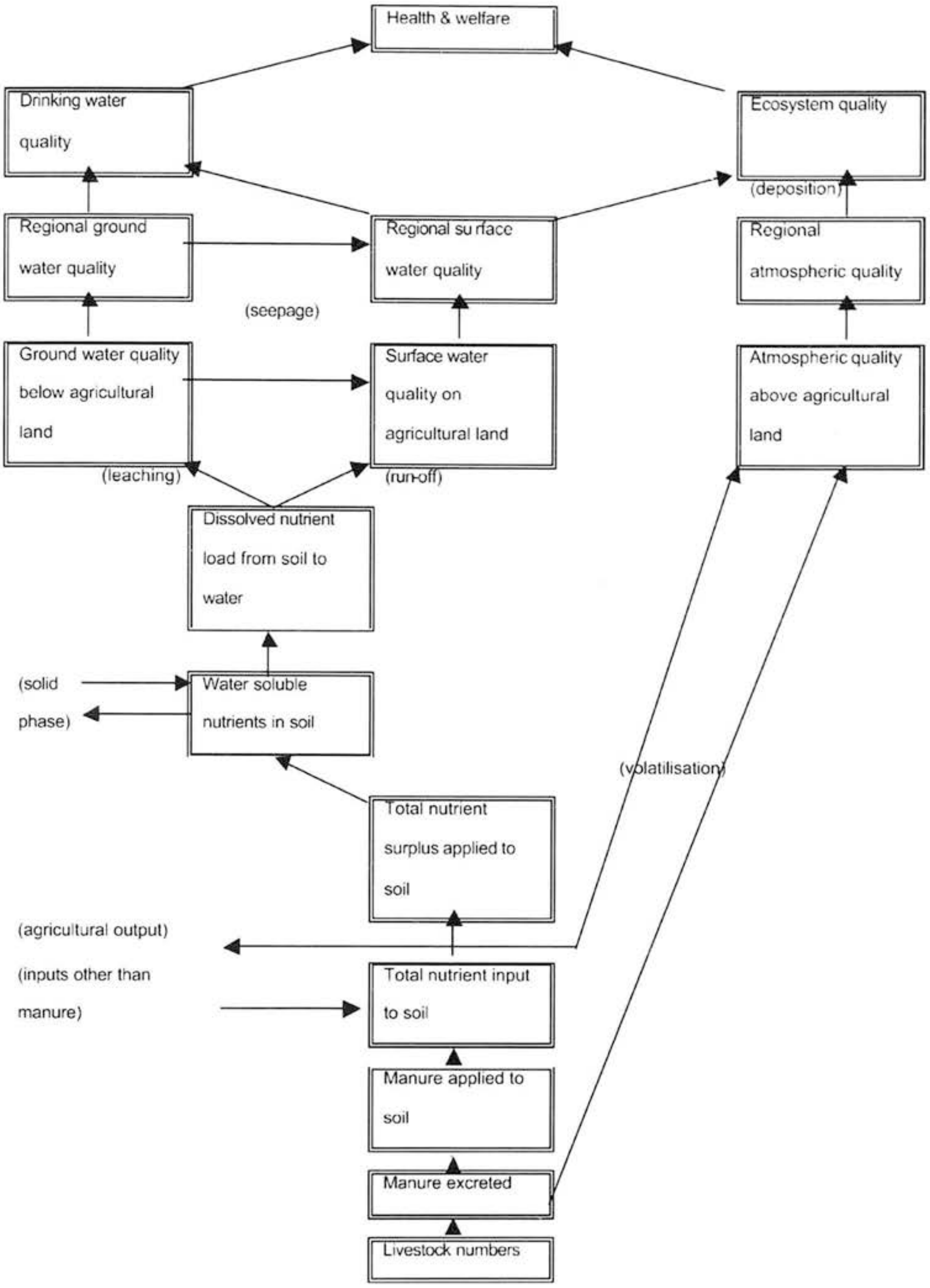

Fig. 3.1 Hierarchy of indicators of nutrient losses from agriculture
Source: Schröder *et al.* (2004)

Focusing on the criterion of the effectiveness of water pollution indicators, it can be suggested that what van der Werf & Petit (2002) define as *effect-based* indicators overshadow *means-based* indicators. *Means-based* indicators are based on farmer production practices, while *effect-based* ones focus on the impacts of these practices on the state of the farming system or on the environment. For example, indicators assessing fertilisation in terms of applied nitrogen or at the establishment of cover crops as a means to decrease leaching would be classified as means-based indicators, while indicators considering nitrate in the soil at crop harvest or nitrate losses to groundwater would be categorised as effect-based indicators (*ibid*).

The advantages of effect-based indicators over means-based indicators have been identified by many authors:

1) The link of the indicator with the objective is more direct and the choice of the best practices or means to reach to this objective is up to the farmer, who can take into account his specific economic, agronomic and environmental situation (van der Werf & Petit, 2002);
2) The need to match technologies to specific environments is not addressed by attempts that link specific strategies to sustainability (Hansen, 1996) and this does not favour the emergence of new practices (van der Werf & Petit, 2002);
3) It is logically impossible to assess the contribution of an approach to sustainability when adherence to that approach has already been classified as a criterion for evaluating sustainability (Hansen, 1996);
4) It is hard to say to what extend the outputs of means-based indicators correlate with real word environmental problems. While one can use an experimental approach to validate effect-based indicators, the only way to validate means-based indicators is expert judgement, which is inherently more subjective (van der Werf & Petit, 2002);
5) Effect-based indicators are more effective than means-based indicators (Schröder *et al.*, 2004).

Clearly, effect-based indicators are associated with more complicated implementation and more costly data collection (van der Werf & Petit, 2002). Therefore, one needs to strike the right balance between the validity and the applicability/practicality of the approach. "Estimation of effects calls for simulation modelling" (*ibid*), but the appropriate degree of methodological and practical complexity for the production of indicators is debatable.

3.4.2 Bio-physical Simulation Modelling of Cropping Systems

From the end of 60s and beginning of the 70s, when computers became easily available, crop simulation modelling developed rapidly (Passioura, 1996; Bouman *et al.*, 1996). The aim and scope of bio-physical simulation model applications have been transforming to adapt to changing research needs and exploit increasing model capabilities. In the last 40 years, the purpose of their use has evolved from increasing understanding of the underlying processes at the crop scale, into applications in research, teaching, agronomic practice and policy making.

Natural science models are now used to an increasing degree for the establishment of production and emission functions (Vatn *et al.*, 2006). Two general categories of bio-physical simulation models are available. The first one is empirical models (also called functional models) that are derived from large amounts of field experimental data, and describe facts such as crop growth through regression functions of key variables. The second category, mechanistic process-based simulation models, focus on the underlying processes of crop growth and thus simulate important interacting ecosystem processes, such as photosynthesis, respiration, decomposition, and nutrient cycling, and the effects of these processes on crop growth and environmental attributes (Peng *et al.*, 2002). In practice, most models combine both functional and mechanistic features, since a model may be functional regarding one mechanism, while being closer to mechanistic models for simulating other processes (Maraux *et al.*, 1998).

Empirical models are often called black-boxes, as they only describe the relationship between input and output, without taking the underlying mechanisms into consideration (Claassen & Steingrobe, 1999). The functions used for empirical models are based on site- and situation-specific data from agronomic experiments. Consequently changes in the weather, soil, management and/or crop types, involves repeating a whole experiment (Steduto, 1997), and thus these models are not always suitable for extrapolation in other sites, climates, etc. Another disadvantage of empirical models is that in some cases they might not permit the effects of fertilisation, irrigation, weather, soil type, previous crop in the rotation, etc. to be analysed separately. These limitations are even greater in the case of pollution functions. The diffuse nature of the phenomenon and the time lags between nutrient applications and losses makes it difficult to establish a clear relationship between all the interacting factors and the resulting losses, even if sufficient experimental data exist.

Mechanistic simulation models seem to be what Passioura (1973; cited in Passioura 1996) calls models with *scientific aspirations*, and are seen as more suitable for scientific purposes since they aim at the understanding of the biological and physiological processes considered to occur in plants and their environments (Claassen & Steingrobe, 1999). Their main advantages are the inclusion of eco-physiological principles and the ability for long-term forecasts within changing environments (Peng *et al.*, 2002) and are thus seen as a viable and reliable alternative, overcoming the scarcity of consistent data and approaches for the estimation of production and pollution functions.

A plethora of bio-physical simulation models are available. The degree of complexity, their purpose and capabilities, the spatial and time scales, the number and level of detail of the representation of underlying processes, the data requirements, and the generated output differ significantly between them. These aspects have been the subject of a number of reviews. These include a review of mechanistic simulation models of nutrient uptake (Rengel, 1993), a comparison of 14 simulation models regarding nitrogen turnover in the soil-crop system (de Willigen, 1991), a comparison between one mechanistic and two functional models for estimating soil water balance (Maraux *et al.*, 1998), a review of 16 models for modelling crop growth, movement of water and chemicals in relation to topsoil and subsoil compaction (Lipiec *et al.*, 2003), a review of 60 models regarding soil structure parameters (Walczak *et al.*, 1997), a review of the modelling of environmental impacts of soil compaction (O'Sullivan & Simota, 1995), and a review of modelling effects of soil structure on the water balance of soil-crop systems (Connolly, 1998).

The most recent review relevant to the present research is provided by Cannavo *et al.* (2008) who reviewed 62 models and their capabilities to model N dynamics in order to assess environmental impacts of cropped soils. The authors analysed the selected models in terms of i) the N processes simulated, ii) the equations used to simulate each process, iii) the time and space scales for calculations and simulations, iv) the ability of the model to simulate different crop species under various conditions, and v) the models' performance in simulating field experimental data. Cannavo *et al.* (2008) conclude by noting important trends observed in the last few years including i) the elaboration and implementation of models in order to couple physical and biological processes, ii) a trend of simplification of the equations involved and the use of correction factors, in the shift from mechanistic to functional models, and iii) the frequent adoption of models where the core element is a mechanistic module. Finally, they identify a number of key future challenges such as the need for i) modular systems with modules describing various processes from which models can be built depending on the requirements, ii) future models to develop generic equations capable of simulating crop growth in a larger range of crop species, and iii) the incorporation of the uncertainty of the input data describing soil and climate.

Effectively, the selection of which bio-physical simulation model is more appropriate for each particular case is a difficult task. Hansen (2002) suggests a number of selection criteria: i) appropriateness for the intended purpose, such as the responsiveness of the model to target decision variables and its spatial scale, ii) the ability of the model to accurately reproduce the relevant eco-physiological processes, and iii) the support that the model developers and its community of users are able to provide. Other important considerations include the data requirements of a model, the extent to which a model has been used and tested in specific bio-physical environments, the number of crops that a model is able to simulate, and the user-friendliness of the model. The latter five characteristics are particularly important for the operationalisation of bio-physical simulation modelling in a bio-economic modelling framework, since the process requires a large number of simulations for different crop and management scenarios, and aims to provide reliable indicators of the agricultural activities to be used in the economic model.

3.4.3 Soil Typologies

Soil typologies are an important element of bio-economic modelling studies. The bio-physical model needs to be run for a number of combinations of climate, rotations, management practices, and soils, and thus the confinement of soil heterogeneity and different soil attributes in more generic soil classes with homogenous characteristics is necessary.

Several established soil typologies are available and are often used in integrated modelling studies. For example, Godard *et al.* (2008) use the *Soil Geographical Database of Europe* (King *et al.*, 1994; cited in Godard *et al.*, 2008), where *soil typological units* are used to describe texture, water regime, stoniness, etc.. Wei *et al.* (2009) employ the *China Soil Taxonomy System* (Chinese Soil Taxonomy Research Group, 1995; cited in Wei *et al.*, 2009). Other typical practices include the grouping of soil types of established typologies into broader soil classes, especially in studies covering a large geographical extent, and/or the combination of existing typologies with other information so that the resulting typology is tailored to the objectives of the specific study. For example, Jansen and Stoorvogel (1998) aggregated 21 soil series into three classes based on fertility and drainage characteristics. Bouman *et al.* (1999) drew their soil types from the classification of the *Atlantic Zone Programme of Costa Rica* (Nieuwenhuyse, 1996; cited in Bouman *et al.*, 1999) and the *USDA Soil Taxonomy classification* (USDA, 1999), and combine them with information on slope and stoniness for the definition of homogenous land units. The use of soil texture as a way to simplify soil heterogeneity is also common in the literature (e.g. Rossing *et al.*, 1997; Gibbons *et al.*, 2005; van Calker *et al.*, 2004, Dietz & Hoogervorst, 1991).

Soil fertility and drainage are often identified as key drivers for the establishment of soil typologies (e.g. Jansen & Stoorvogel, 1998; Bouman *et al.*, 1999; Hengsdijk *et al.*, 1999). Still, the exact criteria against which a soil typology will be formulated vary between different studies. The key factors that seem to be driving the selection of the appropriate criteria include the objectives of the study and the factors to which the results are sensitive, any existing soil typologies and the extent to which they serve the specific objectives of the study, the geographical extent of the area, and the availability of information on the soils of the study area.

3.5 Policy Instruments and Measures

Integrated models are ultimately used for the integrated assessment of policy scenarios and measures that are incentivised through different policy instruments. The policy instruments that are used for encouraging farmers to move towards environmental friendly practices can be effectively distinguished into regulatory instruments and economic incentive instruments:

1) *Regulatory Instruments or "Command and Control"*: They aim at the improvement of the environmental performance of farms by trying to regulate the production process directly, through performance or design standards. Design standards target the management of the resources or facilities of the dischargers, and performance standards target the total emissions of the dischargers (Dowd *et al.*, 2008).
2) *Economic Instruments or "Carrot and Stick"*. They intend to influence, as opposed to regulate, farmers decision making indirectly with the use of market based tools. These effectively include two categories: subsidies and taxes, which are also referred to as *carrot* and *stick* respectively. The former are usually agri-environmental schemes, where farmers are offered some compensation for adopting environmental friendly farming. Most of these schemes are voluntary. The latter have the form of penalising farmers for using practices or inputs that harm the environment, as for example taxing fertilisation. A market of permits for input use or environmental discharge is another evolving economic incentive measure.

The majority of measures targeting diffuse pollution from agricultural sources are identified as Best Management Practices. Best Management Practices have been recognised as an effective flexible way for controlling diffuse pollution from agriculture, and include measures such as better nutrient management, minimal cultivation systems, etc. These measures are usually quite explicit as to what they are trying to achieve and in which manner. They are thought to be measures that can be encouraged through design standard instruments (*ibid*), as they tend to target the production process or infrastructure. Nevertheless, they can also be encouraged by economic incentive instruments such as fines or charges for non compliance or subsidy based agri-environmental schemes.

Economic policy instruments can also target directly the environmental outcome of production processes, such as nitrate emissions, or factors that are highly correlated with the outcome, such as N inputs. In this case the production and management processes are not specified, but the agent is able to decide which process to follow according to what is economically efficient for his business and specific environment. They are further subdivided into *first best* measures that target the outcome, and *second best* measures that target the factor correlated with the outcome. For example in the case of targeting diffuse water pollution, taxation of nitrate emissions would be a first best measure, while taxation of nitrogen use would be a second best measure.

The selection of the appropriate policy instrument for encouraging the uptake of a measure is complex. As Prestegard (2003) states, formulating policy instruments and determining their levels are two major challenges of policy design. Nevertheless, a measure can usually be invoked by using any of the above policy instruments or their combinations. Let us take the example of the implementation of a nutrient programme. This can either be encouraged by an agri-environmental scheme (subsidy type economic instrument), a cross-compliance measure or a fine for not abiding with the regulations (penalty type economic instrument), a tax per kg of nitrogen use above that prescribed by the programme (tax type economic instrument), or legal charges for not abiding with the regulation (regulatory instrument). The cost-effectiveness criterion against which a number of measures and respective policy instruments can be assessed is a commonly used tool for assisting policy makers in formulating policies.

Even though there are no blueprints for the selection of policy measures, a literature review by Dowd *et al.* (2008) identifies some general characteristics that can increase the success of policy frameworks addressing agricultural diffuse pollution:

- There is no single policy tool that can be distinguished as the best way to target diffuse pollution;
- The best way to address the problem is to combine different policy measures (Malik *et al.*, 1994 cited in Dowd *et al.*, 2008; O'Shea, 2002; Segerson & Walker, 2002; Weersink, 2002 cited in Dowd *et al.*, 2008);
- The use of a command and control policy to set a standard that all farmers must meet, accompanied by voluntary and market incentive programmes to achieve further reductions, is widely suggested (e.g., Eisner, 2004; Potoski & Prakash, 2004);
- Targeting policies to specific farms is more effective (e.g. Bennett & Vitale, 2001);
- It is likely that looking at all pollutants and targeting their collective discharge rather than operating on a pollutant by pollutant basis, is more cost-effective (Kampas *et al.*, 2002).

Table 3.1 shows a wide array of measures that are often considered for the reduction of diffuse pollution (e.g. Cuttle *et al.*, 2007). The measures applying to arable cropping systems can be grouped into the categories of fertiliser management, soil management, and farm infrastructure (*ibid*). Some of these measures can be combined with more than one of the policy instruments discussed above.

Table 3.1 Measures for the reduction of N diffuse pollution

Measure	Description
Fertiliser Management	
Tax on pollution emissions	Charge per kg of N leached
Standard on pollution emissions	Maximum permitted level of pollution emissions per ha
Tax on fertiliser inputs	Tax per kg of inorganic fertiliser inputs or excess inputs
Quota on nitrogen input (average per ha)	Maximum fertilisation threshold as an average per ha
Reduce fertilisation below optimum	Reduce fertiliser applications by a certain percentage below the economic optimum
Quota on nitrogen input (specified per activity)	Maximal fertilisation threshold for each of the activities, i.e. limit fertiliser application to crop requirements
Split fertilisation	More fertiliser applications but of smaller doses
Improve fertilisation timing	Time fertiliser applications to minimise the risk of loss of nutrients
Assess manure inputs	Take full account of manure inputs when planning mineral fertiliser applications
Organic farming	Use only organic fertilisation
Tradable input permits	Set a cap on allowable N input use in a region, allocate permits to farmers and allow them to trade the permits
Soil/Land Use Management	
Cover crops	Establish cover crops/grass cover in autumn
Minimal cultivation systems	No tillage or minimal tillage cultivation systems
Preserve soil organic matter	Increase/maintain soil organic matter content by using manure, grass leys, green manure crops and reseeding
Limited irrigation	Ensure that irrigation rates are not excessive
Spring cultivation	Cultivate land for (spring) crop establishment in spring rather than autumn
Ploughing obligations	Early ploughing shortly after harvest
Revert arable land to grassland	Change land use from arable cropping to permanent grassland, either ungrazed or with low stocking rate or low fertiliser input.
Set-aside restrictions	Increase set-aside
Farm Infrastructure	
Manure application close to water bodies	Do not apply manure close to surface waters and boreholes
Hedgerows	Increase or maintain hedgerows
Buffer zones	Maintain grassed buffer zones adjacent to ditches and streams
Wetlands	Creation and maintenance of wetlands

3.6 Conclusions

This chapter has reviewed methods, models and reviews that are applicable to integrated impact assessment of water and agricultural policies. It discussed i) integration approaches in terms of systems (both natural and economic), scales (space and time), and policies (the CAP and the WFD), ii) specifications of economic models regarding approaches used for predicting and understanding behaviour, the model objective function, farm typologies, model calibration, and data management and integration procedures, iii) specifications of ecological model components including indicators of water pollution, bio-physical models and soil typologies, and iv) approaches for applying models regarding the selection of measures and policy instruments to be evaluated.

The key conclusion is that the selection of the appropriate approach boils down to making the appropriate compromises between a sufficient level of representation of the complexities of the natural-economic systems and a suitable level of modelling sophistication required for operational and practical approaches for policy making. Overly simplified representations of the analysed systems may result in the poor consideration of crucial system components, rendering the analysis insufficient for real-life environmental problems. On the other hand, increasing model complexity is associated with higher levels of data requirements, simulation time, and systems understanding. Additionally, overly complex models are likely to be poorly understood and approached with scepticism. Modelling objectives, sensitivity of the results to different methodological specifications, data availability, and system understanding are crucial guiding factors for choosing the appropriate level of complexity of the various model components and characteristics.

4 Case Study Presentation

4.1 Introduction

For the application of an impact assessment study the selection of the case study area is an important part of the exercise as it needs to be representative of the problem to be analysed and also the broader area that it aims to represent. The case study area used in this study is the Lunan Water catchment located on the East Coast of Scotland in the Angus region. One of the main reasons for the selection of the Lunan Water catchment as a case study is that it is representative of intensive mixed arable production in Scotland (SEPA, 2007; Vinten *et al.*, 2008). Additionally, it is one of the two priority catchments monitored under the *Monitored Priority Catchment project*, established in 2005 as a partnership approach between SEPA, the Macaulay Institute and the Scottish Agricultural College (MPCPc, undated), because it is at risk of not meeting the environmental objectives of the Water Framework Directive (SEPA, 2007). This implies that the catchment has significant water pollution issues and also that data availability is likely to be higher compared to other case study catchments.

The aim of this chapter is to present in detail the case study used for this study. This is important for contextualising the problem in hand and also for understanding some of the methodological choices described in Chapter 5. The chapter is structured as follows. Firstly, the data sources used for the characterisation of the catchment are described. The following sections present the natural characteristics of the catchment, the status of the water resources and the related pressures exercised by agriculture. Finally, the land use trends in the catchment are presented and the soils and farms of the catchment are characterised according to existing soil and farm typologies.

4.2 Main Data Sources

The *UK June Agricultural and Horticultural Census Data* (JCD)[13] is one of the main data sources used for the characterisation of the agricultural businesses in the area. The JCD are collected and published annually, and provide information on land use, crop areas, livestock numbers, labour use, and horticulture and glasshouse production. Even though the JCD are collected on an agricultural holding basis, they are publicly available only at the agricultural parish aggregated level. For this research it has been possible to obtain them at the holding level for all the individual farms of the 12 agricultural parishes within which the Lunan Water catchment falls, for the years 2000-2007. Additionally, the classification of each holding in terms of production orientation according to the *U.K. Farm Classification System*[14] has been provided (see section 4.6 for details of the classification system). These data have been used for the characterisation of the study area in terms of farm type composition and production activities.

For the characterisation of the soils composition of the agricultural area, data on the spatial distribution and characteristics of the soil series within the area were made available from the *Scottish Soils Knowledge and Information Base* (SSKIB) held by the MI. These data contain information on the basic characteristics of the topsoil and subsoil of the soil series appearing in the area, such as soil texture, soil drainage, pH, available water capacity, and organic matter. Additionally, spatially referenced data were obtained from the *1:25,000 Scale Soils Data*[15] collection. These consist of vector data providing information on the spatial allocation of soil series and soil associations within the area of the 12 parishes.

Other quantitative and qualitative sources of data for characterising and visualising the catchment area include:

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[13] http://www.defra.gov.uk/evidence/statistics/foodfarm/landuselivestock/junesurvey/index.htm

[14] http://www.scotland.gov.uk/Publications/2005/01/20580

[15] http://www.macaulay.ac.uk/mscl/gis2_dataset.php

1) vector data on the catchment boundaries and sub-catchments and information on their water status from the *Diffuse Pollution Screening Tool*[16] (M. Coull, pers. comm., 30/11/2007);
2) the 1:625,000 map by the *Soil Survey of Scotland Land Capability for Agriculture in Scotland Map of Climatic Guidelines* (MI, 1982);
3) the vector data of the 1:250,000 scale of *Land Capability Classification for Agriculture*[17] (M. Coull, pers. comm., 21/05/2009);
4) characterisation of soil series in terms of their leaching potential according to the *Soil Leaching Potential Classification* (Lewis *et al*., 2000) and their HOST class according to the *Hydrology of Soil Types* (HOST) *Classification* (Boorman *et al*., 1995) (see section 4.5 for details) (M. Coull & A. Lilly, pers. comm., 28/10/2009);
5) an image on the position of the catchment within the area of the agricultural parishes of the broader catchment area (A. Vinten & M. Coull, pers. comm., 28/02/07);
6) an image of the catchment water bodies, their identification numbers, and the boundaries of their drainage area (J. Bowes, pers. comm., 17/11/06);
7) a car-based reconnaissance of the area (Forfar - B9128 - Dunnichen - Idvies Hill - Cononsyth - Friockheim - Chaperton - Lunan Bank) (G. Russell, pers. comm., 24/04/09);
8) a catchment rapid appraisal field trip (Turin Hill - Baldardo Burn - Rescobie Loch - outlet of Balgavies Loch - Friockheim - Boysack Weir - Lunan mouth) (29/04/2009).

4.3 Catchment Natural Characteristics

The Lunan Water catchment is part of the sub-basin of Tay and the Scotland River Basin District. In total, the catchment drains an area of 134 km². The source of the catchment is to the east of Forfar at Lunan Head from where it flows to an easterly direction to the sea at Lunan Bay. The area includes three rivers (Lunan Water, Gighty Burn, Vinny Water) divided into five water bodies (Fig. 4.1). The Lunan

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[16] http://www.sniffer.org.uk/Webcontrol/Secure/ClientSpecific/ResourceManagement/UploadedFiles/WFD77.pdf

[17] http://www.macaulay.ac.uk/mscl/gis2_dataset_5a.php

Water drains the lochs of Rescobie and Balgavies. The Vinny Water and the Gighty Burn feed into Lunan Water at Friockheim and Boysack respectively.

The Rescobie Lock covers an area of 59 ha, with a mean depth of 3.3 m, and is a popular fishery (Vinten *et al.*, 2008). Balgavies is classified as a Scottish Wildlife Trust reserve and extents to an area of 18 ha, with mean depth of 3 m (*ibid*). The two lakes along with Restenneth Moss fall under *Sites of Special Scientific Interest*[18] designations due to their species assemblages and unique biological status (MPCPa, undated). The two lochs are one of the most extensive associations of wetland habitats in Angus supporting over 60 species of breeding bird (MPCPc, undated). The whole catchment falls within a designated river nutrient sensitive area and an NVZ (MPCPa, undated).

The Lunan Water catchment is a partly groundwater fed catchment. The majority of the catchment area (70.5%) is underlain by groundwater bodies in Old Red Sandstone of moderate permeability and classified as a highly productive aquifer (Vinten *et al.*, 2008; MPCPa, undated; MPCPb, undated). The river channel network is bordered by an area of glacial sands and gravels that is classified as a high productivity drift aquifer (Vinten *et al.*, 2008). The combination of the two types of aquifer leads to large parts of the catchment being designated as highly vulnerable, in terms of groundwater being susceptible to pollution from surface processes (MPCPa).

The most of topography is undulating hills, with the maximum elevation being 251 m (Vinten *et al.*, 2008; MPCPb, undated). The sloping fields are prone to soil erosion especially during autumn when most rain occurs and the soil is most vulnerable to erosion (MPCPc, undated).

Mean annual rainfall is 771 mm (MPCPc, undated). According to the *Land capability of Agriculture in Scotland Map of Climatic Guidelines*, almost the entire catchment is classed as grade 2, implying minor climatic constraints for agriculture.

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[18] http://www.snh.org.uk/about/ab-pa01.asp

A small area near the cost is classed as grade 1 corresponding to very minor or no climatic constraints.

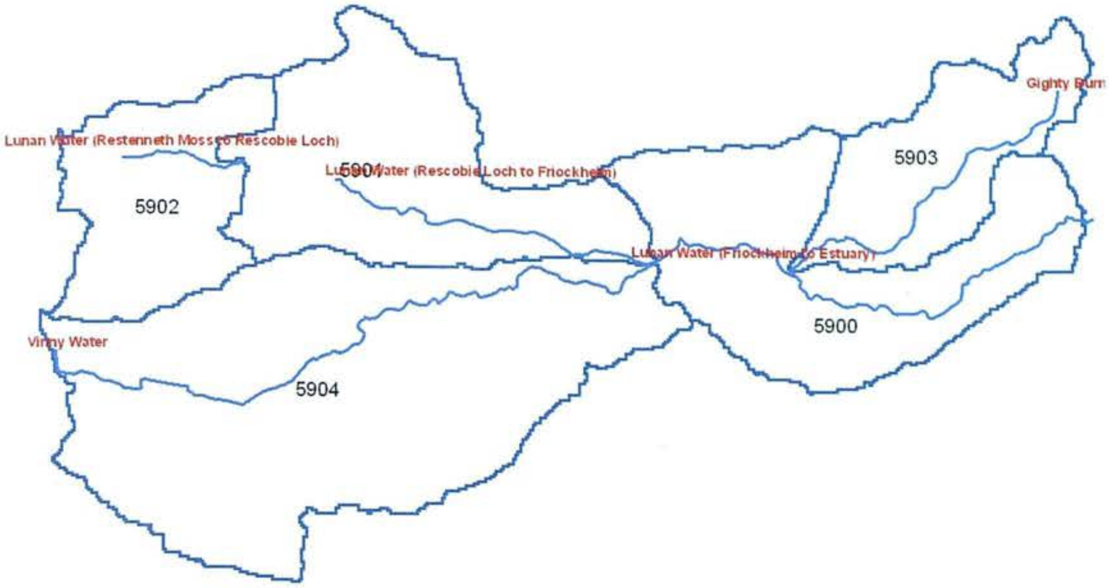

Fig. 4.1 Water bodies of the Lunan Water catchment
Source: J. Bowes, SEPA (pers. comm., 17/11/06)

4.4 Water Resources Status and Agricultural Pressures

In the Lunan Water catchment standing, running and groundwater bodies, pose challenges for the WFD achievement of *good ecological status*. The classification of the different water bodies of the Lunan Water catchment according to the classification provided in the *Characterisation and impact analyses required by Article 5 of the Water Framework Directive* (SEPA, 2005) and the Diffuse Pollution Screening Tool can be seen in Table 4.1.

Groundwaters seem to be one of the main water bodies that are at risk. Recent reports state that they are not achieving the drinking water standards for N (Vinten *et al.*, 2008; MPCPb, undated). Also results of recent measurements in groundwater boreholes under the Monitored Priority Catchment project show that three of the five boreholes measured have mean N concentrations above or very near to the standard, and that two out of five show elevated soluble P concentrations (Vinten *et al.*, 2008) (Table 4.2).

Regarding surface running waters, the part of the Lunan Water extending from Restenneth Moss to the Rescobie Loch has been classified as *definitely at risk*, while the Gighty Burn, the Viny Water and the part of the Lunan Water from the Rescobie Loch to Friockheim as *probably at risk* from both the SEPA characterisation report and the Screening Tool. The part of the Lunan Water from Friockheim to the Estuary has been characterised as *probably at risk* by SEPA and *definitely at risk* by the Screening Tool. Recent measurements indicate that the streams in the catchment meet good ecological status regarding water chemistry (Vinten *et al.*, 2008).

Table 4.1 Characterisation of the Lunan Water catchment water bodies

Water Body ID	Name	Status SEPA	Status Scr. Tool	Pressures
150068	Groundwater	1a	n/a	Diffuse source pollution Point source pollution
5900	Lunan Water	1b	1a	Diffuse source pollution Morpholog. alterations Point source pollution Abstraction Flow regulation
5901	Lunan Water	1b	1b	Diffuse source pollution
5902	Lunan Water	1a	1a	Diffuse source pollution
5903	Gighty Burn	2a	1b	Diffuse source pollution Point source pollution Morpholog. alterations
5904	Vinny Water	1b	1b	Diffuse source pollution Morpholog. alterations Point source pollution Abstraction
100226	Rescobie Loch	1a	n/a	Diffuse source pollution
200078	Coastal	2a	n/a	Morpholog. alterations

n/a: not available; 1a: water bodies at significant risk; 1b: water bodies probably at significant risk but further information is needed to make sure this view is correct; 2a: water bodies probably not at significant risk; 2b: water bodies not at significant risk.
Source: MPCPa (undated); Diffuse Pollution Screening Tool

Table 4.2 Groundwater borehole chemistry data (mg/l)

Borehole	NO_3^-N	NH_4^+N	$PO_4^{3-}P$	Tot-P	Tot-N
Murton	3.9	0.029	0.005	0.007	4.1
Focus Farm Shallow	10.4	0.016	0.005	0.007	10.2
Focus Farm Deep	9.0	0.016	0.005	0.010	9.3
Kirkton Mill Bedrock	11.6	0.012	0.032	0.034	11.7
Kirkton Mill Drift	11.2	0.013	0.032	0.034	11.6

Means of three sampling dates
Source: Vinten *et al.* (2008)

Both lochs fail the WFD standards for good ecological status, as they are eutrophic and enriched with both N and P (Vinten *et al.*, 2008; MPCPb). According to the classification for ecological status of surface waters of the *WFD United Kingdom Technical Advisory Group* (UKTAG)[19], the Rescobie Loch is designated as *Moderate/Poor* and Balgavies as *Poor* (Vinten *et al.*, 2008).

The contribution of agriculture to the water pressures in the catchment is through drainage to groundwater, sediment run-off and soil erosion, and water abstraction (MPCPb, undated). The groundwater is under pressure from contamination by nitrates, and soluble P inputs contribute to running waters and loch eutrophication (MPCPa, undated). According to the Diffuse Pollution Screening Tool, the main pathway for N is through the soil profile and then through agricultural drains. Most P enters the system through agricultural run-off. Also, much water is abstracted to meet the demands for irrigation (MPCPa, undated). Finally, soil erosion can also occur on sloping fields in potatoes or cereals, especially on fields left uncropped over winter.

4.5 Soils

The soils in the area have been characterised using the *Scottish Soil Type Classification System*[20], the *Soil Leaching Potential Classification* (Lewis *et al.*, 2000), the *HOST Classification* (Boorman *et al.*, 1995), the *Scottish Land Capability for Agriculture* (LCA) *Classification*[21], and the typology described in the *SAC Technical Note T516 Nitrogen Recommendations for Cereals, Oilseed rape and Potatoes* (Sinclair, 2002).

The Scottish Soil Type Classification System uses five categorical levels for the classification of soils: *division, major soil group, major soil subgroup, soil association and soil series*. Using the categorical levels of *division* and *major soil subgroup*, the soils in the Lunan Water catchment are mainly freely-draining brown forest soils (also known as brown earths) and podsols (MPCPc, undated; see Table

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[19] http://www.wfduk.org/

[20] http://www.scotland.gov.uk/Publications/2006/09/21115639/17

[21] http://www.macaulay.ac.uk/explorescotland/lcfa1.html

4.3). These soils are vulnerable to both leaching and to erosion, and are classified under the division of *leached soils*. Podsols are often considered inappropriate for productive agricultural use and only useful for forestry and rough grazing[22]. However, in this region many years of cultivation, use of soil amendments and fertilisation has resulted in some now being used for arable cropping. On the other hand, most of the brown forest soils are used for arable or horticultural crops, due to high levels of natural fertility, free drainage and their deep nature[23].

Table 4.3 Soil divisions and subgroups in the Lunan Water catchment

Division	Major Soil Subgroup	Area (km²)	Area (% of Total)
Leached	Humus-iron podsol	66.450	49.5
Leached	Brown forest soil with gleying	38.985	29.0
Leached	Brown forest soil	11.895	8.9
Subtotal Leached		117.331	87.4
Immature	Mineral alluvial soil (undif)	8.776	6.5
Immature	Noncalcareous gley	5.127	3.8
Subtotal Immature		13.903	10.4
Peat	Peat	0.678	0.5
n/a	Skeletal soil	0.276	0.2
n/a	Mixed bottom land	0.492	0.4
n/a	Quarries, Lochs, Built-up land	1.527	1.1
Subtotal Others		2.974	2.2
Total		134.209	100

Source: own elaboration from SSKIB and http://www.macaulay.ac.uk/explorescotland/soils2.html

Soil associations are differentiated by being formed in different soil parent materials. Each soil association consists of one or more soil series differentiated by soil type as a consequence of differences in topography, climate and other factors affecting soil development. The soil series is the lowest class in the hierarchy of the Scottish Soil Type Classification System. As soil series differ in natural drainage class and nutrient holding capacity, their *LCA* and their actual land use can also differ. The spatial distribution of the soil series can be seen in Fig. 4.2, and their distribution in terms of area and percentages, and their assigned drainage class are given in Table 4.4.

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[22] http://www.macaulay.ac.uk/explorescotland/podzols.html

[23] http://www.macaulay.ac.uk/explorescotland/brownearths.html

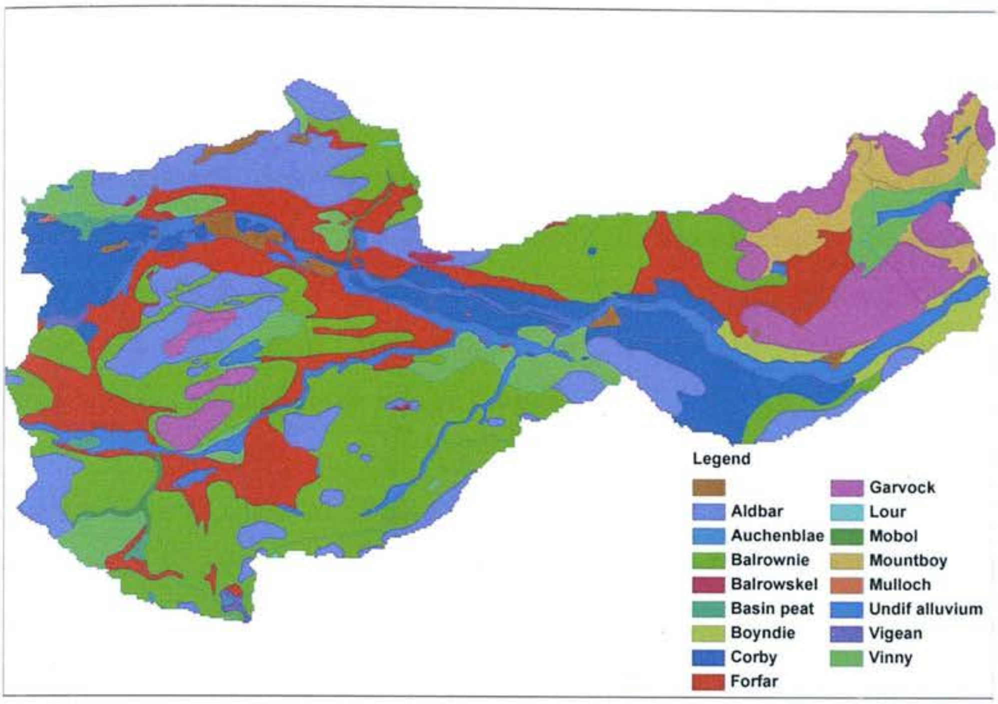

Fig. 4.2 Lunan Water catchment soil series spatial distribution
Source: own elaboration from SSKIB

The HOST is a hydrologically-based soil classification based on different conceptual models that explain dominant pathways of water movement through the soil (Boorman & Hollis, 1990), and on existing data sets describing the soils and their distribution and also the hydrological response of catchments (Boorman *et al.*, 1995). The resulting classification has 29 HOST soil classes, based on 11 response models (*ibid*). The main consideration of the water response models is the depth within the soil/substrate profile at which, and the reasons for which, lateral water movement becomes a significant factor in the response of the soils. The description of the classes that are present in the Lunan Water catchment can be seen in Annex IV and the assigned class for each of the catchment soil series in Table 4.4.

The typology described in the SAC Technical Note T516 Nitrogen Recommendations for Cereals, Oilseed rape and Potatoes (Sinclair, 2002) (Annex V) is aiming at target fertilisation and reduction of N losses. The different soils are characterized by soil depth, soil texture, and organic matter content. This typology is recommended by the Scottish Government for the improvement of nutrient planning and nutrient management of the farm businesses and used in the *Guidance for*

Farmers in Nitrate Vulnerable Zones (Scottish Executive, 2008b). Although the assumptions behind these recommendations are not available in the literature, Sylvester-Bradley and Kindred (2009) state that in the U.K. government-sponsored recommendations (Sinclair, 2002; MAFF, 2000) provide the official version of economic rules for on-farm N use. Therefore, the construction of the associated soil typology seems to be taking into account both yield and leaching effects of on-farm N use. The assignment of the main soil series of the Lunan Water catchment into classes of this typology is shown in Table 4.4.

The agricultural potential of land is shown by the LCA Classification. The LCA is based on the degree of limitations imposed by bio-physical constraints related mainly to soils, climate, and topography[24]. The higher classes (1, 2, and 3.1) are together defined as prime land and are the most flexible in terms of productive capacity (*ibid*): Class 1 is capable of producing a very wide range of crops; Class 2 a wide range of crops; Classes 3.1 and 3.2 a moderate range of crops; Classes 4.1 and 4.2 a narrow range of crops; Classes 5.1-5.3 can only be used as improved grassland; and classes 6.1-6.3 as rough grassland. Classes 888 and 999 refer to built-up areas and water bodies respectively. An LCA class can span several soil series and a soil series may appear in more than one LCA class. It is important to recognise that the LCA class only indicates potential uses for agriculture, without being a direct indication of productivity. In the Lunan Water catchment, except from some minor areas where land is suited only to improved grassland and rough grazing (LCA 5.1; 2.8% of total area) and some areas that are suited to the production of a narrow range of crops (LCA 4.1; 2.3%), the remainder of the area is capable of producing a wide (LCA 2; 46.2%) or a moderate (LCA 3.1 or 3.2; 48%) range of crops (Fig. 4.3). As discussed in section 4.3, the climatic limitations in the area are minor, which means that the actual limitations in terms of the possible enterprises are those set by soils and topography (G. Russell, pers. comm., 16/04/2009). The land use capability for the soil series in the broad area of the catchment according to Laing (1976) are given in Table 4.4.

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[24] http://www.knowledgescotland.org/briefings.php?id=57

Table 4.4 Soil series characteristics and areas

Soil Series	Area (%)	Area (km²)	Drainage Class	Leaching Potential	HOST Class	T516 Class	Land Use Capability for Agriculture
Balrownie	29.0	38.985	Imperfect	I1	18	SL	Good moisture and nutrient holding capacity, but occasionally requires tile drainage.
Forfar	16.7	22.396	Imperfect	I1	18	SL	Agriculturally important soil with good nutrient and water holding capacity.
Aldbar	13.6	18.313	Free	I1	6	O	Good quality land.
Corby	10.5	14.051	Free	H1	5	S	Allows cultivation in most conditions, but nutrient hungry with poor nutrient and water holding capacity.
Garvock	8.9	11.895	Free	I1	6	SL	Good quality land, except where limited by shallow soil and topography.
Vinny	7.0	9.457	Free	I1	16	SL	Agriculturally important soil with good nutrient and water holding capacity.
Undif alluvium	6.5	8.776	Free	H1	8	S	Usually under grass but with some arable.
Mountboy	3.4	4.568	Imperfect	I1	18	SL	Good quality land, except where limited by shallow soil and topography.
Boyndie	1.6	2.152	Free	H2	5	S	Ease of cultivation, bad poor water and nutrient holding capacity.
Basin peat	0.5	0.678	Very poor	L	12	PS	Rough grazing only.
Mobol	0.4	0.492	Variable	H	n/a	n/a	Usually under grass but may be some arable.
Vigean	0.3	0.458	Poor	L	24	SL	Poorly drained with some cultivation constraints.
Balrowskel	0.2	0.276	Poor	H1	4	Not av.	Rough grazing or permanent pasture only.
Auchenblae	0.1	0.079	Free	H1	5	S	Allows cultivation in most conditions, but drought prone with poor moisture and water holding capacity.
Lour	0.0	0.056	Poor	L	24	O	Poorly drained but sufficiently capable of improvement.
Mulloch	0.0	0.044	Poor	H1	10	Not av.	Permanent pasture.
Lochs	0.6	0.870	n/a	n/a	n/a	n/a	n/a
Quarries	0.4	0.495	n/a	n/a	n/a	n/a	n/a
Built-up land	0.1	0.161	n/a	n/a	n/a	n/a	n/a

Source: own elaboration from SSKIB; M. Coull & A. Lilly (pers. comm., 28/10/2009); Laing (1976); Sinclair (2002)

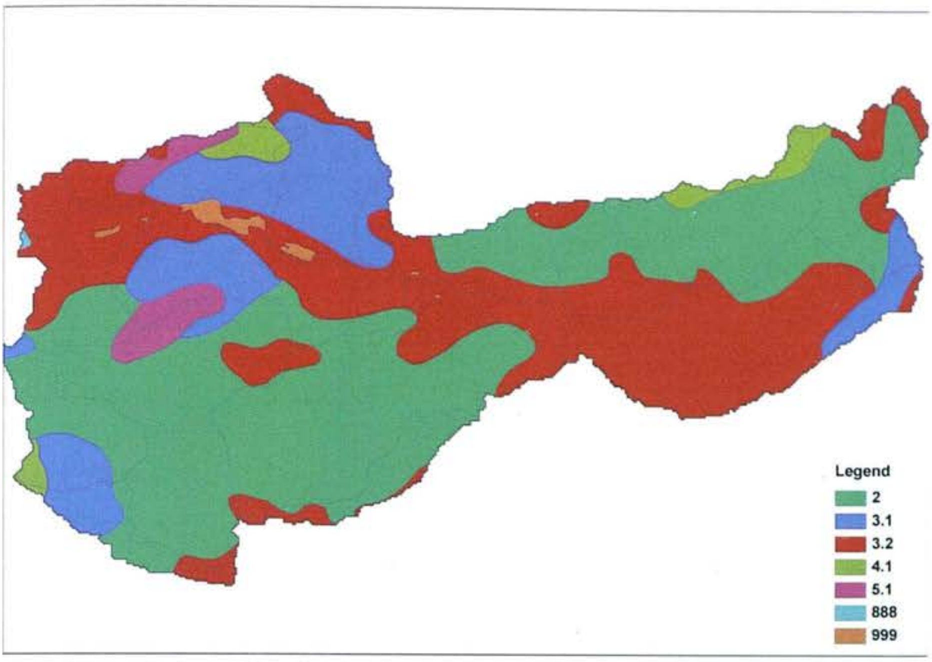

Fig. 4.3 Lunan Water catchment LCA classes
Source: own elaboration from 1: 250 000 scale of *Land Capability Classification for Agriculture* Data

4.6 Agricultural Land Use and Farm Types

The Lunan Water catchment is a predominantly rural catchment with no major settlements (MPCPa, undated). Land use consists mainly of intensively arable agriculture with cereal, potato and root crops cultivation over wide areas of the catchment and a small proportion of the land given over to pasture, set-aside and forage (Table 4.5). The Lunan Water catchment is a predominantly arable catchment, but a number of animal husbandry activities take place, including cattle, sheep, poultry, and pigs growing (Table 4.6). The catchment is situated within an area of 12 agricultural parishes (Fig. 4.4). The analysis regarding crop areas and farm type numbers corresponds to farms of the area of the parishes rather than the catchment area. This is for two main reasons: i) the JCD data use administrative boundaries and are thus collected and published on a parish basis, while the catchment is defined by natural boundaries; ii) the identification of the farms of the broader parishes area that fall within the catchment is possible with the use of the *Integrated Administration and Control System* (IACS) data, which provide spatially referenced information on the land use of agricultural parcels per year. However, the IACS data were not available to this research due to confidentiality issues.

Table 4.5 Crop areas as percentage of the total area

	2000	2001	2002	2003	2004	2005	2006	2007
Spring Barley	25.9	31.3	28.7	30.2	28.1	28.3	24.8	24.5
Wheat	14.9	10.2	12.7	11.5	14.1	13.0	14.1	14.7
Perm Gr – Grazing	7	6.8	7	7.6	7.4	7.9	7.7	7.6
Set-aside	7.0	7.9	7.5	7.6	5.8	7.3	7.2	6.9
Seed Potatoes	6.6	6.0	6.2	5.6	5.6	5.1	5.2	4.6
Winter OSR	6.4	6.8	5.8	7.1	7.2	6.4	6.4	6.7
Winter Barley	6.0	5.2	6.7	5.0	5.1	4.6	4.7	5.0
Temp Gr – Grazing	4.6	3.9	4	3.6	4	3.8	3.8	3.3
Temp Gr – Mowing	4	3.9	4.3	4	4.2	4.2	4.1	4.3
Main Crop Potatoes	3.2	3.9	3.9	4.0	4.4	4.6	5.1	5.7
Rough Grazing	2.7	3.0	2.6	2.4	2.5	2.6	2.5	3.3
Spring Oats	1.0	1.1	1.0	0.9	1.1	1.0	1.5	1.1
Peas	0.7	0.7	0.5	0.6	1.0	0.9	1.7	2.1
Perm Gr – Mowing	0.8	0.9	0.9	0.9	1.1	0.8	0.7	1
Calabrese	0.6	0.4	0.4	0.3	0.1	0.1	0.2	0.3
Beans	0.6	0.5	0.7	0.9	0.4	0.1	0.1	0.0
Spring OSR	0.5	0.3	0.5	0.3	0.3	0.3	0.1	0.1
Turnips Stock Feed.	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Winter Oats	0.4	0.2	0.1	0.4	0.4	0.4	0.8	0.7
Carrots	0.3	0.3	0.2	0.2	0.3	0.5	0.6	0.5
Turnips	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.4
Peas for Combining	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2
Total (%)[25]	94.1	94.4	94.2	94.1	93.8	92.7	92.0	93.4
Total Area (ha)	26250	26317	26239	26158	25999	25935	25622	25678

Source: own elaboration from JCD

Table 4.6 Livestock numbers ('000 of heads)

	2000	2001	2002	2003	2004	2005	2006	2007
Total Cattle	11.3	10.7	11.0	11.5	11.3	11.8	12.0	11.1
Total Sheep and Lambs	7.9	6.7	4.3	5.3	5.3	5.7	7.2	5.3
Total Pigs	7.8	8.9	8.1	6.6	6.8	7.9	9.1	8.3
Total Poultry	643.4	664.6	621.6	684.0	676.2	225.1	170.4	378.6
Total Horse and Ponies	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Source: own elaboration from JCD

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[25] The majority of the remaining areas are covered with woodland, buildings, and unspecified/other crops.

Fig. 4.4 Lunan Water catchment and surrounding parishes
Source: A. Vinten & M. Coull (pers. comm., 28/02/07)

The number of agricultural holdings per farm type and the area they occupy expressed in percentages can be seen in Table 4.7 and Table 4.8. The farm typology is based on the U.K. Farm Classification System. The classification by *type* is based on the estimated standard gross margin contributions of the different crops and livestock activities to each agricultural business. A holding is classified in a certain farm type if more than two-thirds of the total estimated gross margin comes from the activity related to the farm type. For example, if cereal activities in a farm contribute more than the two-thirds of the total estimated gross margin, then this farm will be classified as a *cereal farm*. If no single crop or livestock group category makes up more than two-thirds of the total SGMs, then the respective farm is classified as a *mixed farm*. The system uses three hierarchical levels of farm classification. At the first level farms are classified into *robust* classes, in the second under *main* classes, and thirdly into *U.K.* farm types. It should be noted here that the farm unit used in the JCD is a farm *holding* rather than a farm *business*, and thus the assigned farm types correspond to farm holdings even though some of these holdings might be part of the same farm business. Due to lack of other data, in the remainder of this study farm holdings will be regarded as farms businesses.

Table 4.7 Percentage of farms per robust farm type

	2000	2001	2002	2003	2004	2005	2006	2007
Farm Type				**No Farms (%)**				
Cereals	12.1	12.6	12.2	12.2	14.2	12.7	11.3	9.9
General Cropping	45.3	44.7	45.5	43.4	41.4	40.3	39.6	40.2
Horticulture	2.7	2.3	2.3	2.0	2.0	1.7	2.3	3.1
Cattle and sheep (Lowland)	4.7	4.1	4.7	4.1	5.2	5.5	6.1	7.1
Cattle and sheep (LFA)	*	*	*	*	*	*	*	*
Dairy	*	*	*	*	*	*	*	*
Pigs and Poultry	3.0	2.9	2.9	2.9	3.2	3.7	2.9	4.0
Mixed	5.9	5.0	4.1	5.2	4.9	6.1	7.2	5.1
Other	24.9	27.2	27.1	28.9	27.5	28.5	29.2	29.5
Total (%)	100	100	100	100	100	100	100	100
Total (No of Holdings)	338	342	343	343	345	347	346	353

Source: own elaboration from JCD
*: no data can be presented for types of less than five holdings

Table 4.8 Occupied areas per robust farm type

	2000	2001	2002	2003	2004	2005	2006	2007
Farm Type				**Area (%)**				
Cereals	8.4	8.1	8.8	8.1	12.1	10.8	12.5	8.2
General Cropping	79.7	81.2	80.8	80.3	76.2	74.8	71.9	78.5
Horticulture	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.6
Cattle & sheep (Lowland)	0.6	0.4	0.6	0.4	0.5	1.0	0.3	0.7
Cattle & sheep (LFA)	*	*	*	*	*	*	*	*
Dairy	*	*	*	*	*	*	*	*
Pigs and Poultry	0.7	0.7	0.7	0.8	0.9	0.5	0.5	0.3
Mixed	6.7	5.7	5.3	6.1	6.1	8.8	10.8	8.3
Other	2.6	2.7	2.7	3.3	2.9	2.9	2.4	2.2
Total (%)	100	100	100	100	100	100	100	100
Total (ha)	26250	26317	26239	26158	25999	25935	25622	25678

Source: own elaboration from JCD
*: no data can be presented for types of less than five holdings

The great majority of holdings in terms of *robust* farm numbers and occupied areas are *general cropping* farms, with 39.6-45.5% of farm numbers and 71.9-81.2% of the total agricultural area. Farms under the heading of *other* farms are second in terms of number of holdings, but due to their small size they only cover less than 2.2-3.3% of the total agricultural area. *Cereal* farms, even though they are about half the number of *other* farms, they occupy 8.1-12.5% of the area and represent 9.9-14.2% in terms of farm numbers. *Lowland cattle and sheep* farms, and *mixed* farms each represent around 5-7% of the number of farms. Regarding area coverage, *mixed* farms are much more extended covering 5.3-10.8% of the total area as opposed to *cattle and sheep* farms covering less than 1%. There is also some limited *horticultural* activity and some *poultry and pigs* units. The farms of each of these last categories add up to around 2-4% of the total farm numbers and cover less than 1% of the area. Finally, very few holdings represent the categories of *LFA cattle and sheep* and *dairy*. More details on farm numbers using the hierarchical levels of the *main* and the *U.K.* farm type criteria for the categories present in the area can be seen in Annex VI.

4.7 Conclusions

The analysis demonstrated that the Lunan Water catchment is a representative case study area for the analysis of water pollution problems arising from agricultural activities. Additionally, it is a catchment with sufficient diversity in terms of soils, land use and farm types, and at the same type representative of intensive arable cropping in the East of Scotland. It proved to be a catchment on which there exists considerably high data availability and documentation, as initially assumed, since it is a monitored priority catchment. An important methodological issue that arose is that even though it is a catchment with high data availability, the publicly available data might not be sufficient for integrated economic-environmental analysis. This is demonstrated by the lack of sufficient information for separating the farms of the catchment from the farms of the broader area of the parishes. This issue is further discussed in Chapter 7.

5 Methodology

5.1 Introduction

The principal message of Chapter 3, that reviewed approaches for integrated impact assessment of water and agricultural policies, was that there is a very broad range of modelling techniques and methodologies with varying levels of complexity, and that the selection of the appropriate approach regarding model components and characteristics should be mainly guided by the specific objectives of the modelling exercise. The aim of this chapter is to present and discuss the key features of the methodology that was employed for achieving the specific objectives of this thesis. The chapter firstly outlines the mechanisms engaged for achieving integration across systems and scales. Following this, the characteristics and specifications of the economic and bio-physical components, and the data management procedures for the operationalisation of the methodological framework, are described. Subsequently, the Chapter progresses with the system and data specifications for the application of the methodological tools to the Lunan Water catchment case study. Specifically, these are the establishment of the farm and soil typologies, the approach for combining them in order to identify the soils distribution for the modelled farm types, the definition of agricultural activities, the data used, and the considered bio-physical and economic scenarios.

5.2 Integration across Systems and Scales

Bio-economic modelling is a methodology that aims at the integration of socio-economic and natural systems (as identified and described in Chapter 1). In this research, a bio-economic model is used for modelling farmers' decision making. This is FSSIM-REG[26], a model based on FSSIM-MP (Louhichi *et al.*, 2010a; 2010b) that was developed under the EU FP6 Project SEAMLESS (van Ittersum *et al.*, 2008). Integration in FSSIM-REG is achieved through the incorporation of information on yields and a number of environmental indicators associated to the defined

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[26] The adapted model version of FSSIM-REG, as opposed to FSSIM-MP, includes also the farm type dimension. This model upgrade has been implemented by K. Louhichi in the context of the *BECRA* project.

agricultural activities. This information is generated by bio-physical modelling simulations. The bio-physical model used for this study is COUP (Jansson & Karlberg, 2004).

The specification of the production activities is one of the most important steps in the conceptual and practical integration of the bio-physical and the bio-economic components. Clearly, the agricultural activities need to be consistent between the two models, for the outputs of the bio-physical model to be successfully incorporated into the bio-economic model. Therefore, the choice of the dimensions to be used for the characterisation of an agricultural activity needs to be based upon, firstly the factors that are of importance for analysing the problem at hand, and secondly the characteristics of the activity that can be effectively simulated by both models.

The main characteristics of a cropping agricultural activity that influence yields and nitrate losses are i) the crops grown and the sequence of these crops in crop rotations, ii) the production techniques used, with a focus on fertilisation levels, and iii) the soil types on which each of the activities take place. As it will be seen in sections 5.3.3.2 and 5.4, these factors can be incorporated into the definition of agricultural activities of both FSSIM-REG and COUP. Consequently, a crop production activity has been defined as a rotation, consisting of a sequence of crops, with the use of a certain fertilisation level and cultivated on a specific soil type.

The levels of spatial and temporal resolution and extent have been chosen according to the specific processes to be modelled and the principles discussed in sections 3.2.2 and 3.2.3. The methodology applied is analogous to what Rastetter *et al.* (1992) call *partitioning* for the aggregation of fine scale ecological knowledge into coarser-scale attributes. Partitioning is a way of reducing aggregation errors by reducing the variability among the components to be aggregated through their classification into relatively homogenous sub-aggregates. As the number of partitions increase the level of aggregation errors will decrease (*ibid*).

The first level of resolution in the spatial hierarchy is the field level. Fields are partitioned into homogenous groups according to their soils properties (see section 5.6.2 for details). At this level crop growth and nitrate leaching are simulated by COUP for a range of rotations and management practices on a daily basis for a series of years (see section 5.7.1 for details). The key outputs extracted from the simulation outputs are average seasonal yields per crop in a rotation and average nitrate leaching per rotation, over the simulation period.

The following level of the hierarchy is the farm. Farms are classified into farm types according to their production orientation and size (see section 5.6.3 for details). The aggregation from fields to farms is done in two ways: i) a constraint in the economic model specifies the number of fields of each soil class that is available to each of the farm types; ii) the rotation and management on each of the available fields are selected through the optimisation procedure of the economic model. The information that has been generated at the field level enters the economic model in the form of yield and leaching coefficients. That is, each of the field types that is characterised by soil, rotation and management is associated to a coefficient of average annual yield per crop in the rotation and a coefficient of average annual leaching per rotation.

The natural upper spatial level of the analysis is the catchment. However, in our case due to data limitations discussed in section 4.7 the area of the 12 agricultural parishes within which the catchment is situated has been used as the upper spatial level of the analysis. Aggregation of farms at this level is achieved through a formal aggregation procedure in FSSIM-REG that uses an aggregate objective function where the individual farm types are multiplied by the number of farms per farm type. At this level, farmers' decision making for each of the individual farm types is simulated for a number of scenarios in a comparative static framework. This generates information for each of the farm types and scenarios modelled on a number of i) socio-economic indicators, such as farmer utility, income, premiums, gross production, costs, labour use, ii) technical information including land use and choice of rotations and management, and iii) environmental indicators such as average per hectare input use and nitrate leaching at the farm level. Information such as utility, income and land use is also provided at the aggregate level.

5.3 Economic Component: FSSIM-REG

5.3.1 Model Selection

The selection of FSSIM-REG for achieving the objectives of this study was guided by a number of principles discussed in previous chapters. As identified in Chapter 1, a bio-economic modelling approach was suited to the needs of the study due to its ability to consider farmers' reactions to policy change, take into account both the socio-economic and environmental outcomes of agricultural production, and allow the comprehensive representation of the complexity of the agricultural system. Further, as concluded in Chapter 3: i) the use of MPMs based on a utility maximising behaviour is a widely used and appropriate approach for agricultural economics policy analysis due to its ability to perform ex-ante impact assessment of policies, and to allow sufficient representation of ecological and behavioural heterogeneity in a bio-economic modelling framework; ii) the choice of an objective function that represents farmer's objectives allows a direct assessment of the effects of policies and the potential adoption of policy measures and generates information for policy makers through a scenario approach; iii) the most commonly assumed farmers' objectives are associated to profit and risk considerations; iv) non-embedded risk methods are simpler to handle analytically and are thus more appropriate in cases where there is no evidence of considerable uncertainty regarding the coefficients of the model constraints; and v) exact calibration approaches based on PMP have the advantages of achieving automatic and exact calibration based on information on the observed behaviour of economic agents, they have lower data requirements, and they conform to a generic procedure that is easily applicable to different regions and farm types. FSSIM-REG is a model that adheres to the economic modelling characteristics described above. It is a bio-economic farm level non-linear MPM, where farmers' objectives are associated to profit and risk considerations, non-embedded risk is used for the incorporation of risk and uncertainty, and a number of PMP variants are implemented for model calibration.

Another important characteristic of FSSIM-REG is that it is an activity based model with primal representation of technology. Specifically, the production processes are represented by discrete production activities defined as vectors of technical/environmental coefficients which describe the production inputs, the agricultural outputs (desirable products), and their environmental effects (undesirable products). The key advantages of an activity based primal approach are outlined by Heckelei & Britz (2005) as follows: i) it allows simulating policy instruments that are tied to production activities, such as some of the CAP instruments including set-aside obligations, the nitrates directive, etc.; ii) it elegantly handles a representation of joint production of agricultural impacts by allowing for a straightforward link between economic and bio-physical models; iii) it eases and enhances communication in multi-disciplinary research projects; iv) agricultural economists can put in use their engineering background and access to data or knowledge on the actual production process, allowing a more accurate representation of the production feasibility set. Further, Baumgärtner *et al.* (2001) explore the concept of joint production and identify its importance for opening up fruitful research drawing on concepts and methods of economic and the natural sciences.

5.3.2 FSSIM-MP within SEAMLESS-IF

FSSIM-MP, the model on which FSSIM-REG has been based, was developed on the assumption that the model would operate within a model chain, known as SEAMLESS-Integrated Framework (SEAMLESS-IF) that would allow hard linkage and flow of information between different models. The key components of the modelling chain of SEAMLESS-IF are shown in Fig. 5.1 and described in more detail in van Ittersum *et al.* (2008). The key linkages of FSSIM-MP with other models were envisaged to be the following: i) *APES*, a BSM that aimed at the estimation of yield and environmental coefficients related to agricultural activities, ii) *FSSIM-AM*, a data module that was built for computing the technical coefficients for the different agricultural activities, iii) the FSSIM-livestock feed-module, that estimates feed requirements of different animal species and level and quality of feed from grass production and other potential feeds, and iv) SEAMCAP, a partial equilibrium model based on the CAPRI model (Heckelei & Britz, 2001) that would feed back to FSSIM-MP information on trends related to yields, prices, and CAP overshooting rates.

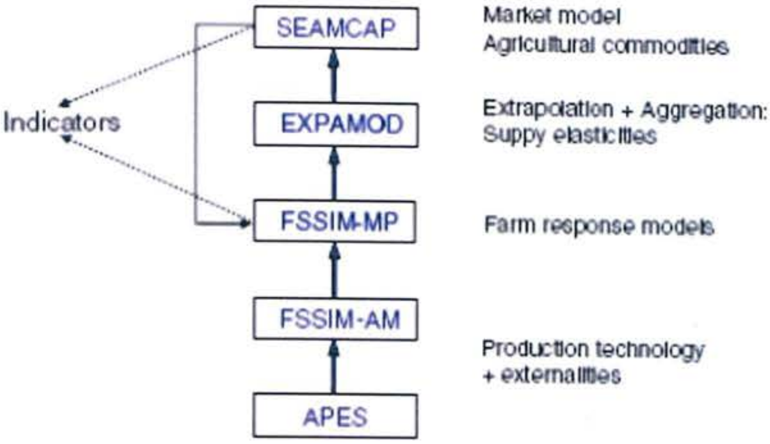

Fig. 5.1 SEAMLESS-IF model chain
Source: van Ittersum *et al.* (2008)

SEAMLESS-IF was built on the assumption that the framework should be able to operate with readily available data at the European level. FADN was identified as one of the key sources of information at this level. Additional information needs to be supplied by experts through a web-based survey. For the user to take full advantage of the designed SEAMLESS-IF capabilities, the scale of operation needs to be the Nomenclature of Territorial Units for Statistics (NUTS) II level[27].

In this study, the standalone model version of FSSIM-REG was used, as opposed to the FSSIM-MP version of the SEAMLESS-IF. This was mainly due to the following: i) the scale of analysis is different to the NUTS II level; ii) the SEAMLESS-IF framework, and some of its components including APES, FSSIM-AM, and the FSSIM-livestock feed-module were not fully operational within the timeline of this thesis; iii) use of SEAMLESS-IF would significantly reduce flexibility regarding direct access and manipulation of the model code and data and it would create notable additional dependencies; iv) FSSIM-REG simulates simultaneously all modelled farms and performs within model aggregation of the results at a higher spatial level, as opposed to FSSIM-MP that is a farm-level model.

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[27] http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

5.3.3 Overview and Specification of FSSIM-REG[28]

5.3.3.1 Objective Function

FSSIM-REG assumes that farmers make their decisions in order to maximise expected income minus some measure of its variability, caused by yield variations due to climatic conditions and price variations due to market conditions. This risk specification is taken into account through the Mean-Standard Deviation method (Hazell & Norton, 1986). According to this method, expected utility is defined under expected income and its standard deviation. The model non-linear objective function represents the expected income and risk aversion towards price and yield variations for a number of farms:

$$maxU = \sum_{f} n_f \left(Z_f - \varphi_f \sigma_f\right) \tag{1}$$

where f indexes farm types, U is expected utility, n is the number of farms per farm type, Z is expected income, φ is a scalar for the risk aversion coefficient, σ is the standard deviation of income defined under price variability and yield variability.

Expected income is defined as total revenues, consisting of sales from agricultural products, such as cereal grains, potatoes, vegetables, and subsidy compensation payments minus total variable costs from crop production. Total variable costs include accounted linear costs for fertilisers, irrigation, crop protection, seeds and plant material, and hired labour, and unaccounted costs due to management and machinery capacity reflected by the quadratic term of the cost function. Using mathematical notation, the non-linear income function is:

$$Z_f = \textstyle\sum_j p_j q_{f,j} + \sum_{i,t}\left(s_{i,t} - c_{i,t}\right)\frac{x_{f,i}}{\eta_i} + \sum_{i,t}\left(d_{f,i,t} + \frac{\Psi_{f,i,t} x_{f,i}}{2}\right)\frac{x_{f,i}}{\eta_i} - \varpi L_f \tag{2}$$

where i indexes agricultural activities, j indexes crop products, t indexes the year in a rotation, p is a vector of average product prices, q is a vector of sold products, s is a vector of subsidies, c is a vector of variable costs, X is a vector of the levels of agricultural activities, η is a vector of the number of years of a rotation within each

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[28] Parts of this section draw from Louhichi *et al.* (2010a; 2010b).

agricultural activity, d is a vector of linear terms used to calibrate the model, Ψ is a symmetric, positive semi-definite matrix of quadratic terms used to calibrate the model, ϖ is a scalar for labour cost, and L is the number of hours of hired labour.

The standard deviation of income is given by:

$$\sigma_f = \sqrt{\frac{\sum_k (Z_f - Z_{f,k})^2}{N}} \tag{3}$$

where k indexes the states of nature, and N is the number of states of nature.

The expected income over states of nature is calculated using the same equation that is used for calculating expected income. The only difference is that the average prices and yields are replaced by the different prices and yields over state of nature. The prices and yields over state of nature are independent normally distributed random numbers, which are estimated using a normal distribution function based on the average and the standard deviation of price and yield. Price and yield variations are assumed to be independent.

The estimation of the risk aversion coefficient φ can be done manually or automatically. In the first case, the user assigns a value ranging from 0 to 1.65 to the risk coefficient (for details on the value see Hazell & Norton, 1986). The higher is the value of the coefficient, the higher is the farmer's risk aversion assumed to be. Alternatively, the model automatically assigns a value (between 0 and 1.65) to the coefficient, as described later in section 5.3.3.5.

5.3.3.2 Production Activities

FSSIM-REG is an activity based model with primal representation of technology. Specifically, the production processes are represented by discrete production activities defined as vectors of technical/environmental coefficients which describe the production inputs, the agricultural outputs (desirable products), and their environmental effects (undesirable products). The definition of the agricultural activities in FSSIM-REG is multi-dimensional, allowing their specification as discrete and independent options, whether they refer to different crops, to different technologies for the same activity, or to variations of the same technology. Crop agricultural activities are defined as a combination of a rotation, soil (or agri-environmental zone), management technique, and production orientation. Let R denote the set of crop rotations, S the set of soil types, T the set of production techniques, and Sys the set of production orientations. The set of agricultural activities can be defined as follows:

$$i = \{i_1, i_2, \dots\} = \{\langle R_1, S_1, T_1, Sys_1\rangle, \langle R_2, S_1, T_1, Sys_1\rangle, \dots\} \subseteq RxSxTxSys \tag{4}$$

5.3.3.3 Model Resource Constraints

The principal socio-economic and technical model constraints are arable land per soil type, irrigable land per soil type, labour and water constraints. Rotational constraints are implicitly included in the model through the definition of agricultural activities as rotations rather than crops. Thus, the objective function shown in section 5.3.3.1 is subject to the following constraints:

$$A_i X_{f,i} \leq B_f \qquad \forall f \tag{5}$$

$$C_i X_{f,i} \leq D_f + L_f \qquad \forall f \tag{6}$$

$$X_{f,i} \geq 0 \qquad \forall f \tag{7}$$

where A is a matrix of technical coefficients for arable land per soil type, irrigable land per soil type or water, X is a vector of agricultural activity levels, and B is a vector of available resource endowments for arable land per soil type, irrigable land per soil type and water, C is a matrix of technical coefficients for labour, and D is a vector of available resource endowments for labour.

Water and irrigated land constraints have not been used in this application.

5.3.3.4 Policy Representation

FSSIM-REG models a number of policy measures, including CAP compensation payments, set-aside, cross-compliance restrictions, and modulation. The modelling of policy measures in FSSIM-REG is achieved through their incorporation either in the model objective function or through model constraints. Three policy scenarios are modelled. The first two scenarios are Agenda 2000 and the 2003 CAP Reform. A third scenario allows the user to simulate an additional policy scenario by altering the value of some predefined parameters. These parameters are the level of the basic premiums, the coupling degree of premiums, the level of the set-aside obligation, and the level of the penalty for premium reductions if cross-compliance measures are not respected.

For Agenda 2000, the premium payments are calculated by multiplying the regional historic yield by the premium rate. For 2003 CAP Reform, a number of estimations are introduced. First, the value of entitlements under the SFP Scheme is estimated. This is equal to the reference amount divided by the reference area. The calculation of reference amounts and reference areas for the estimation of the value of the standard and the set-aside entitlements are implemented separately in the model. The reference amount is estimated by multiplying the payment rates of 2002 by the level of the areas that gave rise to the payments during the baseyear. The reference amount should then be divided by the reference areas, which are effectively the areas that gave rise to the payments, so as to estimate the value per entitlement. In FSSIM-REG, for the estimation of the value of standard entitlements the reference amount is divided by the whole area of the farm. A model constraint limits the maximum level of SFPs to the payments calculated using the above procedure. Compulsory modulation is applied by reducing by the defined modulation rate the difference between total premiums and the amount of SFP that is exempt from modulation. The percentage of set-aside obligation is constrained to a lower level as this is defined by the set-aside obligation. However, as set-aside levels in other model applications were often found to be lower that the required level, set-aside can also be constrained to the observed level in the baseyear.

FSSIM-REG offers the possibility to simulate cross-compliance. A binary variable, that needs to be associated to a specific cross-compliance measure, is included in the model objective function. If farmers do not respect the considered measure, the value of the variable is solved to be equal to one, resulting in a reduction of premiums according to a pre-specified premium cut rate. If the measure is respected the value of the binary variable is solved to be equal to zero, with no implications for the level of premiums. However, abnormal model behaviour was observed for the simulation of cross-compliance measures, as the binary was solved equal to zero (farmers respect measure) even when premium reductions where set equal to zero. Surprisingly, it was found that this occurred when the *sbb* solver was used, but not when the *dicopt* solver was used, although both solvers are typically used for mixed integer non linear programming problems. As a consequence, *dicopt* was used for this application.

FSSIM-REG does not take into account voluntary modulation, overshoot of base areas, and the national reserve. Thus, a factor representing these three features has been added. This factor scales back total premiums according to the sum of voluntary modulation, overshoot, and the national reserve rates. Set-aside has been set equal to the level of the observed situation during to base year, as opposed to using the 10% obligation. This way the set-aside constraint, as opposed to the calibration constraints, was binding the level of set-aside.

Income equations (8) and (9) have been used for the Agenda 2000 and the 2003 CAP Reform scenarios, respectively:

$$Z_f = \sum_j p_j q_{f,j} - \sum_{i,t} c_{i,t} \frac{x_{f,i}}{\eta_i} + \sum_{i,t}(d_{f,i,t} + \frac{\Psi_{f,i,t} x_{f,i}}{2}) \frac{x_{f,i}}{\eta_i} - \varpi L_f + \\ (\sum_{i,t} s_{i,t} \frac{x_{f,i}}{\eta_i})(1 - v) \tag{8}$$

$$Z_f = \sum_j p_j q_{f,j} - \sum_{i,t} c_{i,t} \frac{x_{f,i}}{\eta_i} + \sum_{i,t}(d_{f,i,t} + \frac{\Psi_{f,i,t} x_{f,i}}{2}) \frac{x_{f,i}}{\eta_i} - \varpi L_f + \\ \left((\sum_{i,t} s_{i,t} \frac{x_{f,i}}{\eta_i})(1 - v) - P_f m\right)\left(1 - rV_f\right) \tag{9}$$

where v is a scalar for representing the rates of voluntary modulation, overshooting of base areas and national reserve, P is a vector of the amount of premiums that exceeds the amount that is exempt from compulsory modulation, m is a scalar for compulsory modulation rate, r is a scalar for the rate of premium reductions if cross-compliance is not respected, and V is a vector of the binary variable associated to the cross-compliance measure.

5.3.3.5 Model Calibration

FSSIM-REG is calibrated in two stages. The model first automatically assigns a value between 0 and 1.65 to the risk aversion coefficient, choosing the value which gives the best fit between the model's predicted crop allocation and the observed values in the base year reference period, after a number of parametric simulations. The quality of the calibration is assessed by the difference between predicted crop allocation and the actual observed values in the base year period. This is statistically represented by the Percent Absolute Deviation (PAD). The closer the PAD value is to zero, the more satisfying the results of the calibration are.

$$PAD_f = \frac{\sum_{i=1}^{n} |\widehat{x_{f,i}} - x_{f,i}|}{\sum_{i=1}^{n} \widehat{x_{f,i}}} 100 \qquad (10)$$

where $\widehat{X}_i$ is the observed activity level, and X_i is the simulated activity level.

After the assignment of the risk aversion coefficient, the model is partly calibrated. For exact model calibration, one out of three possible variants of PMP (Howitt, 1995) can be used: 1) the standard PMP procedure (Howitt, 1995); 2) the Röhm and Dabbert's approach (Röhm & Dabbert, 2003); or 3) the approach described in Kanellopoulos *et al.* (2010). When the first approach is used, the model is calibrated to the level of the observed land use in terms of crops, as opposed to the FSSIM-REG definition of an agricultural activity which in the case of crop activities incorporates the dimensions of rotations, soils and techniques. Röhm and Dabbert's approach (2003) adds to the standard PMP approach by dealing with the problem of zero marginal cost of the non-preferable activity, and the problem of considering the same activity grown under different variants (e.g. management techniques) as two separate activities (Louhichi *et al.*, 2009). This is achieved by separating the slope of the cost function of each activity into two parts: one part depends on the activity and the other part depends on the variant of the activity (*ibid*). This approach requires additional data on the observed activity levels of the activity variants, which in the case of FSSIM-REG translates into data on the observed activity levels of agricultural activities as opposed to crop levels.

The approach of Kanellopoulos *et al.* (2010) also deals with the assumption of a constant marginal gross margin of the non-preferable activity, and with the problem of underestimation of the value of limiting resources. This is achieved by i) raising the value of land to the weighted average gross margin of the observed activity levels, ii) using upper and lower bound calibration constraints for activities with higher and lower gross margins compared to the average gross margin respectively, and iii) using information related to the supply elasticity of different activities along with the dual values of the calibration constraints to determine the weights of the linear and non-linear parts of the quadratic cost functions. The information on the supply elasticity of agricultural activities can be either drawn from econometric studies or estimated by using an ex-post analysis and choosing the value that gives the best forecast (Kanellopoulos *et al.*, 2010). A default value is currently used in FSSIM-REG.

When the model is calibrated to the level of the observed levels of crops, as opposed to the level of a rotation on a specific soil and a specific technique, model calibration is not always automatically achieved, since the occurrence of different crops in the set of included rotations can often be in disagreement with the exact observed crop pattern. The following simple example clarifies this. Assume an average farm with three hectares available land and average land use pattern over three years that corresponds to one hectare of wheat and two hectares of barley. If the only rotation included in the model is wheat-barley, the model will not be able to calibrate as it will be impossible to reproduce a land use pattern where there appears to be more barley than wheat. In order to reach the level of two hectares of barley, the level of wheat would need to increase in an analogous manner, so it would need to be exactly as much as barley. On the contrary a rotation of wheat-barley-barley would allow the model to calibrate, by selecting three hectares of this rotation, corresponding to one hectare of wheat and two hectares of barley. Within SEAMLESS-IF, rotations of one single crop are added, so as to allow the model to calibrate. Alternatively, model calibration can be achieved through altering the set of rotations included in the model. FSSIM-REG facilitates this by solving a sub-model that aims at the minimisation of PAD. The results of the sub-model include the estimated deviation between the observed crop pattern and the simulated levels per crop. Using this information, the user is able to adjust the rotations accordingly through a trial and error procedure until model calibration with a set of realistic agricultural activities is achieved.

In this study, we used the approach of Kanellopoulos *et al.* (2010) for model calibration, as it has been shown that it results in better model predictive capacity compared to the standard PMP approach (*ibid*) and as the data required for the Röhm and Dabbert's PMP approach were not available. In order to achieve accordance between observed crop levels and model rotations, different sets of rotations have been tested until calibration was achieved. This way the rotational constraints are taken into account when the risk aversion coefficient and the coefficients of the PMP quadratic cost function are estimated through the two step calibration procedure, thus avoiding biases in the results of the calibration that could be carried over to simulation.

The FSSIM-REG standard version is calibrated using the FADN crop list as opposed to the actual crop list. The FADN crop list contains fewer crops compared to the model crop list, and as a consequence some groups of model crops are assigned to the same FADN crop (e.g. both winter and spring barley are represented by the crop *barley* in FADN). This procedure would lead to the assignment of the same PMP linear and non-linear terms to all crops mapped to the same FADN crop (e.g. both winter and spring barley would be assigned the same PMP related terms). This has been treated by fixing model data so that each crop is treated as an individual crop.

Additionally, risk neutrality by setting the risk aversion coefficients equal to zero for all farm types has been assumed. This was because risk was found to interfere in an abnormal way with the selection of the value of the binary variable used for cross-compliance. Assuming risk neutrality was, therefore, necessary for ensuring consistency of the assumptions between the scenarios that have been simulated.

5.4 Bio-physical Component: the COUP Model

5.4.1 Model Selection

Section 3.4.2 identified a number of criteria for the selection of a bio-physical model. These include i) appropriateness for the intended purpose, such as the responsiveness of the model to target decision variables, ii) ability of the model to accurately reproduce the relevant eco-physiological processes, iii) support that the model developers and its community of users are able to provide, iv) data requirements, v) extent to which it has been used and tested in specific bio-physical environments, vi) number of crops that it is able to simulate, and vii) user-friendliness of the model.

There is a significant number of BSMs that can be used for the estimation of yield and leaching coefficients. The models considered for this application include CropSyst (Stöckle *et al.*, 2003), NDICEA (van der Burgt *et al.*, 2006), DNDC (Li, 2000), APES (Donatelli *et al.*, 2009) and COUP (Jansson & Karlberg, 2004). The key criteria for narrowing down the list of potential models to the ones mentioned above were criteria (iii) and (v), due to the particularity of Scottish natural conditions relating to high soil organic matter, low temperatures, and high rainfall. Thus, there was a need for a model that would have been developed, used and tested in similar conditions or that the developers' community would be able to propose model adjustments for capturing particularities related to Scottish conditions.

CropSyst was initially identified as the most appropriate BSM for the needs of this research. CropSyst is a multi-year, multi-crop, daily time step, simulation model that simulates crop growth, nitrogen leaching and run-off, and soil erosion taking into account climatic characteristics, soil types, crop characteristics, and farming management options such as crop rotations, nitrogen fertilisation, tillage, and residue management. It has been widely used to analyse the effects of alternate fertilisation practices on crop growth and the associated environmental effects in different environments (e.g. Belhouchette *et al.*, 2004; Sadras, 2002; Le Grusse *et al.*, 2006). The model has been previously used in Scotland to explore the impacts of climate change on agriculture (Rivington *et al.*, 2007) and it is part of the LADSS[29] integrated modelling framework. However, even though CropSyst is being used in Scotland for the estimation of crop growth, the performance of the model for estimating externalities relating to nitrates was not considered satisfactory. That was due to model failure to capture high soil organic matter which is an important characteristic of Scottish soils (K. Topp, pers.comm., 28/09/2008) and the redevelopment of the model N component that was not expected to be ready in time for this work (M. Rivington & G. Russell., pers. comm., 31/10/2008).

The next model considered was NDICEA. NDICEA is a process-based simulation model which simulates soil water dynamics, N mineralization and inorganic N dynamics over the course of a rotation on a weekly time-step. NDICEA has been validated for Dutch and German datasets and has been previously used to represent Scottish conditions (van der Burgt *et al.*, 2006). Additionally, it has low data requirements, represents a wide range of crops, and is relatively user-friendly. The key disadvantage of NDICEA is that the model crop component is target-oriented, and thus target yield is required as an input to the model. In bio-economic modelling, yields for a range of soils and fertilisation levels are a typical output of the BSM, due to the difficulties associated with finding yield estimates for the specific scenarios. Use of NDICEA would imply assuming the levels of yields for the relative scenarios, which would generate concerns over the robustness of the assumptions made on yield levels according to soil type and fertiliser level, and the knock-on effect of these assumptions on model outputs regarding nitrate leaching.

The next two models considered were the SEAMLESS developed BSM, named APES, and DNDC. APES is built on similar to CropSyst principles, aiming at a more generic and modular model architecture. Even though the process of model validation in Scottish conditions was initiated, this was halted by the removal of the model soil component for re-development. Thus model development and testing was incomplete within the timeline of this project. DNDC is a model primarily aiming at the prediction of trace gas emissions from agricultural systems (Li, 2000), but has

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[29] http://www.macaulay.ac.uk/LADSS/dss_home.html

also been used for the estimation of nitrate leaching (e.g. Britz & Leip, 2009). To our knowledge there are no published results from DNDC applications regarding nitrate losses in Scottish conditions, and therefore even though the model is well validated for gaseous emissions, there were concerns on the capacity of the model to simulate nitrate losses (K. Topp, pers. comm., 14/12/2010).

The COUP is a dynamic and deterministic model of plant and soil processes. It simulates soil water and heat processes, and plant growth processes on a daily time step. The SOIL (Jansson, 1996) and SOILN models (Eckersten *et al.*, 1996), which are integral parts of the COUP model (Jansson & Karlberg, 2004) have been previously used and validated for Scottish conditions (McGechan *et al.*, 1997; Wu *et al.*, 1998). McGechan *et al.* (1997) explored the suitability of SOIL for studying the processes of water transport in soil. Their simulations showed sufficient agreement with measured data to permit the use of the model for the study of soil water dynamics and the transport of water-borne pollutants through the soil. Wu *et al.* (1998) showed that simulated yields agreed with measured values for both cereal and grass crops, and that there were similar trends in nitrate leaching between simulations and site experiments. They concluded that SOILN can make realistic predictions about the effects of varying crop, soil and fertiliser management practices. Other model applications in Scotland include Lewis *et al.* (2003), McGechan *et al.*, (2005), and Liu *et al.* (2003). Extended model use and successful model validation are due to the sound theoretical soil water and heat principles, and the inclusion of features that make the model suitable for the representation of water transport processes in Northern Europe, where soils are generally wet and subject to periods of snow and frost cover (McGechan *et al.*, 1997).

5.4.2 Overview, Specification and Set-up of COUP[30]

COUP has been used to simulate forestry as well as agricultural systems (e.g. Norman *et al.*, 2008; Conrad & Fohrer, 2009). In COUP, the plant is described by

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[30] This section draws from the description of the model processes and set-up provided by D.Tarsitano for the purposes Mouratiadou *et al.* (forthcoming) that has now (April 2011) been submitted for publication in *Bio-economic Models applied to Agricultural Systems: an Integrated Approach to Relations between Agriculture, Environment, and Natural Resources - Tools for Policy Analysis*. Model set-up has been performed by D. Tarsitano.

four C pools: leaves, stem, roots and grains. The C required for plant development is calculated as function of the global radiation absorbed by the canopy, with temperature, water conditions and N availability being considered as limiting factors. The plant demand for N is a function of the plant C:N ratio. N enters into the soil in the form of manure application, fertiliser and atmospheric deposition, which are external inputs. In addition, a smaller fraction of the N input is provided by the vegetation litter, which contributes to the main C input into the system. Organic C and N are added to the soil organic pools, faeces and litter, while mineral N goes into the ammonium and N mineral pools. The organic pools are characterised by a fast decomposition rate, which determines the flux of C and N into a third organic pool (humus), characterised by a slow decomposition rate. Part of the C present in this pool will be lost due to soil respiration. The N cycle is described in terms of immobilisation/mineralisation between the organic and mineral pools, nitrification, which determines the flux between the ammonium and N pool, denitrification where N is lost into the atmosphere, and finally N leaching. These key model processes are depicted in Fig. 5.2.

Soil water dynamics is a crucial part of the overall system as several of the N processes are strongly dependent on water content and fluxes. Denitrification is particularly dependent on the oxygen present in the soil layer. Therefore, the higher the water content in the soil layer, the faster the process of denitrification taking place. The soil profile is divided into layers, where water and heat fluxes are estimated from soil characteristics, such as the water retention curve, and the hydraulic and thermal conductivities.

The crop model was manually tuned using as guidelines values reported in the literature (e.g. Eckersten & Jansson, 1991; Kätterer *et al.*, 1997; Nylinder, pers. comm., 20/11/2010). In addition, expected crop yields for Scottish conditions reported in the Farm Management Handbook (FMH) (Chadwick, various years) have been used as target values for the parameterisation process. COUP has been previously parameterised for a representative Scottish soil (M. McGechan, pers.

comm., 20/06/2010). This sub-model parameterisation has been used in this study, as it is similar to the soil scenarios under investigation, described in Section 5.6.2.

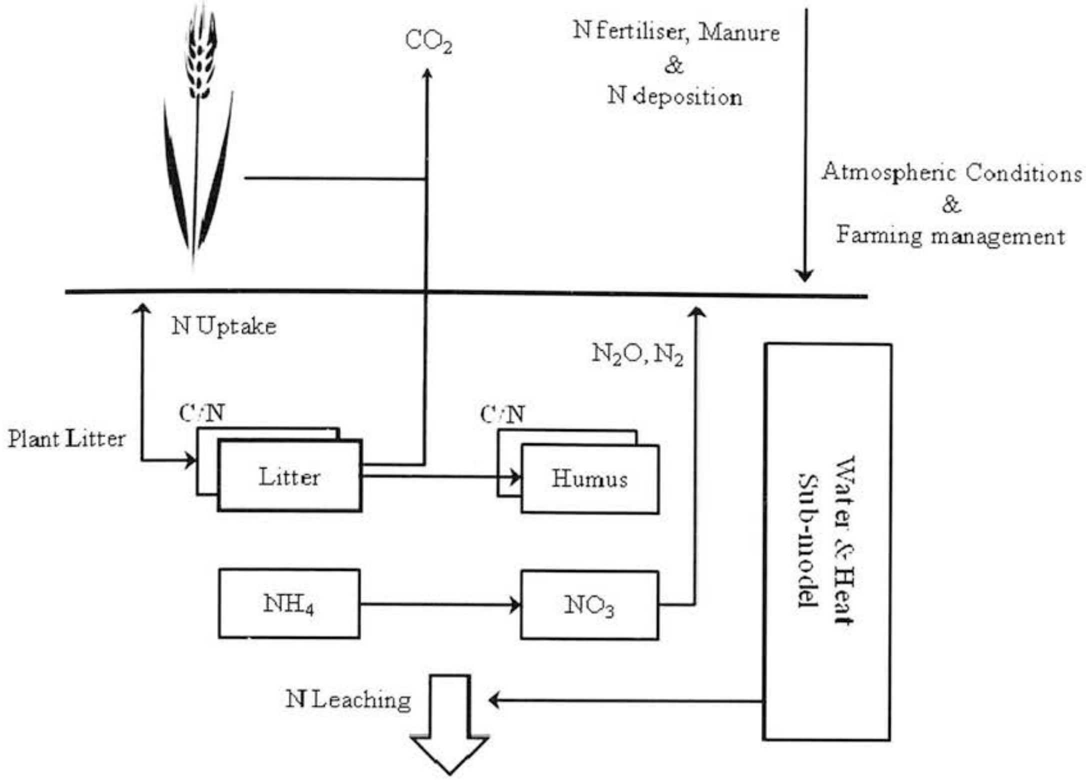


Fig. 5.2 Block diagram of the COUP model
Source: D. Tarsitano (pers. comm., 17/03/2011)

5.5 Data Management and Integration Procedures

5.5.1 Procedural Requirements

The need for data management and model integration procedures is directly related and reversely analogous to the degree of coupling between the different modelling components of a methodological framework. Use of the FSSIM-REG model and the COUP model, as opposed to the SEAMLESS-IF modelling tools and modelling chain, imposed loose coupling between the main modelling components of the framework. This resulted in the lack of readily available automatic methods for the practical implementation of the methodology, associated to three major tasks: i) substitution of the SEAMLEFF-IF tools for the generation of the data files required as input for FSSIM-REG at the pre-disposed format inflicted by SEAMLESS-IF; ii) transformation of data from different sources and degrees of aggregation into the data definitions used by FSSIM-REG and imposed by the relevant model assumptions; iii) linkage between the points of integration between FSSIM-REG and COUP. The tools employed for the achievement of these tasks are respectively discussed in the three next sections of this Chapter.

5.5.2 Data management Facility for FSSIM-REG

5.5.2.1 Tool Overview

Section 3.3.5 discussed the need for structured data management procedures, in particular regarding generic models such as FSSIM-REG. The standalone FSSIM-REG model version corresponded to a model requiring a considerable amount of data, but with no defined procedures to feed these data into the model. Additionally, model input files had to be consistent with the format of the input files used within SEAMLESS-IF so as to achieve consistency between the two alternate ways of model application, required by the simultaneous development and numerous updates of the FSSIM-MP model. The model input files consist of GAMS *include* files which are stored in a number of folders hierarchically ordered. The include files are essentially text files that can be read by GAMS, and contain the data declarations and data definitions of the corresponding data items. In order to enable model use outside the SEAMLESS-IF, a model-specific data management facility for entering, storing, editing and importing the required data has been developed. The use of MS Access in conjunction with the mdb2gms utility was identified as the most appropriate approach on the grounds of striking the right balance between sophistication of data management capacities, user-friendliness, and generic nature aiming at tool re-usability (see section 3.3.5 for details). Thus, these tools have been used for the development of the Data Management Facility (DMF) for FSSIM-REG.

The DMF serves two specific purposes. It is used as a database for storing, manipulating and interfacing the FSSIM-REG data (database module - DM), and as a tool for retrieving the data from the DM and transforming them into a readable by FSSIM-REG format (integration code module - ICM). The development of the DMF followed model development and therefore a number of versions are available. The first prototype version (Jan. 08), deals only with crop model components and it has been used for a number of model applications (e.g. Mouratiadou *et al.*, 2008; Majewski *et al.*, 2009; Traoré *et al.*, 2009; Mouratiadou *et al.*, 2009b; Mouratiadou *et al.*, 2011; Mouratiadou *et al.*, 2010; Belhouchette *et al.*, 2011). The last version (Aug. 09) includes changes related to the addition of the additional dimensions of FSSIM-REG, the addition of the livestock component data, and any other changes implemented in the model until the release of the final model version. The latest DMF version has been used for the purposes of this study. The characteristics of the DMF are described in detail in Annex II, and thus only a short summary of the key components is provided here.

5.5.2.2 Database Module

The DM data model draws from the *relational model* for database implementation (Date, 1990) regarding normalisation and integrity rules. Additionally, it follows closely the data structure of FSSIM-REG, in the sense that the actual relationships between different data fields that exist in FSSIM-REG have been used for establishing the relationships between the different DM fields.

The building blocks of any database are the database tables. The Aug. 09 version of the DM contains 67 tables. Each table is characterised by a table name, which is a unique identifier for the relationship defined in the table. The main types of information contained in each table are the primary key, the respective unique natural key, and any data associated to the domain described by these keys. The primary key is a unique identifier securing that there is no row duplication. Surrogate primary keys have been used, however the single or compound natural keys which reveal the actual set/parameter domains, are also contained in the tables and indexed as unique. The unique natural keys reveal the GAMS labels of the sets that are used in FSSIM-REG, hence defining the model domains for sets and parameters. The data associated to the keys provide the values of each of the parameters that are associated to the respective domain. Each of the parameters is included as a separate column in the relevant table and is assigned a specific value type (e.g. string, numerical, boolean, etc.).

The established referential integrity constraints follow the conceptual and technical links of the FSSIM-REG input data for the establishment of one-to-many relationships, as implicitly established by the dimensions of the set and parameter domains in the model. Hence, referential integrity is enforced using the indexed unique natural keys which are used as foreign keys in subsequent tables. For each table, the combination of the relevant foreign keys forms then the unique natural key of the multi-dimensional set or parameter table. An example of some referential integrity constraints is shown in Fig. 5.3.

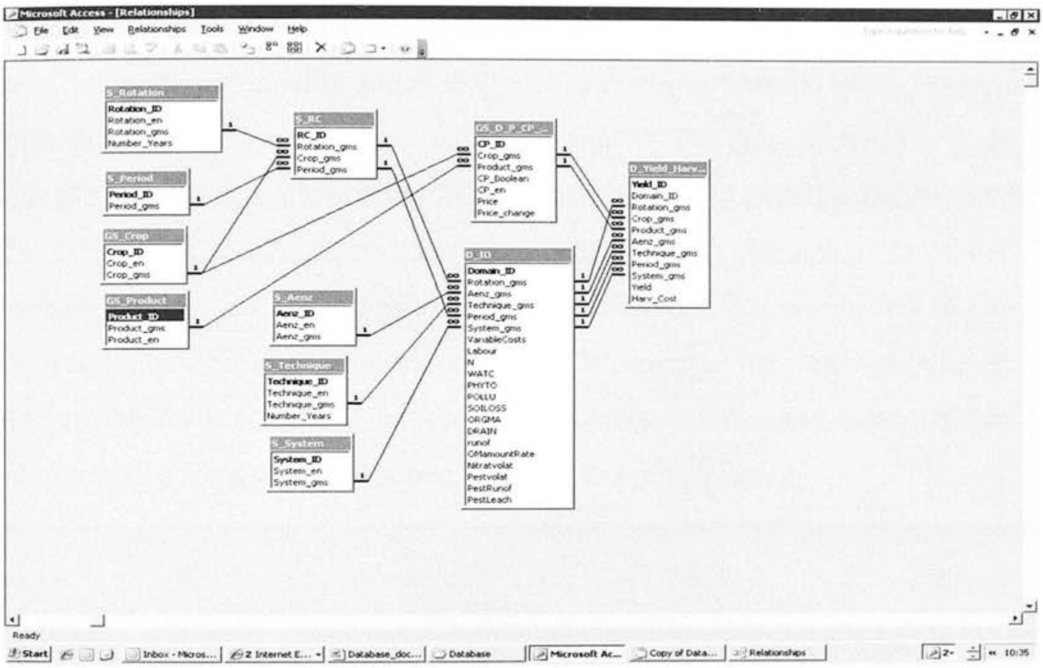
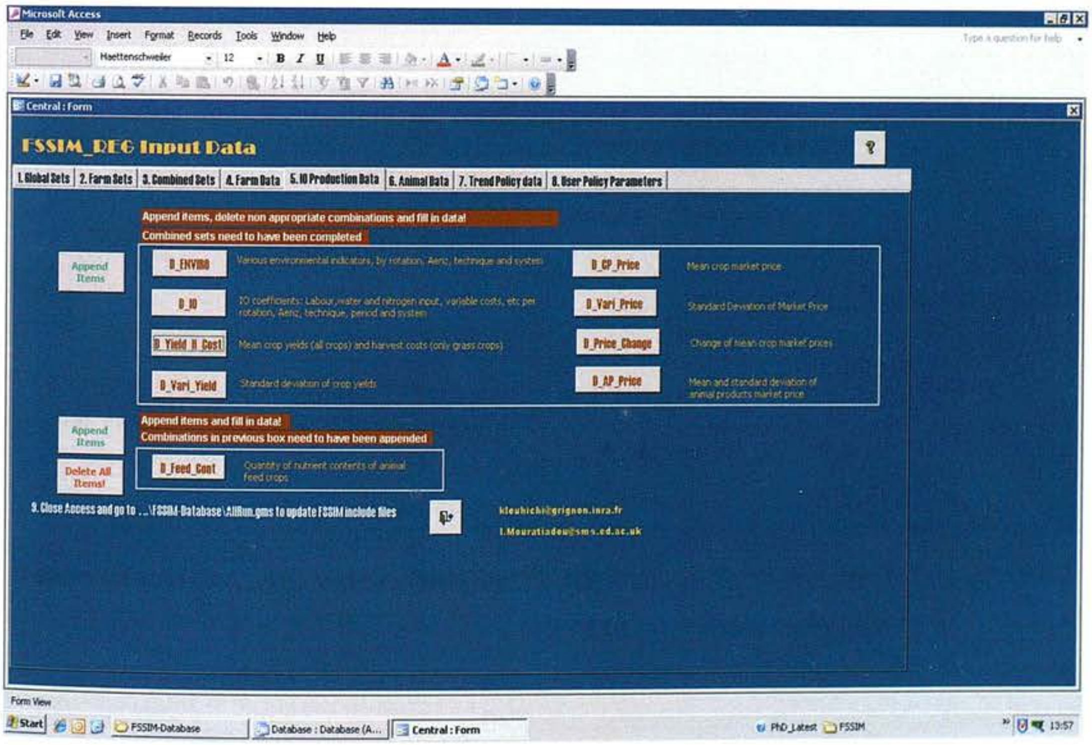


Fig. 5.3 Example of referential integrity constraints in the DMF

The database tables corresponding to SEAMLESS-IF defined data have been populated by accessing and extracting the respective data from the SEAMLESS Database (Janssen *et al.*, 2009). The rest of the tables are to be populated by users on a case study basis. For the facilitation of this task, a number of SQL append queries have been developed. These queries combine information and rules on natural keys that have already been entered in other tables and import these combinations on the dependant table, so that the user does not need to manually re-enter all the required information. A SQL query has been developed for each table that its natural key is a combination of two or more foreign keys, with at least one of them being a user-defined set. The Aug. 09 version contains 34 queries.

A database interface has been developed to facilitate DM navigation (Fig. 5.4). This consists of an MS Access form written in Visual Basic for Applications. An initial template for the form has been provided by S. Uthes (pers. comm., 04/11/2008). The interface displays each of the required data items and their corresponding description. Each data item is associated to a command button that opens the respective table where the data are stored using event procedures written in Visual Basic for Applications. The tables are grouped into eight data categories organised under different tabs of the interface. The grouping and ordering of the data follows the underlying hierarchical relationships between sets and parameters and the associated referential integrity rules, in a way that the user is first prompted to insert data of lower dimensionality and then gradually continue towards filling in data with higher dimensions. Between the different steps of the data population there are command buttons that allow using SQL append queries to populate the natural keys of the tables, and/or SQL delete queries to delete the data contained in the tables. The command buttons are associated to macros with queries that correspond to specific data groups. In total eight append and five delete macros have been developed and linked to the form command buttons. Additionally, a command button allows the user to access a form with instructions on database population.



Append items, delete non appropriate combinations and fill in data!

Combined sets need to have been completed

D_ENVIRO: Various environmental indicators, by rotation, Aenz, technique and system

D_IO: IO coefficients: Labour,water and nitrogen input, variable costs, etc per rotation, Aenz, technique, period and system

D_Yield_H_Cost: Mean crop yields (all crops) and harvest costs (only grass crops)

D_Vari_Yield: Standard deviation of crop yields

D_CP_Price: Mean crop market price

D_Vari_Price: Standard Deviation of Market Price

D_Price_Change: Change of mean crop market prices

D_AP_Price: Mean and standard deviation of animal products market price

Append items and fill in data!

Combinations in previous box need to have been appended

D_Feed_Cont: Quantity of nutrient contents of animal feed crops

9. Close Access and go to ...\FSSIM-Database\AllRun.gms to update FSSIM include files

kleuhichi@grignon.inra.fr

I.Mouratiadou@sms.ed.ac.uk

Fig. 5.4 Example of a tab of the database interface

5.5.2.3 Integration Code Module

The ICM operates through the mdb2gms utility. The purpose of the ICM is to retrieve the data contained in the DM and to write them in GAMS *include* files. In the code one needs to specify the source database, an SQL query for each data item, and the data destination file for each data item. The approach uses the batch multi-query operation, as it is considerably faster and semi-automatic. A small part of the code is shown in Fig. 5.5. The ICM is run independently from the rest of the FSSIM-REG code. It comprises of i) five modules retrieving the data from the DM and transferring them into the respective include files, ii) one module for running all the five modules previously mentioned, that can be used to update all the data files, and iii) 12 modules for data declaration, that are called into the FSSIM-REG model code.

```
*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*
* Filetype:   GAMS program file
* Created:    December 2007
* Updated:     August 2009
* Authors:    Mouratiadou
* Purpose:    Data transofrmation into text files (farm data)
*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*


$setlocal DataRepository ..\FSSIM-DM\INPUTDATA
$setlocal commandfiles temporary.txt
$onecho > %commandfiles%

I=%system.fp%Database.mdb

************Data for Farm_Data.gms

Q1="SELECT MState_gms, Region_gms, F_Type_gms, No_Farms from RG_D_All_comb"
O1="%DataRepository%\farm_data\weight.inc"
Q2="SELECT distinct(Rotation_gms), Number_Years from S_Rotation"
O2="%DataRepository%\Farm_set\NR.inc"
Q3="SELECT MState_gms, Region_gms, F_Type_gms, Miscdat_gms, 'TOTAL', Miscdat_value
from D_Misc_Farm Union SELECT MState_gms, Region_gms, F_Type_gms, Miscdat_gms,
Aenz_gms, Land_value from D_Land_Farm"
O3="%DataRepository%\Farm_data\MISCDAT.inc
Q4="SELECT MState_gms, Region_gms, Rotation_gms, Aenz_gms, Technique_gms,
Period_gms, System_gms, 'N', N from D_IO UNION SELECT MState_gms, Region_gms,
Rotation_gms, Aenz_gms, Technique_gms, Period_gms, System_gms, 'WATC', WATC from
D_IO"
O4="%DataRepository%\IO_data\INPUT.inc"
Q5="SELECT MState_gms, Region_gms, Rotation_gms, Aenz_gms, Technique_gms,
Period_gms, System_gms, VariableCosts from D_IO"
O5="%DataRepository%\IO_data\COSTS.inc"
M
$offecho
$call =mdb2gms @%commandfiles%
```

Fig. 5.5 Example of ICM code

5.5.3 Data Transformation procedures

The DMF requires data inputs at the exact format that is required by FSSIM-REG. This format is dependant on the system definition employed by the user for each specific case study, and for the key data it boils down to two specific data types: i) mean values for data on the model farms according to the defined farm typology, and ii) data on the agricultural activities according to the defined rotations, crops, soils and techniques. As expected, no publicly available data can be provided at such a format which is highly detailed case study specific information. Thus, existing information had to be linked to the required data through the implementation of rules.

Additionally, some FSSIM-REG data dimensions can in effect be redundant, due to either limited data availability or due to the assumptions employed for a specific application. For example, labour requirements are defined according to the dimensions of an agricultural activity, namely rotation, crop, soil and technique. One can argue that the key dimension to be considered and provided by publicly available data is the crop, and hence the rest of the dimensions can be ignored. However, as the data definition is fixed in FSSIM-REG, labour requirements need to be provided according to the defined agricultural activities. Thus, what could have been a simple data entry of labour requirements per crop (e.g. about 10 crops in this case study), is in fact a time-consuming exercise of the population of the field per agricultural activity (e.g. represented by about 570 rows in this case study).

Finally, due to the calibration issue discussed in section 5.3.3.5, the model had to be run with a considerable number of different sets of rotations, in order to identify the set of rotations that would allow it to calibrate. As a great number of data are structured according to the defined rotations, changing rotations implies updating all the relevant data fields. This task would have been extremely time-consuming and ineffective without the use of a standardised procedure.

For the maximisation of efficiency of the above mentioned processes, the following data management procedures have been employed: i) the raw data, as provided by the original data sources, were entered and stored in an MS Access database; ii) a considerable amount of SQL queries were coded for implementing rules for the transformation of the data into the format required by FSSIM-REG; iii) the output tables were linked to the DMF that would contain the data for the Lunan Water catchment application; iv) standardised macros based on a number of SQL queries for linking the information between the *sender* and the *recipient* tables were implemented; v) for model calibration, the above procedure was further extended though a macro implementation that performs a sequence of operations where the data related to rotations are deleted and then re-populated according to pre-defined rules.

5.5.4 Transformation of COUP Output into FSSIM-REG Input

For loosely integrated models, external to the models procedures need to be employed for establishing communication between the different modelling components. Moreover, it is often the case that when two modeling components have been independently developed, the exact points of integration between them, in terms of the output provided by the bio-physical component and the input required by the bio-economic model, are not entirely consistent and thus some data transformation needs to occur.

As described in section 5.2, the points of integration between FSSIM-REG and COUP are information on yield and nitrate leaching coefficients associated to the defined agricultural activities. The specific FSSIM-REG inputs for this application include: i) average annual yield across the bio-physical simulation period for each crop within a rotation, soil and technique, and ii) average annual nitrate leaching across the bio-physical simulation period for each rotation, soil, technique. The corresponding COUP outputs are daily figures on yield harvest and accumulated nitrate leaching across the simulation period for each simulation scenario corresponding to a rotation, soil, technique.

For the transformation of the COUP output into FSSIM-REG input, a code in MS Visual C#[31] has been used. The code is based on a template provided by E. Casellas (pers. comm., 16/12/2010), that had been originally written for transforming CropSyst outputs into FSSIM-MP inputs. The code has been tailored to estimate FSSIM-REG inputs from COUP, as opposed to CropSyst, outputs. The final version that has been used for this application can be seen in Annex IX. The input required for the code to be operational is: i) an individual folder for each rotation, named after the rotation label used in FSSIM-REG (created manually for each of the simulated scenarios); ii) within each of these folders, firstly an MS Excel file containing for each year of the bio-physical simulation period a column with the name of the crop corresponding to each year (created manually) and a column with the respective yield (copied from COUP formatted output), and secondly an MS Excel file containing the daily accumulated nitrate leaching for the bio-physical simulation period (copied from COUP output). Using the above as input, the code produces i) a text file where each row contains the name of the rotation, the name of the crop within the rotation, and the mean yearly yield of the respective crop for each agricultural activity; ii) a text file where each row contains the name of the rotation and the mean annual nitrate leaching for each rotation. The content of the text files has been slightly altered in MS Excel so as to match the exact format of input in the FSSIM-REG database, and the respecting fields in the database have been updated using SQL queries with MS Access.

5.6 System and Data Specification

5.6.1 Production Activities

As discussed in section 5.2, the specification of the production activities is one of the most important steps of systems integration, and thus needs to be consistent between the two models, for the outputs of the bio-physical model to be successfully incorporated into the bio-economic model. The production activities discussed in this section have been used for both FSSIM-REG and COUP simulations.

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[31] http://www.microsoft.com/express/Windows/

The selection of crops to be modelled was determined by the identification of the most dominant crops in the Lunan Water catchment with the use of the JCD. The local agricultural consultant was also advised (E. Hart, pers. comm.., 04/07/07). The majority of crops occupying more than 1% of the total area, in any single year, were selected for the analysis (see Table 4.5). A comparison with 2003 IACS data[32] (E. Guillem, pers. comm., 11/03/2010) confirmed the identification of these crops as the most common in the area. Except from the activities occupying more than 1% of the area, carrots were also considered because they are a high value crop. Land uses associated to grass have not been taken into account as these are related to livestock activities that have not been considered in this study. Interestingly, both *spring* and *winter wheat* are represented jointly in the census items. We have assigned the whole area to winter wheat, as an analysis of the IACS data for 2003 showed that spring wheat represents less than 1% of the catchment agricultural area. *Set-aside* assumes the *sown cover* option under the set-aside management rules, and *peas* are assumed to be *peas for human consumption* or *vining peas*, as these were shown to be the most common options in the 2003 IACS data. The final list of crops/land uses consists of *winter wheat, winter barley, spring barley, spring oats, winter oilseed rape, seed potatoes, main crop potatoes, peas, carrots,* and *set-aside*. The selected land uses cover 72-74% of the area (Table 4.5). The crop products considered include *grain* and *straw* for cereals, *grain* for winter oilseed rape and peas, *seed* for seed potatoes, and *ware/root* for maincrop potatoes and carrots.

For the combination of these crops into rotations, three expert consultations took place with two experienced agronomists (J. Elcock, pers. comm., 30/11/07; 28/02/08; S. Hoad, pers. comm., 04/03/08). The first consultation aimed at the elicitation of the basic agronomic and behavioural rotational rules that farmers usually follow (Table 5.1). The last two consultations aimed at i) checking whether the rotations composed out of these rules were consistent, and ii) reducing them into the most common ones so as to keep simulation time and data at a manageable level. The maximum number of periods of the composed rotations was restricted to 6 years. Nevertheless, the

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[32] Even though these data were not available to this research due to confidentiality agreements, indirect use of the data has been achieved through collaboration with E. Guillem that was authorised to use them.

identified rotations were altered due to the problem related to calibration of different farm types identified in 5.3.3.5. The rules prescribed by the consultations were used for this procedure. The composition of the final set of used rotations can be seen in Annex VII. The rotations with rotational set-aside were only considered for the CAP scenarios but not for the nitrate pollution control scenarios (for a description of scenarios see 5.7.2).

Table 5.1 Rules for the composition of rotations

Cereals
1) Most cereals, such as wheat and barley, are grown for 1 to 3 consecutive years. However, winter wheat and spring barley usually appear for 1-2 years, while winter barley for 1 year. 2) Barley usually follows wheat, as it is less nutrient demanding.
Break Crops
3) Cereals are followed by a break crop. Break crops do not appear in a field more often than every four years, due to the profitability of cereals. 4) The most common break crops are: oats, oilseed rape, peas, carrots, potatoes, and set-aside. 5) Oats, even though a cereal, they are considered as a break crop in rotational combinations. 6) Potato crops do not appear in a field more often than every five/six years, due to risk of disease.

Source: J. Elcock (pers. comm., 30/11/07; 28/02/08); S. Hoad (pers. comm., 04/03/08)

The used soil typology consisted of two soil types (Soil A and Soil C) which are further discussed in section 5.6.2. For the identification of the possible combinations of crops and soil types, a calculation of the percentages of areas of each soil series for each of the crops was achieved by combining the *1:25,000 Scale Soils Data* and the IACS data in collaboration with E. Guillem (pers. comm., 11/03/2010). The information per soil series were then aggregated for the defined soil types. It was found that even though the occurrence of different crops on each of the soil types differs, no combinations can be in effect excluded with confidence, so all combinations of land uses and soils were considered.

The techniques considered in the analysis are:

1) Fertilisation: Each activity can be characterised by two possible levels of N fertilisation. The first level represents the fertiliser recommendations for farmers

in NVZs provided by Scottish Executive (2008b) (*ScA*) and the second level corresponds to a 20% reduction of the recommended values (*ScB*).

2) Tillage: Traditional tillage has been assumed for all the activities, as the local agricultural consultant advised that the majority of farms follow traditional cultivation systems (E. Hart, pers. comm., 04/07/07).

Information on N fertiliser levels is used by both FSSIM-REG and COUP. FSSIM-REG requires information on total N use per crop within each agricultural activity, and COUP requires the timing and N levels for all fertilisation doses within an agricultural activity. The publicly available sources of information on N use and recommendations in Scotland are the FMH (Chadwick, various years), the RB209 (MAFF, 2000), the SAC Technical Note T516 (Sinclair, 2002)[33], the Guidelines for Farmers in Nitrate Vulnerable Zones (Scottish Executive, 2008b) and the British Survey of Fertiliser Practice (BSFP) (DEFRA & SEERAD, various years). While the latter reports information acquired through farm surveys on actual fertiliser use on different crops, the other four sources provide recommendations on fertiliser doses. Further information on figures from these sources can be found in Annex VIII.

In this study, we used information mainly from the Guidelines for Farmers in Nitrate Vulnerable Zones, as i) they take into account crop and soil requirements, ii) they are tailored to Scottish agricultural systems, and iii) a great part of the Lunan Water catchment falls within an NVZ. The two assumed N fertiliser scenarios are based on the assumption that farmers take into account crop and soil requirements by respecting the rules in NVZs. The N fertiliser levels vary per crop, soil, and technique, but the effect of different crop residual groups in a rotation has not been taken into account. As shown in Annex VIII, the difference between the recommended N levels for each of the two crop residual groups involved in this study is just 10kg/annum. It has thus been assumed that such a small difference would not have had a significant effect on yield and nitrate leaching levels within rotations of different crops simulated with long-term weather data. Thus, the average

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[33] The recommendations in SAC Technical Note T516 (Sinclair, 2002) form the basis for the more recent recommendations in Guidelines for Farmers in Nitrate Vulnerable Zones (Scottish Executive, 2008b).

values between the recommendations for each of the two crop residual groups have been used. The guidelines do not provide information on seed potatoes and carrots. Thus the SAC Technical Note T516 (Sinclair, 2002) and the FMH (Chadwick, 2000-2002) values have been used for these crops, respectively. Timing and percentage of N application per N dose have been provided by S. Hoad (pers. comm., 03/09/2008). The data used for the parameterization of the two models are shown in Table 5.2.

Table 5.2 N fertilisation data

Crop	Soil	Fertiliser Scenario	1st N dose timing	2nd N dose timing	1st N dose quantity (kg/ha)	2nd N dose quantity (kg/ha)	Total N (kg/ha)
Winter Wheat	A	A	05/04	05/05	78	117	195
Winter Wheat	A	B	05/04	05/05	62.4	93.6	156
Winter Wheat	C	A	05/04	05/05	86	129	215
Winter Wheat	C	B	05/04	05/05	68.8	103.2	172
Winter Barley	A	A	15/03	15/04	70	105	175
Winter Barley	A	B	15/03	15/04	56	84	140
Winter Barley	C	A	15/03	15/04	78	117	195
Winter Barley	C	B	15/03	15/04	62.4	93.6	156
Spring Barley	A	A	05/03	25/03	62.5	62.5	125
Spring Barley	A	B	05/03	25/03	5	5	100
Spring Barley	C	A	05/03	25/03	72.5	72.5	145
Spring Barley	C	B	05/03	25/03	58	58	116
Spring Oats	A	A	05/03	05/04	47.5	47.5	95
Spring Oats	A	B	05/03	05/04	38	38	76
Spring Oats	C	A	05/03	05/04	57.5	57.5	115
Spring Oats	C	B	05/03	05/04	46	46	92
W. Oils. Rape	All	A	15/03	15/04	88	132	220
W. Oils. Rape	All	B	15/03	15/04	70.4	105.6	176
Seed Pot.*	A	A	10/05	30/05	42.5	42.5	85
Seed Pot.*	A	B	10/05	30/05	34	34	68
Seed Pot.*	C	A	10/05	30/05	52.5	52.5	105
Seed Pot.*	C	B	10/05	30/05	42	42	84
Maincr. Pot.*	A	A	06/05	26/05	110	110	220
Maincr. Pot.*	A	B	06/05	26/05	88	88	176
Maincr. Pot.*	C	A	06/05	26/05	120	120	240
Maincr. Pot.*	C	B	06/05	26/05	96	96	192
Carrots*	A	A	06/05	26/05	25	25	50
Carrots*	A	B	06/05	26/05	20	20	40
Carrots*	C	A	06/05	26/05	30	30	60
Carrots*	C	B	06/05	26/05	24	24	48
Peas	All	All	n/a	n/a	0	0	0
Set-aside	All	All	n/a	n/a	0	0	0

Source: own elaboration from Scottish Government (2008); Sinclair (2002); Chadwick (2000-2002); S. Hoad (pers. comm., 03/09/2008)

* Dates originally provided have been altered.

5.6.2 Soil Typology

The construction of the soil typology has been based on the SSKIB data, the leaching potential and the HOST class of the soil series, and the SAC Technical Note T516 (see sections 4.2 and 4.5 for a description of these datasets). Additionally, the IACS data were indirectly used. The secondary information consisted of a GIS shapefile with farm boundaries for the farms of the catchment with no information on farm identifiers (E. Guillem, pers. comm., 08/03/2010).

Ideally, the soils used for the construction of the soil typology should be the soils of the agricultural area of the 12 parishes. The separation of agricultural from non-agricultural land for this area has not been possible due to lack of data for identifying the location of the farms outside catchment boundaries. However, a two-step comparison between i) the soils of the catchment agricultural area with the soils of the whole catchment area and ii) the soils of the whole catchment area with the soils of the area of the 12 agricultural parishes, has been carried out. The identification of the soils of agricultural land for the farms of the catchment has been achieved with use of the GIS shapefile of farm boundaries. This has been combined with the SSKIB spatial data using the ArcGIS *union* operation that allows combining information of several shapefiles into one. ArcGIS *field calculator* operations have been used for the calculation of the area of the polygons with the combined attributes, revealing the areas of soils that were within farm boundaries. The two-step comparison showed no significant differences in terms of percentages of the area per soil series between these three types of land (Fig. 5.6; Table 5.3). Thus, the soil series distribution of the 12 parishes' has been used for representing the soil series distribution of the agricultural area within the parishes.

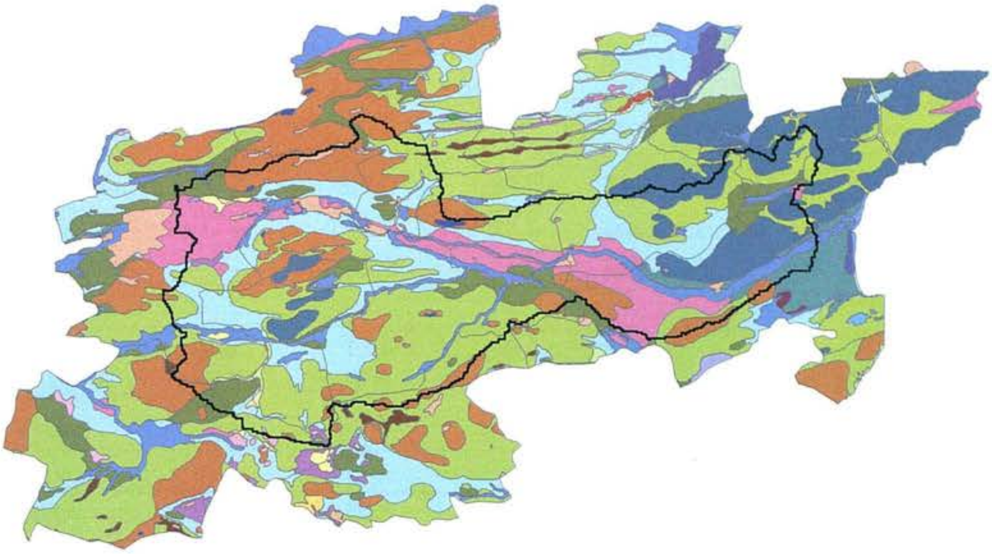

Fig. 5.6 Comparison of soils of Lunan Water catchment and broader area
Source: own elaboration from SSKIB

For the construction of the soil typology, the soils representing less than three per cent of agricultural area, the catchment area and/or area of the parishes have not been taken into account. The remaining soil series (Table 5.3) cover 96.8% of the catchment agricultural area, 95.6% of the catchment area and 90.7% of the broader parishes' area.

For this study, the soil typology needs to adequately confine soil heterogeneity within the area in terms of yield and leaching effects, without however being too extensive, as this would imply unrealistic data requirements, excessive bio-physical simulations, and difficulty in transposing the results into meaningful policy actions. As already seen in section 4.5, a number of classifications of Scottish soils and soil attributes are available for characterising the soils of the Lunan Water Catchment. For the needs of this study, the classification of homogenous soil classes has been achieved with use of the classifications of *Scottish Soil Type Classification System*, the *Soil Leaching Potential Classification*, the *HOST Classification*, and the typology described in the *SAC Technical Note T516*. The specific attributes that have been used for the classification are *drainage class*, *leaching potential*, *HOST class*, and *T516 class* of the involved soil series. The resulting initial classification is shown in Table 5.3.

Table 5.3 Classification of soil series into soil types

Soil Series	Area (%) Lunan Agr. Area	Area (%) Lunan	Area (%) Parishes	Drainage Class	Leaching Potential	HOST Class	T516 Class
Type A							
Balrownie	29.5	29.0	24.9	Imperfect	I1	18	SL
Forfar	17.4	16.7	15.6	Imperfect	I1	18	SL
Mountboy	3.8	3.4	3.9	Imperfect	I1	18	SL
Type B							
Aldbar	14.0	13.6	16.2	Free	I1	6	O
Garvock	9.3	8.9	9.9	Free	I1	6	SL
Vinny	7.4	7.0	8.1	Free	I1	16	SL
Type C							
Corby	9.6	10.5	5.6	Free	H1	5	S
Undif All.	5.8	6.5	6.5	Free	H1	8	S

Source: own elaboration from SSKIB; M. Coull & A. Lilly (pers. comm., 28/10/2009); E. Guillem (pers. comm., 08/03/2010); Sinclair (2002)

The first class consists of the series *Balrownie*, *Forfar*, and *Mountboy* covering around half of the area. Soils of this class, labelled *Type A*, are characterised by imperfect drainage, intermediate leaching potential, HOST class *18*, and sandy loam soil textures. The second soil type is *Type B*, consisting of the soil series *Aldbar*, *Garvock* and *Vinny*. This class is similar to the previous one in terms of leaching potential, but it is associated to free drainage and different HOST classes. In terms of the T516 classification and their soil texture, two of the soils are sandy loams, and one of the soils is in the *other mineral soils* category. Finally, *Type C* consists of the soil series *Corby* and *Undif alluvium*. Type C is the lightest of the three categories, and it is differentiated from the other two due to high leaching potential, sandy texture, and different HOST class. In terms of land use capability, soils of Type A and B are generally characterised as good quality agricultural lands, while the soils of Type C have higher nutrient demands and poor nutrient and water holding capacity (see Table 4.4). Eventually, due to the great similarity between soil types A and B and constraints regarding the possible number of simulations to be run with COUP, soil types A and B have been merged into one soil class.

5.6.3 Farm Typology

Farm-level models can be used to simulate either average farms or representative farms. The use of average farms allows upscaling farm level analyses, includes a more diverse crop mix than the crops observed in a limited number of representative farms, and has lower data requirements (Louhichi *et al.*, 2010a). For these reasons an average farm typology has been used for this study.

The construction of the farm typology has been achieved with the use of the JCD for the years 2001-2003 (see section 4.2 for a description of JCD). The U.K. Farm Classification System has been the starting point for the establishment of the typology, as it is tailored to British agricultural production systems. Additionally, it is used by the JCD and other data sources, allowing consistency between data sources and farm level modelling. This typology uses the main source of income of the farm as its main classification criterion. This is expressed by the farm classification by *type*, described in section 4.6.

Nevertheless, the introduction of additional stratifying variables to the existing typology can allow capturing in a more refined manner farm production patterns and provide more meaningful results from the point of view of agricultural and environmental policy analysis. Table 5.4 shows the crucial classification factors regarding the objectives and methodological assumptions of this study, their main determinants, and the criteria that were available in our farm data set of the JCD for the representation of these determinants.

The criteria of *robust* and *main* farm types were used as the first criteria for the classification of farms by production orientation. These criteria reflect to a great extent farm land use, even though they are expressed in economic rather than physical terms. The robust and main classification criteria allow significant farm diversity in terms of cropping and livestock activities. As cropping farms have different production possibilities, equipment, farmers' abilities and knowledge, and fertilisation potential from manure, compared to farms with livestock activities, farms have been further segregated into cropping and livestock farms.

Table 5.4 Potential farm classification factors

Classification Factors	Main Factor Determinants	Available Criteria
Production orientation	Land use	Areas per land use
	Proportions of gross margins per land use	Robust/main/U.K farm type
Resource endowments and size	Land availability	Total area of holding Area owned by the occupier
	Labour availability	Family labour Hired full-time, part-time and casual labour
	Equipment availability	Not available
	Animal availability	Animal Numbers
	Land/labour ratio	Land availability/labour availability
	Farm gross margins	Calculated standard gross margins
	Standard labour requirements	Not fully available
Inputs, outputs and intensity	Climate	n/a
	Soils	Not available
	Fertiliser inputs	Not available
	Stocking density	Animal numbers/land availability
	Feeding	Not available
	Farm production intensity	Farm SGM per area unit

Source: own elaboration partly drawing from JCD

Farm resource endowments and size can be represented by a number of indicators. Regarding arable farms land availability is often used as a means to expresses farm potential. The ratios between different production factors can reveal the technological orientation of the farm and influence the proportionality of farm model constraints. On the other hand, the criterion of the economic farm output expressed in standard gross margins allows accounting for the economic size of the farm, it can be used for assessments between farms of different production orientation, and it is closely correlated to farm size. Thus, the economic size of the farm expressed in European Size Units (ESUs) has been used as the criterion to represent farm size. ESUs are estimated using standard economic output coefficients for the different agricultural activities and one ESU is equivalent to 1200 units of standard gross margin (Scottish Government, 2001). The numbers of ESUs per farm have been estimated by dividing the standard gross margins of the individual farms by 1200. The ESU thresholds have been drawn from the Economic Report on Scottish Agriculture (ERSA) (Scottish Government, 2001-2003), which identifies five ESU classes: i) less than four, ii) from four until less than eight, iii) from eight until less than 16, iv) from 16 until less than 40, and v) from 40 and above. Due to the small size of our farm sample, the above classes have been merged into two classes: i) 40 and less, and ii) above 40.

The input-output coefficients are determined by factors related to natural factors and production intensity. Regarding natural factors, climate is considered to be homogenous across the Lunan Water catchment. On the other hand, as it has been shown in section 4.5 and further analysed in section 5.6.4, significant soil variability exists both within and across farms. Even though this implies that soils distributions should be taken into account for the construction of the farm typology, this was hindered by limited data availability. Second, production intensity is appropriate for characterizing farm strategy and the environmental performance of farms. Farm intensity is best captured with the use of information on actual farm inputs and outputs, but this information is rarely recorded in practice. As a consequence, no intensity classification criterion has been used in our classification.

To sum up, the resulting farm typology represents production orientation using the criteria of *robust* and *main* farm types and *land use* regarding the existence of livestock activities, and represents farm size with the criterion of the *economic size* of the farm expressed in ESUs.

Prior to the application of the classification factors, some farms have been removed from the farm sample. Farms classified under robust types that represented less than 5% of total farm numbers, were removed as they corresponded to very small farm numbers and to specialized farms that cannot be merged with other farm classes. These were *horticultural*, *dairy*, *cattle and sheep in Less Favoured Areas*, and *pig and poultry* farms. *Other* farms have also been removed, as they are associated to very small holdings where the main source of farmers' incomes is in effect off-farm activities (S. Thomson, pers. comm., 04/03/2010). Indeed, an analysis of the JCD showed that the only crop grown in the majority of *other* farms was grass associated to horses and ponies, while average size was equal to 9.2 hectares, and average gross margin £34.4. The remaining categories corresponded to *cereals*, *general cropping*, *cattle and sheep-lowland*, and *mixed* farms. From the farms under these robust categories, farms belonging to certain *main* farm types associated with very small farm numbers or related to land uses that are dominant in the excluded robust farm types have also been removed. These are i) *cropping and dairy*, ii) *cropping, pigs and poultry*, iii) *mixed poultry and non-dairy cattle*, iv) *cattle and sheep-goats*, and v) *mixed* farms where livestock corresponded to horses and ponies. The number of remaining farms was 222, 223, and 218 in 2001, 2002, and 2003 respectively.

The application of the classification factors in the described farm sample resulted in 14 farm types (Table 5.5). Classes corresponding to less than five holdings in any one year have not been included in the analysis, as i) merging them with other farm types would increase within farm type variability without significantly increasing the farm sample; ii) no information can be publicly presented for classes related to less than five holdings due to confidentiality reasons. The main characteristics of the remaining seven farm types, regarding total area, crop area, animal numbers, economic output, and ratios of labour and ESUs per land unit, in terms of averages and standard deviations, for each of the farm classes for 2003 are shown in Table 5.6.

Table 5.5 Farm typology criteria and farm numbers

Robust	Land Use	ESU	No Farms 2001	No Farms 2002	No Farms 2003
Cereals	Crops	<40	31	30	29
	Crops	>40	6	6	8
	Crops, livestock	<40	*	*	*
	Crops, livestock	>40	*	*	*
G. cropping	Crops	<40	8	16	12
	Crops	>40	74	73	70
	Crops, livestock	<40	*	*	*
	Crops, livestock	>40	67	64	63
Cattle & Sheep	Cattle, sheep	<40	10	11	9
	Sheep	<40	*	5	5
Mixed	Crops, cattle	<40	*	*	*
	Crops, cattle	>40	5	6	7
	Crops, cattle, sheep	<40	*	*	*
	Crops, cattle, sheep	>40	*	*	*

Source: own elaboration from JCD

Table 5.6 Farm type characteristics – averages and standard deviations

Type	Robust	Land Use	ESU	Area (ha)	Crops (ha)	Grass (ha)	Cattle (Head)	Sheep (Head)	ESU	Labour/ ha	ESU/ Ha
CC1	Cereals	Crops	<40	21	16	4	0	0	8	96	0.43
				(25)	(18)	(9)	(0)	(0)	(10)	(241)	(0.14)
CC2		Crops	>40	129	113	10	0	0	78	17	0.63
				(66)	(52)	(20)	(0)	(0)	(40)	(18)	(0.15)
GC1	G. crop.	Crops	<40	22	17	3	0	0	21	40	1.36
				(15)	(12)	(8)	(0)	(0)	(12)	(73)	(1.04)
GC2		Crops	>40	126	110	9	0	0	126	15	1.01
				(88)	(79)	(16)	(0)	(0)	(98)	(15)	(0.26)
GL2		Crops, livestock	>40	187	145	30	105	53	169	15	0.94
				(165)	(131)	(45)	(117)	(216)	(145)	(12)	(0.26)
LC1	Cattle, sheep	Cattle, sheep	<40	8	0	7	24	6	4	280	0.63
				(8)	(0)	(8)	(26)	(16)	(4)	(329)	(0.80)
MC2	Mixed	Crops, cattle	>40	112	58	48	284	0	108	13	0.98
				(47)	(28)	(21)	(149)	(0)	(42)	(12)	(0.20)

Source: own elaboration from JCD
( ): standard deviations

Ultimately, as no established framework for the simulation of livestock activities with FSSIM-REG was available until the end of this thesis, farms associated with livestock activities (*GL2, LC1, MC2*) have not been simulated.

5.6.4 Matching Farm and Soil Types

Matching farm and soil types is a key task of integration of economic and natural systems. Farmers' choices, revenues, input levels, and agricultural externalities, are to a great extend determined by farm availability of land resources of differing characteristics. The identification of the soils distribution for the modelled farm types was achieved by combining the SSKIB data, the IACS data and the JCD.

Each land parcel is characterised by a farm identifier number in the IACS data, and a soil series identifier in the SSKIB spatial data. Firstly, each land parcel was assigned a soil type using the typology described in 5.6.2. Secondly, each land parcel was assigned a farm type according to the typology described in section 5.6.3. This involved firstly assigning farm types to each of the JCD farms for the years 2001, 2002, 2003, and secondly assigning land parcels to a specific JCD farm by linking the IACS farm identifiers and the JCD farm identifiers. This work allowed characterising the individual parcels by a soil type and a farm type, and then calculating the soil distribution per soil type for each farm type. The above operations were achieved with use of SQL commands performed in MS Access. The parts of this work that involved the IACS data were implemented in collaboration with E. Guillem as no direct access to the IACS data was permitted. Due to a number of data limitations, the soil types for about only half the holdings were identifiable. The main data limitations were that the IACS farm identifiers for some land parcels were missing, and that the IACS data were available only for the catchment area while the used JCD sample corresponded to farms of the 12 parishes.

The results of this exercise regarding the percentages of average land availability per soil type and farm type for the years 2001-2003 are shown in Table 5.7. The associated percentages have been found to change significantly for farm types *CC1* and CC2, and slightly for farm type *GC1*. For farm type GC2 which is associated with large farm numbers the percentages appeared to be more stable across the three years. These percentages represent soils for farms within the catchment area. Due to lack of data for matching soils and farms outside the catchment this information has been extrapolated so as to characterise farms both within and outside the catchment. The soil distributions per farm type have been used for the estimation of land availability per model farm for each farm type, as further described in section 5.6.5.5.

Table 5.7 Percentage of availability of soil types per farm type

	2001			**2002**			**2003**		
	Type A	**Type B**	**Type C**	**Type A**	**Type B**	**Type C**	**Type A**	**Type B**	**Type C**
CC1	39.6	10.2	50.2	25.5	21.6	52.9	70.9	11.2	17.9
CC2	16.4	47.2	36.4	44.6	41.8	13.6	52.8	39.1	8.1
GC1	71.4	18.0	10.7	80.6	19.4	0.0	85.4	14.6	0.0
GC2	49.9	34.9	15.1	52.8	33.2	14.0	49.7	35.5	14.8

Source: own elaboration from SSKIB; IACS; JCD

In order to examine soil variability within farms, the occurrence of the number of different soil types per farm has been counted. Subsequently, the number of farms for each of the farm types that owned different number of soil types has been counted.

The results of this exercise for 2003 can be seen in Table 5.8. The majority of farms have endowments of land of all three soil types (34 farms), followed by farms with land of two different soil types (33 farms), and farms with only one soil type (14 farms).

Table 5.8 Number of farms per farm type and count of soil types

Farm Type	Count of soil types	Count of farms
CC1	1	3
CC1	2	5
CC2	2	1
CC2	3	3
GC1	1	1
GC1	2	1
GC2	1	8
GC2	2	10
GC2	3	18

Source: own elaboration from SSKIB; IACS; JCD

5.6.5 FSSIM-REG Data

5.6.5.1 Modifications of Set Lists

A consequence of the SEAMLESS-IF is that some of the sets and cross-sets (i.e. set combinations) in FSSIM-REG are using predefined lists (see Annex II for details). Some of these lists were modified so as to accommodate additions related to the inclusion of seed potatoes and the separate calibration of spring and winter barley. The modified sets were the *crops* list, the *FADN crops* list, the *products* list, the *link* between *crops* and *FADN crops* lists, the *link* between *crops* and *crop families* lists, and the *link* between *crops* and *CAP premiums* lists.

5.6.5.2 Input Coefficients

The input coefficients for the characterisation of the agricultural activities per rotation, crop, soil, and technique in our application are i) labour requirements, and ii) fertiliser inputs.

For the estimation of labour requirements, the Standard Labour Requirements (SLR) published by DEFRA (2010) were compared to those published in the FMH (Chadwick, 2000-2002). These coefficients represent SLRs in hours per hectare and per annum for different crop groups as opposed to specific crops, e.g. the same coefficient is provided for all cereal crops. For some of the crops, the SLRs published by DEFRA were smaller than the SLRs published by the FMH. This could be due to lower level of mechanisation and smaller size of holdings in Scotland as opposed to England and Wales. It has been assumed that the SLRs of the FMH are more representative of practices in Scotland and have thus been used for most crops. For set-aside, seed potatoes and carrots the FMH does not provide SLRs figures. The SLR coefficient published by DEFRA has been used for set-aside, and it has been assumed that the SLRs for carrots and seed potatoes are the same as those for maincrop potatoes. No changes per rotation, soil type, or technique are assumed. The respective figures can be seen in Table 5.11.

N fertiliser inputs have been discussed in section 5.6.1. P and K inputs have been extracted from the FMH (Chadwick, 2000-2002) (Table 5.11). These values take into account crop requirements, but they do not consider potential soil, rotational and N input effects.

5.6.5.3 Output Coefficients

The output coefficients considered for each agricultural activity correspond to i) yield per crop product for each rotation, crop, product, soil, and technique, ii) yield variability per crop, iii) nitrate leaching per rotation, soil and technique, and iv) phosphorus losses per rotation, soil, and technique.

Yields for the main crop products and nitrate leaching coefficients are the key outputs of the bio-physical simulations, and are thus presented and discussed in the following Chapter of this thesis. Yields of straw for cereal products have been estimated in function of the grain yields using a percentage coefficient between straw and grain yields estimated through the FMH (Chadwick, 2000-2002). The coefficients were estimated to be equal to 0.65 for winter wheat, 0.75 for winter and spring barley, and 0.86 for spring oats.

Yield variability per crop has been estimated using the ERSA (Scottish Government, 1994-2003). ERSA provides national and regional yield estimates for cereal crops.

As expected yield estimates for the South East part of Scotland, where the Lunan Water Catchment is located, tend to be higher that the average country level yield estimates. However, as the regional yield data are not provided for all crops included in our analysis, the average country estimates have been used so as to avoid bias in favour of cereal crops. No such figures are published for figures prior to 1994, thus the standard deviation has been estimated using data from 1994 to 2003. Assumptions had to be made for the crops for which ERSA provided no information. The used figures are shown in Table 5.11.

Estimates on P losses per crop have been provided by Balana *et al.* (2010) (Table 5.11). Although P losses vary significantly with soil type, slope, rotation, and levels of P inputs, such information was not available, Thus, the simplifying assumption that P losses vary only per crop has been made. Again, some assumptions have been made for the crops for which no information was available.

5.6.5.4 Economic Data

The used economic data are i) variable costs (except fertiliser costs) per rotation, crop, soil, and technique, ii) fertiliser costs per rotation, crop, soil, and technique, iii) prices per agricultural product, iv) price variability per crop, and v) wages for hired labour per farm type. Costs are not disaggregated in FSSIM-REG, and thus fertiliser costs are part of variable costs. Operations to calculate separately fertiliser and other variable costs and then add the two have been carried out outside the model, using MS Access queries.

Variable costs per crop have been estimated using the FMH (Chadwick, 2000-2002). The included variable cost categories per crop are shown in Table 5.9 and the average variable costs per crop over the three reference years 2001-2003 are shown in Table 5.11. It has been assumed that crop variable costs remain constant regardless of the rotation, soil, and production technique. Nevertheless, no major such differences are expected to occur for the included cost categories. The only exceptions are packaging costs for cereal and potato crops, and grade and spray costs for potatoes, which might change slightly per yield level. However, as such changes are insignificant as a percentage of total costs, they are not expected to influence model results.

Table 5.9 Variable cost categories per crop

	Seed	Spray	Contract**	Casual Labour***	Other****
Cereals*	√	√			√
Winter Oilseed Rape	√	√	√		
Seed Potatoes	√	√	√	√	√
Maincrop Potatoes	√	√	√	√	√
Peas	√	√	√		
Carrots	√	√		√	√
Set-aside		√			

Source: own elaboration from Chadwick (2000-2002)

* Winter Wheat, Winter Barley, Spring Barley, Spring Oats

** Windrowing or desiccating for oilseed rape; application of sulphuric acid for potatoes; two ground sprays for peas;

*** Lift and grade for potatoes; harvesting and washing for carrots;

**** Packaging for cereals and carrots; British Potato Council levy and sprout suppressant for potatoes; market commission and handling for carrots.

The estimation of fertiliser costs was based on prices quoted in the FMH (Chadwick, 2000-2002). The average price for N is equal to 0.35 £/kg, for P equal to 0.32 £/kg, and for K equal to 0.20 £/kg. N costs per crop, soil, and technique are derived by multiplying the quantities displayed in Table 5.2 by 0.35. P and K costs per crop are shown in Table 5.11.

Regarding crop prices, the figures published in the FMH and ERSA were considered. The figures published in the FMH were found more appropriate to represent average prices as they are more likely to represent farmers' expectations on prices. On the other hand, ERSA reports past prices as these have been formed in the market and is thus more suitable for expressing the year-to-year variability of past prices. The 2000-2002 editions of the FMH have been used for the calculation of average prices for the years 2001-2003 (Table 5.10), and the ERSA 1994-1996, 2000, 2003 and 2006 editions have been used for the estimation of price variability for the period 1991-2003 (Table 5.11). For peas and carrots, the same variability as for maincrop potatoes has been assumed due to lack of information in ERSA.

Wage has been assumed to be equal to the average minimum rate for full time workers in Scotland for years 2001-2003 that is £4.52/hour.

Table 5.10 Product prices (£/t)

Crop	Grain	Straw	Seed	Ware/ Root
Winter Wheat	64	25		
Winter Barley	61.3	30		
Spring Barley	61.3	30		
Spring Oats	60.7	35		
W. Oils. Rape	123.3			
Seed Pot.			170	
Maincrop Pot.				85
Peas	230			
Carrots				213.3
Set-aside				

Source: own elaboration from Chadwick (2000-2002)

Table 5.11 Various input-output coefficients

Crop	SLRs (hours/ha /annum)	P Input (kg/ha)	K Input (kg/ha)	Yield Variab.	P Losses (kg/ha)	Variable Costs (£/ha)	P and K Costs (£/ha)	Price Variab.
W. Wheat	20	70	70	0.46	0.7	161	36.4	19.2
W. Barley	20	70	70	0.46	0.7	120	36.4	24.4
S. Barley	20	50	50	0.44	0.2	113	26	24.4
S. Oats	20	40	40	0.46**	0.2	117	20.8	20.7
W. Rape	20	58	58	0.29	0.6*	187	30.2	23.5
Seed Pot.	170*	200	135	4.94	1	1804	91	39.8
M. Pot.	170	150	240	6.35	1	1594	96	40.6
Peas	32	25	25	0.41	0.4	208	13	40.6*
Carrots	170*	125	125	6.35*	1*	4486	65	40.6*
Set-aside	1	0	0	0	0*	51	0	0
Fallow	0	0	0	0	0*	0	0	0

Source: own elaboration from Chadwick (2000-2003); DEFRA (2010); ERSA (Scottish Government, 1994-2003; 2006)

* Assumed value

**Corresponds to both spring and winter oats.

5.6.5.5 Farm-related Data and Constraints

The data related to the characterisation of farm types are i) farm numbers, ii) land availability per soil type, iii) family labour availability, and iv) crop pattern. The estimation of all farm-related data has been achieved by calculating averages per farm type for each of the base years 2001-2003 and then estimating the average per farm type over the three years. The basic source of the above information was the JCD data.

The number of farms per farm type (Table 5.12) has been estimated by performing a count operation in MS Access and then approximating the calculated estimates to the closest integer value.

Land availability per soil type and farm type (Table 5.12) has been estimated in three steps: i) the average percentage of soil type per farm type for the years 2001-2003 has been calculated, as described in section 5.6.4; ii) the sum of the area under the different crops included in our crop list for each farm type, representing land availability per farm type has been estimated; and iii) the two above values have been multiplied. This procedure has been followed so as to ensure that the level of available land matches the sum of the observed activity levels for each of the farms, which is a necessary condition for model calibration.

The JCD provide 21 variables with information on on-farm labour use. These express information on family labour of the occupier, spouse and other family members, and full time and part time hired males and females. For the estimation of labour availability of the occupier and spouse, the number of occupiers and spouses working *full-time, half-time or more,* or *less than half time* per farm type have been counted and multiplied by their hours per year equivalent. These have been assumed to be 1900 hours per annum for *full-time*[34], 1425 for *half-time or more*, and 475 for *less than half time*. The work of other family members is expressed by the variables *Full-time Family Females*, *Part-time Family Males*, and *Part-time Family Females*. The work of other family members has not been taken into account for the estimation of family labour availability as it is unclear whether they are paid and also because the variable *Full-time Family Males* is not present in our JCD sample. The results representing family labour availability are shown in Table 5.12.

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[34] http://www.scotland.gov.uk/Topics/Statistics/Browse/Agriculture-Fisheries/agritopics/farmstruc

For the estimation of observed activity levels per crop and farm type, the average land use per crop and farm type for each of the years 2001-2003 has been calculated and then averaged over the three years. The results can be seen in Table 5.13.

Table 5.12 Resources availability per farm type

Farm Type	Farms (No)	Land Soil Type A (ha)	Land Soil Type C (ha)	Family Labour (hours/annum)
CC1	30	8.83	5.97	585.37
CC2	7	92.15	22.14	1,886.81
GC1	12	17.38	0.64	788.37
GC2	72	88.40	15.11	1,481.69

Source: own elaboration from JCD (2001-2003)

Table 5.13 Observed activity levels per farm type (ha)

Crop	CC1	CC2	GC1	GC2
W. Wheat	0.54	29.81	0.63	16.07
W. Barley	0.81	4.41	0.08	7.43
S. Barley	9.85	50.06	10.59	38.43
S. Oats	0.54	0	0.15	1.82
W. Rape	0.75	12.84	0	10.23
Seed Pot.	0	0.68	2.01	8.7
M. Pot.	0	2.58	1.59	6.96
Peas	0	0	0.14	1.45
Carrots	0	0	0	0.7
Set-aside	2.31	13.91	2.83	11.7

Source: own elaboration from JCD (2001-2003)

5.6.5.6 Policy Data

The required policy data related to the CAP are i) regional historic yield, ii) premium rates, iii) overshoot rates, iv) modulation rates, and v) set-aside obligations.

For the calculation of premiums under Agenda 2000, the required data are regional historic yield and premium rates per crop group. The regional historic yield was set equal to 5.67 t/ha (Chadwick, 2000-2002). The yearly premium rates are shown in Table 5.14. The estimated average rates over the three years have been converted into £/t using the average exchange rate for the years 2001-2003 (Chadwick 2000-2002). The resulting rates for each premium crop group are shown in Table 5.15. The yearly and average overshoot and modulation rates are shown in Table 5.14 and the values used for each of the CAP scenarios in Table 5.15.

Table 5.14 Data for the calculation of premiums under Agenda 2000

	2001	2002	2003	Average
Exchange Rate[35] (£/€)	0.65	0.608097	0.643937	0.634011
Premiums (€/t) Cereals	63	63	63	63
Oilseeds	72.37	63	63	66.1
Set-aside	63	63	63	63
Protein crops	72.5	72.5	72.5	72.5
Overshoot of base area[36] (%)	4	2.2	4.44	3.55
Voluntary modulation (%)	2.5	3	3.5	3

Source: own elaboration from Chadwick (2000-2002); Meat and Livestock Commission's Planning & Forecasting Group (2002)

For the calculation of the value of entitlements under the Reform, the reference amount has been estimated using the payment rates of 2002 converted into pounds using the exchange rate on 30 September 2006 (Chadwick, 2006), which was equal to 0.677869 £/€[37]. No coupled premiums have been included as the Protein Crop Premium does not apply to peas for human consumption, and the Energy Crop Scheme is only payable for production that is covered by a contract between a processor and a producer (Chadwick, 2006). Compulsory and voluntary modulation rates have been averaged over the years 2005-2008 for the 2003 CAP Reform, and over the years 2009-2012 for the CAP Health Check, according to the rates shown in Table 2.3. The amount of SFP that is exempt from compulsory modulation is equal to €5000. No information has been found on the exchange rates used for the conversion of this amount into UK sterling, so the conversion rate of 0.677869 £/€ that has been used for the premium rates conversion was used, resulting in £3389. The overshoot of the base areas and the national reserve have been set equal to 3.1% (Scottish Executive, 2005a) and 4.2% (Chadwick, 2006), respectively. Further details on the policy data for the different CAP scenarios are shown in Table 5.15.

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[35] These are the exchange rates forecasted at the beginning of the growing season and suggested in the FMH.

[36] These are estimates of expected overshooting rates based on observed values of previous years reported in the FMH.

[37] http://www.x-rates.com/cgi-bin/hlookup.cgi

Table 5.15 Data for CAP scenarios

		Agenda 2000	2003 CAP Reform	2008 CAP Health Check
Premiums (£/t)	Cereals	39.9	42.7	42.7
	Oilseeds	41.9	42.7	42.7
	Set-aside	39.9	42.7	42.7
	Protein	46	49.2	49.2
Compulsory Modulation (%)		0	4.3	8.5
Voluntary Modulation (%)		3	5.3	5.4
Overshoot (%)		3.5	3.1	3.1
National Reserve (%)		0	4.2	4.2

Source: Chadwick (2000-2002; 2006); Scottish Executive (2005a; 2007b); Meat and Livestock Commission's Planning & Forecasting Group (2002)

5.6.6 COUP Data

5.6.6.1 Weather Data

COUP requires information on daily precipitation, mean air temperature, net and global radiation relative humidity, and wind speed (Jansson & Karlberg, 2004). Two weather data sets for the years 1974-1998 and 1999-2007 were obtained from the meteorological station at Mylnefield Dundee, which was considered representative of the Lunan Water Catchment. Missing daily values have been filled in by assuming equality to mean values of the previous and following day or to values corresponding to the same day of the year from other years. Mean air temperature, net radiation, relative humidity, and wind speed have been estimated by D.Tarsitano from the raw data.

5.6.6.2 Soil Parameters[38]

COUP requires a considerable amount of data for the parameterisation of the water/heat sub-model, which were not available for the soil series of the area considered. Values for hydraulic and thermal conductivity are not regularly measured. The values used have been obtained by D. Tarsitano from a soil characteristics database present in COUP. The two soil candidates have been selected considering the similarities in organic matter, sand and silt content through the soil profile, with the Scottish soils scenarios. The use of these soils has not been

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[38] This section draws from the description of model parameterisation provided by D.Tarsitano for the purposes of Mouratiadou *et al.* (forthcoming) that has now (April 2011) been submitted for publication in *Bio-economic Models applied to Agricultural Systems: an Integrated Approach to Relations between Agriculture, Environment, and Natural Resources - Tools for Policy Analysis.*

considered a limiting factor, as the COUP level of detail makes the similarities between the two areas adequate for this study.

5.6.6.3 Management Data

The key management data required by COUP for this application are i) sowing and harvest dates and ii) fertilisation data. Sowing dates have been provided by G. Russell (pers. comm., 08/08/2008). They correspond to middle of October for winter wheat; middle of September for winter barley; beginning of March for spring barley, spring oats, and peas; beginning of September for winter oilseed rape; beginning of May for maincrop and seed potatoes; and beginning of July for carrots. Harvest dates have been automatically calculated by the model as a function of crop development. The fertilisation data have been presented in Table 5.2.

5.7 Modelling Scenarios

5.7.1 Simulation of COUP Scenarios and Output Conversion

The defined agricultural activities described in section 5.6.1 constitute the 118 simulation scenarios run with COUP. That is 29 rotations, under two alternative fertilisation scenarios, on two different soils, and the continuous set-aside rotation on two different soils.

The long term 35-year simulation period of the years 1974-2008 has been used for all scenarios. The output of the first 10 years (1974-1983) has not been used for the estimation of yield and leaching coefficients, as the first few years of the simulation are needed for model stabilisation of initial conditions. Additionally, the output of the last year has not been used as the corresponding weather file was not complete. Hence, the estimation of the coefficients was based on model outputs corresponding to years 1984-2007. Since the rotations do not all consist of the same number of years, the occurrence of a rotation within the simulation period is not the same across rotations. Table 5.16 shows how rotations of different length have been simulated within the 35-year simulation period.

The different steps for running and acquiring the output for each individual simulation in COUP are as follows:

i) *set-up rotation*: this required specifying the sequence of crops and dates that correspond to each individual year of the 35-year simulation period (performed by D.Tarsitano);

ii) *creation of fertiliser files*: the dates and quantities of fertiliser inputs for each fertilisation occurrence within the 35-year simulation period are provided through an external file; these files were first created in MS Excel and then saved as text files so that the date format was consistent with COUP requirements (performed by author); an example of such a file is shown in Annex X;

iii) *run scenario*: this required loading the fertiliser file corresponding to the respective scenario and running the simulation (performed by D.Tarsitano);

iv) *extract output*: this involved selecting the desired output from the COUP list of potential outputs, waiting for the output extraction in a table within COUP interface, and copying the output from COUP to an MS Excel file corresponding to the specific scenario; COUP provides a daily output report for each day of the simulation period (12775 days in our case) and thus the extraction of the extensive output file lasts 15-20 minutes per simulation (performed by D.Tarsitano);

v) *format and re-arrange output*: firstly, the output regarding yield harvest needed to be re-arranged into one single column; this is because the harvest output is provided in different columns depending on whether it corresponds to *grain harvest* (all crops except potato crops) or to *stem harvest* (potato crops) (performed by the author and D.Tarsitano); secondly, the specific days in each year that correspond to yield harvest were identified using MS Excel estimation and filtering operations, and then isolated from the rest of the results in a separate MS Excel file, so that the output transformation code described in section 5.5.4 was operational; thirdly, the columns with the different outputs were rearranged, as consistency between file set-up was required for the output transformation code; finally, each of the output files was placed in their corresponding rotation folder, which was also a requirement for the output transformation code (performed by author).

Due to the above procedures, the total time required for each simulation scenario spanned from one to two hours.

Table 5.16 Rotations within simulation period

	Year	Six-year Rotation	Five-year Rotation	Four-year Rotation	Three-year Rotation
Period Used for Model Stabilisation	1974	2	1	2	2
	1975	3	2	3	3
	1976	4	3	4	1
	1977	5	4	1	2
	1978	6	5	2	3
	1979	1	1	3	1
	1980	2	2	4	2
	1981	3	3	1	3
	1982	4	4	2	1
	1983	5	5	3	2
Period Used for Estimation of Coefficients	1984	6	1	4	3
	1985	1	2	1	1
	1986	2	3	2	2
	1987	3	4	3	3
	1988	4	5	4	1
	1989	5	1	1	2
	1990	6	2	2	3
	1991	1	3	3	1
	1992	2	4	4	2
	1993	3	5	1	3
	1994	4	1	2	1
	1995	5	2	3	2
	1996	6	3	4	3
	1997	1	4	1	1
	1998	2	5	2	2
	1999	3	1	3	3
	2000	4	2	4	1
	2001	5	3	1	2
	2002	6	4	2	3
	2003	1	5	3	1
	2004	2	1	4	2
	2005	3	2	1	3
	2006	4	3	2	1
	2007	5	4	3	2
Incomplete weather	2008	6	5	4	3

Firstly, all the simulations relating to fertilisation ScA were implemented according to the steps described above. After a first analysis of the results, it appeared that the yield and N leaching coefficients for potato crops and carrots were not following a consistent pattern, as yields were considerably smaller than the expected yield and leaching significantly higher. Therefore, some single crop rotations were run by the author for each of the crops on soil type A. A similar pattern to the multi-annual rotations was observed. After communication of the issue to D.Tarsitano, it was found that this was caused by delayed timing of fertiliser applications for the two crops. A number of additional simulations were run by D.Tarsitano so as to identify the correct timing for fertiliser applications for these crops. Thus, the whole procedure for the 36 scenarios related to potato and carrot crops, under fertiliser ScA, on both soils was re-implemented. Step (ii) described above was re-implemented for fertiliser ScB so as to correct the timing of N applications, and then the remaining steps in relation to these simulation scenarios were carried out.

After receiving the semi-formatted COUP output (D. Tarsitano, pers. comm., 23/02/11), the results were fully formatted and then checked for errors following the following procedures: i) creation of box plots of average crop yields and average crop leaching values for the whole set of rotations, for each soil and technique, in GenStat[39]; ii) basic statistical analysis depicting averages, standard deviations, minimums and maximums, for crop yields and crop leaching, for the whole set of rotations, for each soil and technique, in MS Access; iii) estimation of relative differences between soils and fertiliser scenarios, for crop yields within a rotation, crop leaching within a rotation, and average annual leaching within a rotation.

Yield values laying outside the range of other COUP results were isolated and tracked back to the received output to exclude errors in the formatting procedure. Subsequently, the original simulation and fertilisation files used for the simulations were obtained so as to check if the rotational sequences, fertilisation files attached to the rotations, and provided output from the simulations were matching. Few

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[39] http://www.vsni.co.uk/software/genstat/

errors were found through the second procedure. For the remaining cases, the specific scenarios were re-run by D.Tarsitano, providing identical results. The final semi-formatted COUP outputs (D.Tarsitano, pers. comm., 26/02/11) consisted of the corrected output for the scenarios where errors were identified and the original files for the rest of the scenarios. Yield values for the remaining cases were corrected using as points of reference the average yields per crop under the respective soil and fertilisation scenario, and the relative differences between soils and fertiliser scenarios per crop. Relative differences were estimated using the following formula:

$$RD = \frac{X_2 - X_1}{0.5(X_1 + X_2)} 100 \tag{11}$$

Further, average crop yields under ScA were compared to the FMH (Chadwick, 2000-2002) and the Guidelines for Farmers in NVZs (Scottish Executive, 2008b) yield targets, using the above formula. It was found that the values for maincrop and seed potatoes were considerably underestimated. Thus, the yield output for these crops for each scenario has been multiplied by a conversion factor using the formula shown below:

$$X' = X_1\left(1 + \frac{X_2 - X_1}{X_1}\right) \tag{12}$$

where X' is the converted yield value, X_1 is the final (original or corrected) model output, and X_2 the yield value quoted in the FMH.

The values corresponding to annual and rotational leaching have not been altered, due to the multiplicity of factors affecting leaching and the lack of a straightforward relationship between yield and leaching levels.

After an analysis of the annual leaching values per rotation, it was found that rotations with rotational set-aside corresponded to considerably higher leaching compared to other rotations. An attempt to correct this took place, where steps (iii), (iv), and (v) described above were re-implemented for the 32 scenarios relating to rotations with rotational set-aside, after a modification of the N requirements of the crop representing grass vegetation cover during the set-aside period. This caused reductions in average annual leaching for these scenarios. However, the rotational set-aside rotations were still found to be the most polluting ones, and significant knock-on effects for the yields of the crops following set-aside were observed. Thus, the results of these simulations have not been used.

5.7.2 Simulation of FSSIM-REG Scenarios

A number of CAP and nitrate pollution control scenarios were simulated with FSSIM-REG. The three CAP scenarios correspond to Agenda 2000, the 2003 CAP reform, and the CAP Health Check. The nitrate scenarios correspond to cross-compliance measures, agri-environmental measures, taxes on N inputs and nitrate leaching, standards on nitrate leaching and quotas on N inputs.

5.7.2.1 CAP Scenarios

Agenda 2000 was used as the *baseyear* scenario policy regime. The baseyear reflects a specific base period that relates to both model calibration and policy representation. The model is calibrated using data inputs representing the reference years of the base period. Thus, the selected period should be representative of the typical socio-economic and climatic environments of the case study under examination, so that model calibration is free of bias associated to farmers' production choices in specific years. Additionally, the years included in the base period should be homogenous in terms of policy regime so that this can be modelled uniformly. The selected baseyear reference period for this study consists of the years 2001-2003. These reflect the Agenda 2000 policy regime, that was introduced in Scotland in July 2000 and remained in force until the implementation of the 2003 CAP Reform in 2005. The year 2004 has not been included in the base period as it was the first year after the introduction of the NVZ regulations in February 2003.

The 2003 CAP Reform has been modelled as described in section 5.3.3.4.

The 2008 CAP Health Check represented the *baseline* scenario. This represents the policy environment against which additional scenarios are compared. The CAP

Health Check has been modelled similarly to the 2003 CAP Reform scenario. However, the calculation procedures for standard and set-aside entitlements have been altered, so that set-aside payments make part of the standard entitlements and that set-aside land is eligible for standard entitlements. Also, the set-aside obligations have been relaxed.

5.7.2.2 Nitrate Pollution Control Measures

The full set of the simulated nitrate pollution control measures is shown in Table 5.17.

Tax scenarios explore the effects of per unit taxes on N inputs or nitrate emissions. The tax level has been set as a function of the price of N fertiliser in year 2010, assumed to be equal to 0.52£/kg (McBain & Curry, 2009). For nitrate leaching the tax has been ranged between 0-10 times the fertiliser price, while for N input between 0-5 times. Tax scenarios have been simulated by the incorporation of additional cost factors in the model income equation.

N input quotas and nitrate emissions standards simulate the effects of these measures on an average per hectare basis. The starting value for quotas and standards respectively has been the highest level of average N use or nitrate leaching at the farm level in any of the four farm types for the baseline scenario. Thus, quotas ranged between 170-10 kg/ha, and standards between 42-20 kg/ha. Leaching reductions below 20 kg/ha was infeasible. Quota and standard scenarios have been simulated by the addition of model constraints.

The cross-compliance measure relates to the management of nutrient use to minimise losses to the water environment. That is a requirement of the WFD and the NVZ regulations. The NVZ regulations are also defined as SMR 4 under CAP cross-compliance. Farmers are already advised on the quantities of nutrient use per crop, soil, climatic area, and previous crop in a rotation by the Scottish Executive (2008b). The modelled scenario explores the potential implications of lowering further the existing recommended levels through the implementation of a cross-compliance measure. The reduced fertiliser scenarios for each agricultural activity correspond to fertiliser ScB described in section 5.6.1. If farmers do not respect these fertiliser levels, premiums are reduced by a pre-specified premium reduction. The premium reduction has been ranged between 0-25 % of premium payments. The cross-compliance measure has been simulated by adding a model constraint that represents the measure.

The subsidies measures aim at the reduction of fertiliser levels corresponding to fertiliser ScB through the payment of a per hectare based subsidy. For each hectare of land where the crops are grown under fertiliser ScB farmers receive a payment according to the pre-specified subsidy rate. Subsidies for both soil types and subsidies for soil type C which is more vulnerable to leaching have been simulated. These ranged from 0-100 £/ha. The subsidy measures have been simulated by adding some revenue factors in the model income equation.

Table 5.17 Nitrate pollution control measures

Tax on Nitrate Leaching	Tax on N Use	Standard on Nitrate Leaching	Quota on N Use	Cross-Compliance Measure	Subsidy Measure	Soil Subsidy Measure
TL-0	TI-0	S-42	Q-170	CC-0	Su-0	SuS-0
TL-1	TI-0.5	S-40	Q-160	CC-10	Su-10	SuS-10
TL-2	TI-1	S-38	Q-150	CC-15	Su-20	SuS-20
TL-3	TI-1.5	S-36	Q-140	CC-20	Su-30	SuS-30
TL-4	TI-2	S-34	Q-130	CC-25	Su-40	SuS-40
TL-5	TI-2.5	S-32	Q-120		Su-50	SuS-50
TL-6	TI-3	S-30	Q-110		Su-60	SuS-60
TL-7	TI-3.5	S-28	Q-100		Su-70	SuS-70
TL-8	TI-4	S-26	Q-90		Su-80	SuS-80
TL-9	TI-4.5	S-24	Q-80		Su-90	SuS-90
TL-10	TI-5	S-22	Q-70		Su-100	SuS-100
		S-20	Q-60			
			Q-50			
			Q-40			
			Q-30			
			Q-20			
			Q-10			

The income equation and constraints used for the nitrate pollution control measures are shown below:

$$\begin{aligned} Z_f = {} & \textstyle\sum_j p_j q_{f,j} - \sum_{i,t} c_{i,t} \frac{X_{f,i}}{\eta_i} + \sum_{i,t} (d_{f,i,t} + \frac{\Psi_{f,i,t} X_{f,i}}{2}) \frac{X_{f,i}}{\eta_i} - \\ & \varpi L_f + \Big((\textstyle\sum_{i,t} s_{i,t} \frac{X_{f,i}}{\eta_i})(1 - v) - P_f m \Big) \big(1 - rV_f\big) - kT_f - \\ & hQ_f + SuX_{f,i'} + SuSX_{f,i''} \end{aligned} \tag{13}$$

$$\frac{T_f}{G_f} \leq St \qquad \forall f \tag{14}$$

$$\frac{Q_f}{G_f} \leq Qu \qquad \forall f \tag{15}$$

$$\textstyle\sum_i X_{f,i'''} - wV_f \leq 0 \qquad \forall f \tag{16}$$

where k is a scalar for the level of tax per kg of nitrate leaching, T is a vector of nitrate leaching at farm level, h is a scalar for the level of tax per kg of N input, Q is a vector of N inputs at farm level, Su is a scalar for the level of subsidies, i' indexes agricultural activities that are grown under fertiliser scenario ScB, SuS is a scalar for the level of soil subsidies, i'' indexes agricultural activities that are grown under fertiliser scenario ScB on soil C, G is a vector of available land per farm type, St is a scalar for the nitrate leaching standard, Qu is a scalar for the N input quota, i''' indexes agricultural activities that are grown under fertiliser ScA, and w is a scalar of a very large number used to solve problems containing binary variables.

The parametric simulations have been achieved by i) declaring and defining a set of simulation scenarios; ii) declaring and defining a parameter the value of which changes per simulation scenario; ii) assigning the value of the concerned policy parameter (tax, standard, quota, subsidy, premium reduction) to the newly declared parameter; iii) using the *loop* command of GAMS to solve the model in a loop for all simulation scenarios; iv) calling a GAMS file replicating the standard FSSIM-REG file for displaying the results.

6 Results

6.1 COUP Results

In order to facilitate comparison between soil and fertiliser scenarios the different combinations have been defined as follows: i) *Sc1*: Soil A + ScB, ii) *Sc2*: Soil C + ScB, iii) *Sc3*: Soil A + ScA, and iv) *Sc4*: Soil C + ScA.

6.1.1 Original and Corrected Yield Values

As discussed in section 5.7.1, the yield values for some simulation scenarios were corrected according to the average yields per crop and scenario, and the relative differences between scenarios per crop. In total, 21 out of the 432 yield estimates have been altered. Tables and graphs depicting details on the i) original and corrected yield values for each simulation scenario; ii) relative differences in yields between soils and fertilisation levels for each simulation scenario; and iii) average yields and average relative differences in yields between scenarios used for the correction procedure for each crop, are provided in Annex XI.

Yield estimates provided in the FMH and the Guidelines for Farmers in NVZs were compared to the fertiliser ScA average values per crop (Table 6.1). Model predictions are satisfactory for most crops with the exception of maincrop and seed potatoes, where yields are significantly under-predicted. Yields are slightly under-predicted for winter wheat and over-predicted for spring barley. Yields from simulations for potatoes and seed potatoes have been multiplied by the estimated conversion factor shown in Table 6.1. Average yields per crop and scenario and relative differences of the averages between scenarios, after the correction process, are shown in Table 6.2. More details on standard deviations, minimums, maximums and counts per scenario are provided in Annex XI.

Cereal crops show a realistic pattern of variability attributed to climate, previous crop in the rotation, soil and fertilisation level. The highest yields are achieved for the highest fertiliser input (Sc4) and the lowest yields correspond to the lowest fertiliser input (Sc1). Sc2 and Sc3 provide very similar outputs, due to the similarity in the fertiliser inputs. Since the fertiliser input for most crops is slightly higher for Sc3, the yields are also higher. This indicates either that that the model is more sensitive to N inputs than to soil attributes, or that the fertiliser levels proposed for soil A result in lower yields compared to those proposed for soil C.

Table 6.1 Comparison of yield estimates from literature and model predictions

Crop	FMH (t/ha)	Guidelines (t/ha)	ScA (t/ha)	RD FMH-ScA (%)	Applied Conversion Factor
W. Wheat	8	8	7.08	-12.20	1
W. Barley	7.5	6.5	7.67	2.24	1
S. Barley	5.5	5.5	6.86	22.01	1
S. Oats	5	5	5.21	4.11	1
W. Rape	3.5	4	3.71	5.83	1
Seed Pot.	23	n.a.	10.38	-75.61	2.22
M. Pot.	50	n.a.	33.27	-40.18	1.50
Peas	4.6	n.a.	4.5	-2.20	1
Carrots	43.7	n.a.	44.73	2.33	1

Source: own elaboration from Chadwick (2000-2002); Scottish Executive (2008b); D. Tarsitano (pers. comm., 26/02/11)
RD: relative difference

Table 6.2 Absolute (t/ha) and relative (%) average crop yields per scenario

Crop	Sc1	Sc2	Sc3	Sc4	RD Sc1-Sc2	RD Sc3-Sc4	RD Sc1-Sc3	RD Sc2-Sc4
WDWH	5.39	6.44	6.52	7.64	17.89	15.83	18.99	16.93
WBAR	6.92	7.47	7.42	7.91	7.71	6.39	7.04	5.71
SBAR	5.88	6.48	6.60	7.13	9.68	7.69	11.50	9.52
OATS	4.16	5.08	4.90	5.52	20.07	11.90	16.44	8.26
RAPE	3.77	3.52	3.88	3.55	-6.95	-9.02	2.88	0.81
SDPO	23.67	22.05	24.00	22.07	-7.07	-8.36	1.38	0.09
POTA	50.17	48.77	50.59	49.22	-2.82	-2.76	0.85	0.91
PEAS	4.74	4.21	4.76	4.25	-11.72	-11.30	0.50	0.92
CARR	44.29	45.16	44.30	45.16	1.95	1.94	0.01	0.00

For the other crops, yield estimates are insensitive to soil, and even less sensitive to fertiliser levels. As opposed to cereals and carrots, yields on soil A are higher than those on soil C for potato crops, peas, and oilseed rape. Differences between fertiliser scenarios within each of the two soil types are insignificant for all crops. This result was unexpected and may be due to the parameterisation of the crop model component in relation to these crops, or to a poor capacity of the model to simulate non cereal crops.

6.1.2 Rotational Leaching Values

Leaching values for the simulated scenarios can be seen in Fig. 6.1; averages standard deviations minimums and maximums per soil and fertilisation scenario in Table 6.3; and absolute and relative differences between simulation scenarios for all rotations in Annex XI.

Leaching values are higher for Sc4 and Sc2, as soil C is more vulnerable to leaching. The average relative difference between soils for each of the two fertiliser scenarios is about 50%, and between fertiliser scenarios for each of the two soils about 10%.

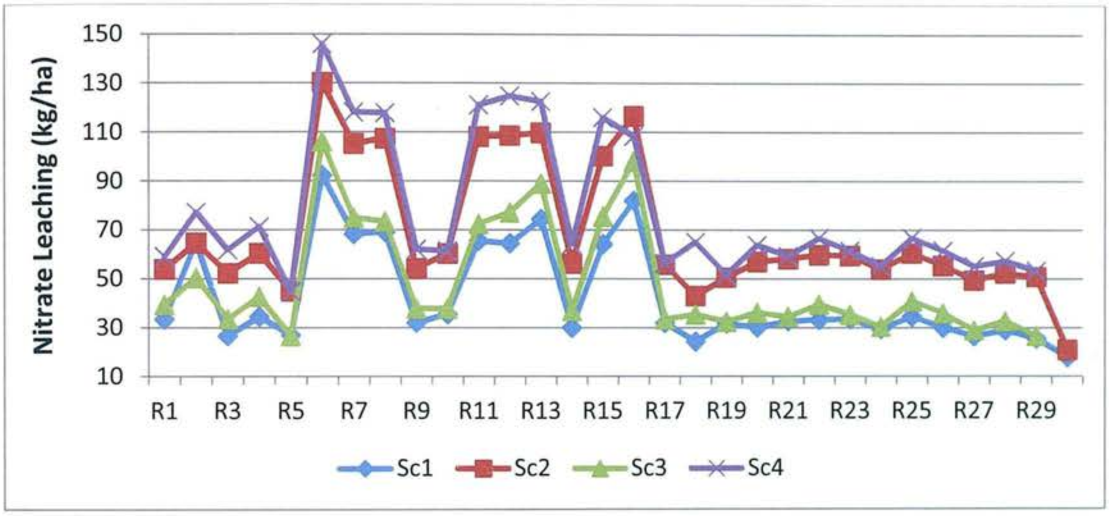

Fig. 6.1 Average annual rotational leaching

The highest leaching corresponds to rotations with rotational set-aside. Despite there being no N fertiliser inputs for set-aside, incorporation of grass cover at ploughing prior to the sowing of the crop following set-aside leads to a massive release of nitrates. However, although expert opinion suggests that leaching from set-aside after ploughing might range from 30 to 200 kg/ha (B. Rees, pers. comm., 17/02/11), the model seems to be over-predicting mineralisation of background N in organic soils. This effect may also have been aggravated by crop model parameterisation in relation to vegetation cover, which results in low N uptake by this land use. This is not the case for the continuous set-aside rotation, which corresponds to the lowest leaching per scenario, as is has been assumed that nutrient demanding weeds occasionally grow in the field.

Table 6.3 Basic statistical figures for average annual leaching

All Rotations except continuous set-aside	**Sc1**	**Sc2**	**Sc3**	**Sc4**
Average (kg/ha)	43.31	70.32	48.78	77.59
Standard Deviation	20.23	26.22	23.12	28.97
Minimum (kg/ha)	24.26	42.96	26.59	44.7
Maximum (kg/ha)	92.28	130.21	106.17	146
Rotations without set-aside	**Sc1**	**Sc2**	**Sc3**	**Sc4**
Average (kg/ha)	32.18	54.90	35.61	60.69
Standard Deviation	8.15	5.36	5.48	7.04
Minimum (kg/ha)	24.26	42.96	26.59	44.70
Maximum (kg/ha)	64.89	64.67	50.37	77.20
Rotations with rotational set-aside	**Sc1**	**Sc2**	**Sc3**	**Sc4**
Average (kg/ha)	72.52	110.79	83.37	121.84
Standard Deviation	9.98	9.08	12.86	10.95
Minimum (kg/ha)	64.11	100.29	72.50	108.37
Maximum (kg/ha)	92.28	130.21	106.17	146

6.2 FSSIM-REG Results

6.2.1 CAP Policies

The main economic and environmental results for the CAP Scenarios are shown in Table 6.4.

Under the CAP Reform, incomes are slightly reduced for all farm types. This is due to reductions in premiums as a consequence of changes in modulation rates. However, the reduction in incomes is lower than the reduction in premiums as a result of farmers' adaptation to the new policy. For the two small farms, changes in N use and nitrate leaching are negligible. For CC2, a very small reduction in N use, accompanied by a slight reduction in N leaching is observed. N use decreases for GC2, but N leaching increases. This is because of changes in the level of rotations, and specifically a significant increase (about 30ha) of R13 under Sc3 corresponding to high leaching (89 kg/ha). Minor land use changes are observed for all farm types. For CC1, there is a slight substitution of oilseed rape by spring barley due to the relative decrease of the subsidy for oilseed rape (see Annex XII for levels of subsidies per crop). A similar trend takes place for CC2, along with a slight increase of maincrop potatoes, since vegetable crops can also be used to activate an entitlement under the CAP Reform. Seed potatoes do not increase due to their low level in the baseyear, which resulted in high PMP estimated costs (see Annex XII for details on PMP estimates). Changes in GC1 are negligible. For GC2 small increases are observed for spring barley and seed potatoes, and slight decreases for oilseed rape, and winter cereals. Seed potatoes increase due to the attribution of premiums to vegetable crops and the low PMP estimated costs in the baseyear, and oilseed rape decreases due to the premium reduction.

Table 6.4 Main economic and environmental results of CAP scenarios

	Agenda 2000	CAP Reform	CAP Health Check
	CC1		
Farm income (£)	8077	8063	8640
Income (£/ha)	546	545	584
Premiums (£)	3140	3125	3113
N use (kg/ha)	120.56	120.11	155.00
Nitrate leaching (kg/ha)	75.80	75.66	39.50
Phosphorus use (kg /ha)	44.07	44.03	54.90
Phosphorus losses (kg/ha)	0.23	0.23	0.36
	CC2		
Farmer utility (£)	65870	64790	69226
Utility (£/ha)	576	567	606
Premiums (£)	23622	22485	21471
N use (kg/ha)	145.46	144.50	168.23
Nitrate leaching (kg/ha)	63.51	60.97	40.86
Phosphorus use (kg /ha)	53.96	54.33	62.47
Phosphorus losses (kg/ha)	0.39	0.39	0.47
	GC1		
Farmer utility (£)	18355	18351	18939
Utility (£/ha)	1018	1018	1051
Premiums (£)	3055	3051	3043
N use (kg/ha)	111.44	111.53	140.40
Nitrate leaching (kg/ha)	67.40	67.41	35.69
Phosphorus use (kg /ha)	68.24	68.26	78.83
Phosphorus losses (kg/ha)	0.35	0.35	0.45
	GC2		
Farmer utility (£)	87162	86804	92283
Utility (£/ha)	842	839	892
Premiums (£)	18588	17722	16955
N use (kg/ha)	137.02	133.92	161.15
Nitrate leaching (kg/ha)	66.54	73.92	39.31
Phosphorus use (kg /ha)	69.00	72.07	77.51
Phosphorus losses (kg/ha)	0.46	0.46	0.57

The abolition of set-aside under the CAP Health Check results in income increases for all farm types (7%, 5%, 3.2%, 5.9% for CC1, CC2, GC1, and GC2 respectively). N use increases in all cases, while nitrate leaching decreases. The latter is due to the reduction of rotations with rotational set-aside which correspond to the highest leaching. Set-aside is primarily replaced by winter wheat in all farm types, due to its high profitability. In CC1, all crops present in the baseyear crop mix increase except spring barley. This is due to the composition of the prevailing rotations in the baseyear, as spring barley was mainly present in rotations with set-aside. As set-aside reduces spring barley also reduces. For CC2, the changes observed under the CAP Reform regarding oilseed rape and spring barley are slightly augmented. Winter wheat is the main crop that replaces set-aside, while winter barley slightly declines. Winter wheat is the crop that replaces set-aside also for GC1. The main changes in GC2 are increases in winter cereals and decreases in spring barley, due to the higher profitability of these crops and the lower PMP cost estimates.

Land use changes at the catchment level (Fig. 6.2) as a consequence of the Reform are minor. These are mainly driven by, and thus similar to, changes related to the GC2 farm type, as this farm type is associated to the largest farm numbers and highest land availability. The same applies to the CAP Health Check scenario, where, however, the abolition of set-aside results in an increase of more profitable winter crops.

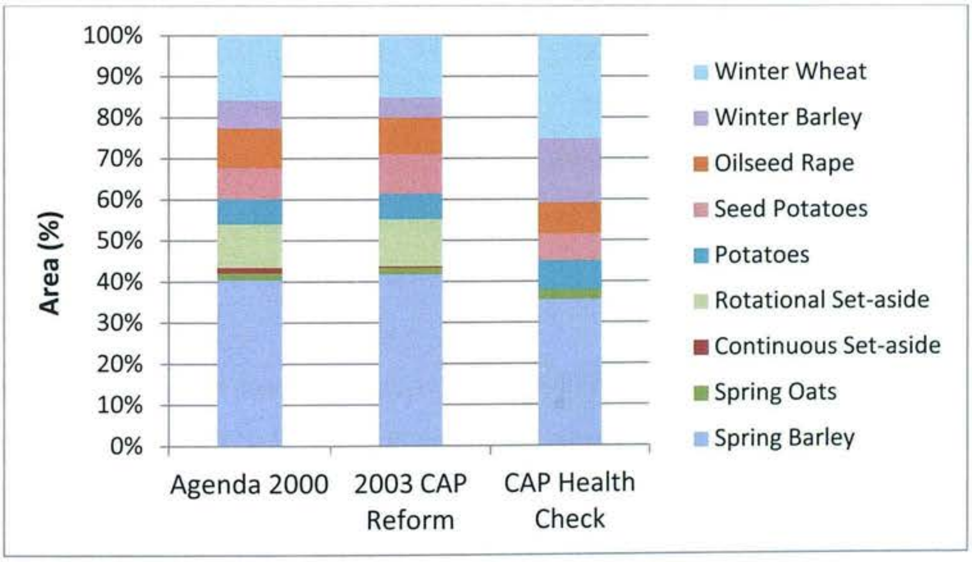

Fig. 6.2 Land use at the catchment level for CAP scenarios

6.2.2 Nitrate Pollution Control Measures

6.2.2.1 Cost-effectiveness of Measures

The relative cost-effectiveness of measures for different levels of emissions is shown with the use of trade-off curves between nitrate leaching and income per hectare for each farm type (Fig. 6.3, Fig. 6.4, Annex XII), and by arranging measures according to their cost-effectiveness ratios estimated as abatement costs per unit of nitrate leaching (Fig. 6.5, Fig. 6.6, Annex XII). The simulated economic and environmental outputs and the cost-effectiveness ratios for all scenarios and farm types are reported in Annex XII.

As expected, the highest incomes are achieved for the subsidy scenarios. The two big farm types react to the subsidy by reducing fertiliser intensity from Su-40 until Su-60. CC1 reacts between Su-40 and Su-50, and GC1 between Su-50 and Su-60. Prior to these scenarios, no changes are observed, because the subsidy is too low to induce any land use and intensity changes. Between these scenarios, the area devoted to activities with lower fertiliser intensity gradually increases with increasing subsidy levels. As a consequence, nitrate leaching gradually decreases. The only exception is observed for CC2, where leaching increases between Su-50 and Su-60. This is due to the substitution of a rotation with lower leaching (R19 - leaching 31.72) by a rotation with higher leaching (R4 - leaching 34.49). Beyond the scenarios where all crops are grown under low fertiliser intensity, the only changes occurring are increases in farmers' incomes. The maximum leaching reduction compared to the baseline scenario is about 10%. Income increases at these scenarios correspond to about 1% for small farms and 2% for big farms.

Soil specific subsidies cause a response at SuS-40 for farm types CC1, CC2 and GC2 and at SuS-50 for GC1. For these scenarios, fertiliser intensity is reduced for all activities grown on soil C. Prior to these, no changes are observed compared to the baseline scenario, whereas thereafter the only changes taking place are increases in farmers' incomes which are analogous to the increase in subsidies and the percentage of soil C at the farm level. Average per hectare leaching reductions compared to the baseline are very limited (CC1 - 1.1%, CC2 and GC1 - 0.5%, GC2 - 1.7%) due to the relative low occurrence of this soil type, and the low relative difference between Sc2 and Sc4 for the majority of rotations taking place at the baseline scenario. Income increases for these scenarios are negligible (circa 0.1%).

The cross-compliance measure starts to be respected, and thus fertiliser intensity is reduced for all activities, at CC-20 for cereal farms and at CC-25 for general cropping farms. Prior to these scenarios, premiums are reduced according to the specified rates with no other changes taking place. The minimum nitrate leaching is equal to the minimum observed for the subsidy scenarios, since this is the amount of leaching that corresponds to all agricultural activities taking place under low fertiliser intensity. Income losses at this level are about 8% for cereal farms and 5% for general cropping farms. The difference between farm types is probably due to the fact that general cropping farms are characterised by higher levels of crops for which COUP estimates of yields did not differ much between fertiliser intensities (e.g. potato crops).

Taxes on leaching cause a significant decrease in farmers' revenues. These costs represent opportunity costs incurred by changing land use and intensity patterns and also costs associated with paying the taxes. Nitrate leaching reduces, showing a very inelastic response. The responsiveness at the first stages of the tax is higher for farm types that correspond to higher nitrate leaching at the baseline conditions (e.g. CC2). Changes in CC2, GC1, and GC2 are due to gradual substitution of one of the high leaching rotations by one of the low leaching rotations. Changes in CC1 are primarily caused by changes in the allocation of rotations on different soil types, and in the last two scenarios by reductions in fertiliser intensity and rotational patterns. The patterns of nitrate leaching reductions compared to the baseline differ between farm types, as they are i) gradually increasing (0.1 - 5 %) for CC1 in an almost linear fashion but with more abrupt changes between TL-4 and TL-5, and then TL-9 and TL-10; ii) gradually increasing (2.8 - 9.8 %) for CC2 with the maximum reduction being achieved at TL-5, after which no further leaching reductions are achieved; iii) gradually increasing in an almost perfectly linear fashion for general cropping farms (0.1 - 0.5 % for GC1, and 0.3 - 2.8 % for GC2). Income reductions are almost linear between scenarios. For farm types CC1, CC2, GC1, and GC2, respectively, they are equal to i) 3.5 - 34.8 % increasing by almost 3.5 % per scenario; ii) 3.5 - 32.2 % increasing by 3.4 - 3.2 % per scenario; iii) 1.8 - 17.6 increasing by 1.8% per scenario; iv) 2.3 - 22.6 % increasing by 2.3 - 2.2 % per scenario.

The economic and environmental responses to taxes on N use are similar to the effects of taxes on leaching. In the first tax scenarios, the results of taxes on inputs and taxes on leaching almost coincide. After a certain point, however, taxes on inputs seem to be reaching lower nitrate leaching levels at a lower cost. These changes are associated with reductions of N intensive crops and fertiliser intensities on both soil types. Nitrate leaching gradually decreases as the tax increases, without, however, following a consistent pattern and with abrupt changes for different pairs of scenarios for each of the farm types. The reductions achieved between TI-0.5 and TI-5 range between i) 0.3 - 11.3 % for CC1; ii) 4.9 - 13.6 % for CC2; iii) 0.1 - 9.6 % for GC1; and iv) 0.4 - 9.6 % for GC2. Income losses for each of the farm types correspond to i) 6.9 - 60.6 %, with marginal per scenario difference decreasing between 6.8 - 5.2 % for CC1; ii) 7.1 - 62.2 %, with marginal differences per scenario decreasing between 6.8 - 5.3 % for CC2; iii) 3.5 - 32.1 %, with scenario differences between 3.5 - 2.7 % for GC1; and iv) 4.7 - 39.9 %, with scenario differences between 4.6 - 3.3 % for GC2.

Standards on leaching cause gradually increasing income losses. Nitrate leaching decreases according to the specified standard, which becomes active at different levels for different farm types depending on their baseline conditions. The land use outcomes are changes in rotational patterns, fertiliser intensities and crop allocations on different soils. Nitrate leaching reduces linearly: i) by 5.1 % between S38-S20 for CC1; ii) by 4.9 % for S40-S20 for CC2; iii) by 5.6 % between S34-S20 for GC1; and iv) by 5.1 % between S38-S20 for GC2. Income losses corresponding to these reductions are increasing at an increasing rate for farm types CC1, CC2, GC1, and GC2 respectively: i) between 1 - 63 %, at a rate of 1.9 - 18.6 % between scenarios; ii) between 0.3 - 62.3 %, at a rate of 1.2 - 18.3 %; iii) between 1.2 - 69.1 %, at a rate of 2.5 - 15.2 %; iv) 0.4 - 68.5 %, at a rate of 1.4 - 17.3 %.

The results of quotas on inputs follow a pattern that is similar to the one of standards on leaching. The quotas are initially as cost-effective as the standards, but their cost-effectiveness is lower than the cost-effectiveness of the standards for achieving lower leaching levels. Land use and intensity changes are similar to those caused by input taxes. However, as the quota gets stricter, the area under set-aside is increasing. As expected and similarly to input taxes, there is no consistent pattern of nitrate leaching reduction between scenarios. These reductions compared to the baseline scenario for CC1, CC2, GC1, and GC2 respectively range between: i) 2.1 - 49.3 % for Q-150 to Q-10; ii) 5.8 - 52.2 % for Q-160 to Q-10; iii) 0.1 - 45.3 % for Q-140 to Q-10; and iv) 0.2 - 49.4 for Q-160 to Q-10. The corresponding income losses increase at an increasing rate between the following levels: i) 0.6 - 65.4 % for CC1; ii) 0.2 - 69.1% for CC2; iii) 1.3 - 78.2 % for GC1; and iv) 0.6 - 76.7 % for GC2.

The measures can be assessed according to their relative cost-effectiveness, where costs express positive or negative costs incurred only by farmers (Fig. 6.3, Fig. 6.5). The most-cost effective measures appear to be subsidies, as they represent a negative cost to farmers. As expected, imposing standards on nitrate leaching is the next most cost-effective measure since it targets nitrate losses directly. The cost-effectiveness of quotas on N inputs is very close to the one of leaching standards for small nitrate leaching reductions, but lower thereafter. Taxes on inputs or leaching are the least cost-effective as i) they impose costs for both paying the taxes and for changing land use and intensity patterns in order to reduce tax payments and ii) they do not achieve significant leaching reductions. The effects of taxes on inputs and taxes on leaching coincide in the first scenarios, while after a point taxes on inputs appear more cost-effective than taxes on leaching. This is due to the lower elasticity of farmers' responses to taxes on leaching, that results in small land use changes and increasing payments for taxes. The elasticity of production decisions with respect to input taxes is greater, because average N use is greater than average nitrate leaching at the farm level. The ranking and cost-effectiveness ratios of measures are similar between farm types (Annex XII). In the case of taxes, however, absolute cost-effectiveness ratios differ between farm types, due to disparities in their responsiveness to the measure.

The latter is triggered by differences in the baseline conditions in terms of nitrate leaching, N use, and land use patterns.

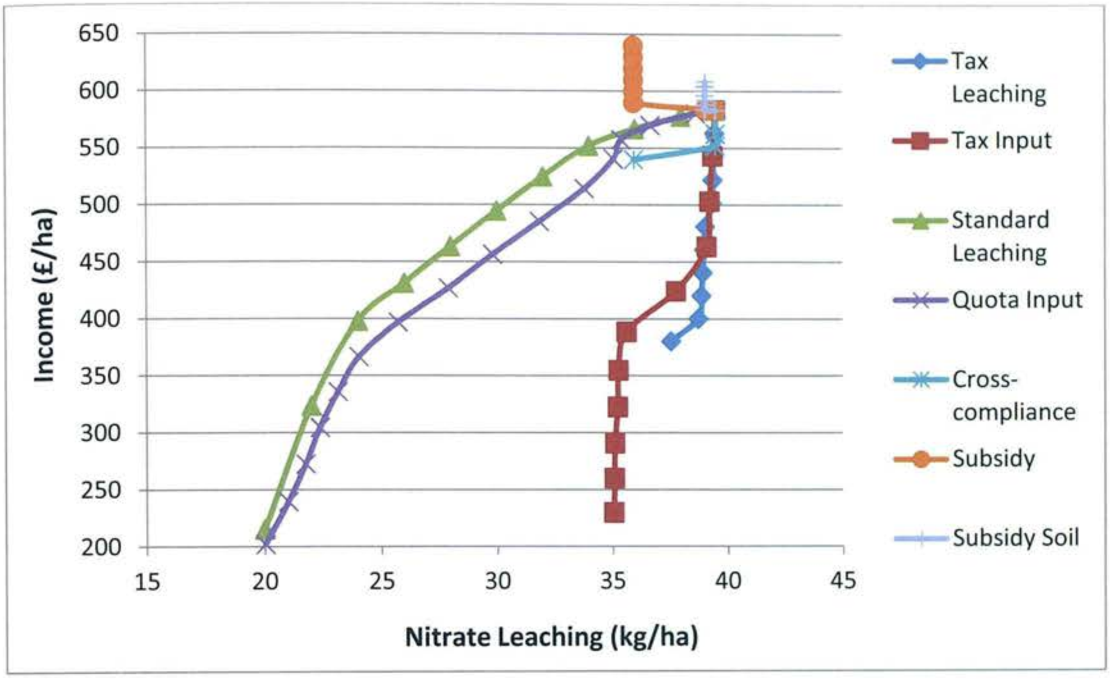

Fig. 6.3 Trade-off curve of nitrate leaching versus income for CC1 (a)

In order to isolate farmers' opportunity costs (i.e. costs resulting from changes in land use and intensity levels due to the enforcement of measures) from costs and revenues associated to taxes and subsidies, tax payments have been added to, and subsidy payments deducted from, farmers' incomes. When these financial transactions with the public sector are removed, the relative cost-effectiveness of measures changes (Fig. 6.4, Fig. 6.6). The most cost-effective measure appears to be taxes on leaching, as it is associated with minimal nitrate leaching reductions that can be achieved at a low cost. This measure is followed by nitrogen standards on leaching, and quotas and taxes on inputs. For small nitrogen reductions, the cost-effectiveness of taxes on leaching and inputs is very close to the cost-effectiveness of leaching standards and input quotas, respectively. This demonstrates the previously made suggestion that the majority of costs associated with these measures represent costs for paying the taxes. Measures aiming at a 20% reduction of inputs, including subsidies and cross-compliance, are similar between them in terms of their cost-effectiveness. However, their cost-effectiveness is lower than the one of standards on leaching for achieving similar leaching reductions, as these measures target leaching indirectly through N inputs. Similar effects are observed for all farm types. The only difference is that in general cropping farms, the cost-effectiveness of subsidy and cross-compliance measures is closer to the one of leaching standards. Soil specific subsidies are associated with the highest cost-effectiveness ratios. As previously mentioned, this is primarily due to the low relative difference in nitrate leaching between Sc2 and Sc4 for most rotations taking place on soil type C at the baseline scenario.

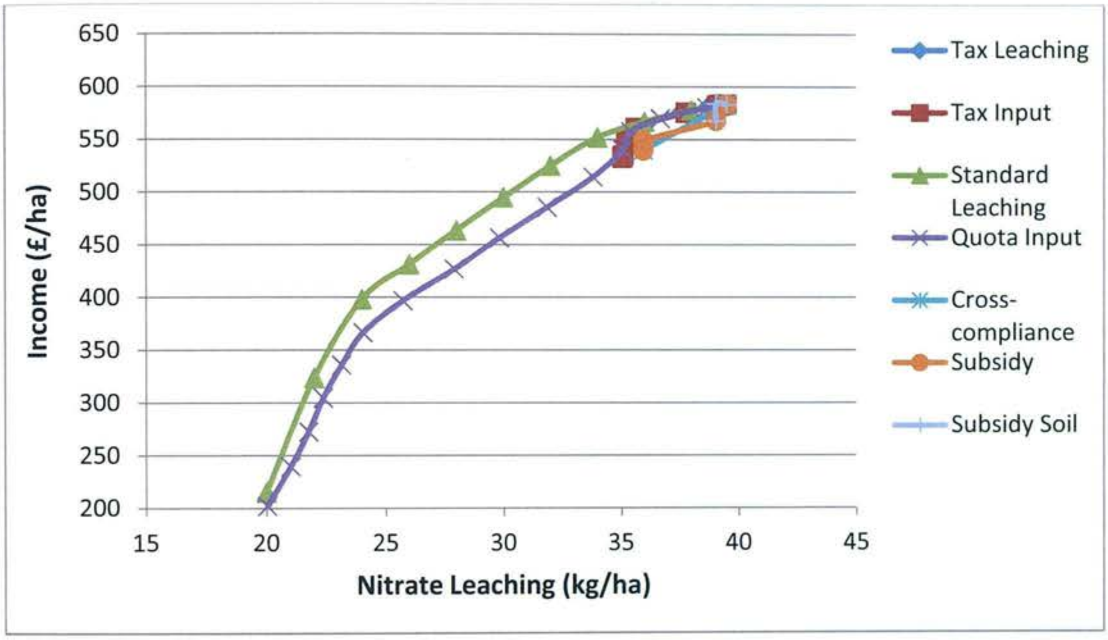

Fig. 6.4 Trade-off curve of nitrate leaching versus income for CC1 (b)

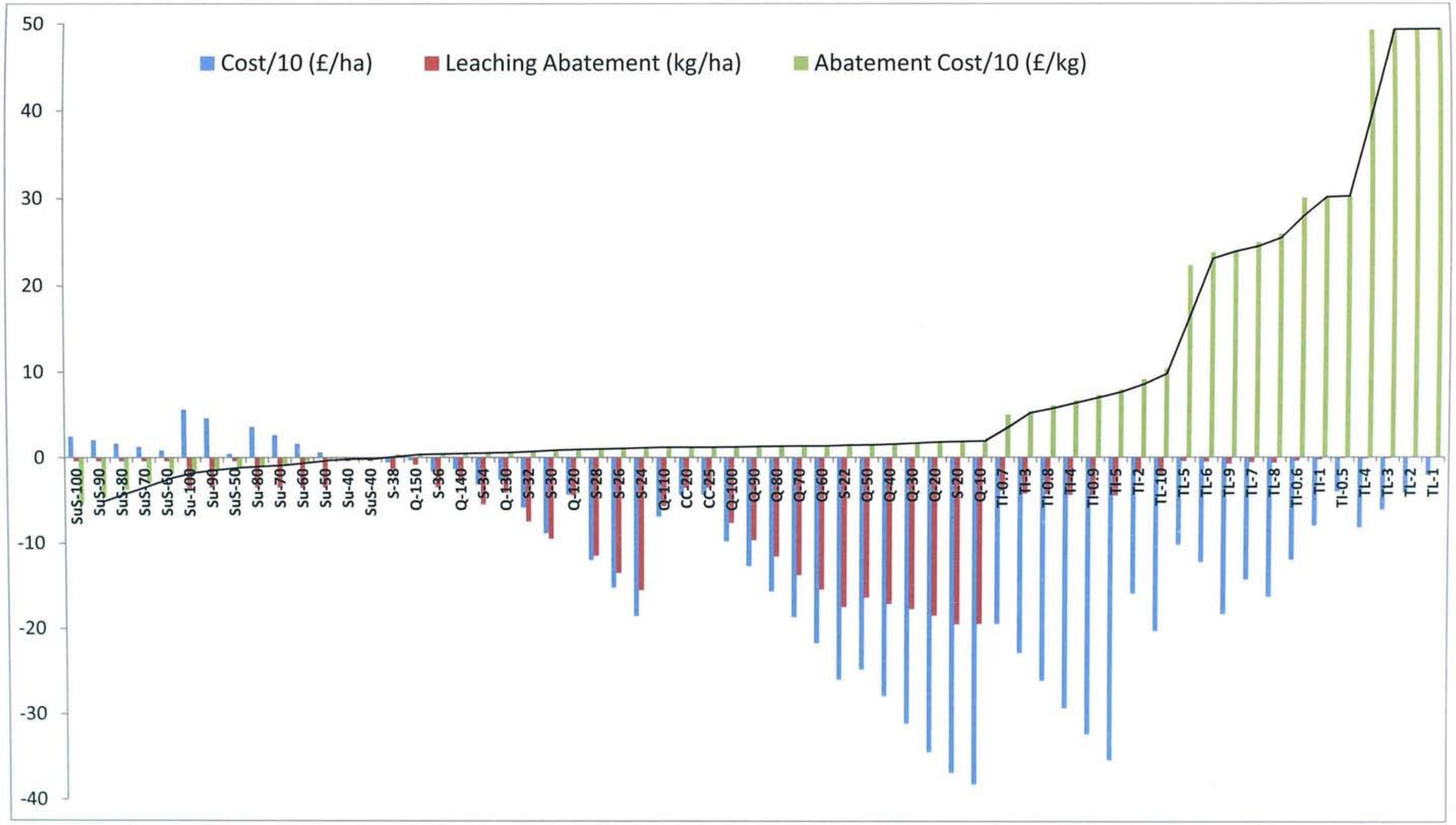

Fig. 6.5 Nitrate leaching abatement costs for CC1 (a)

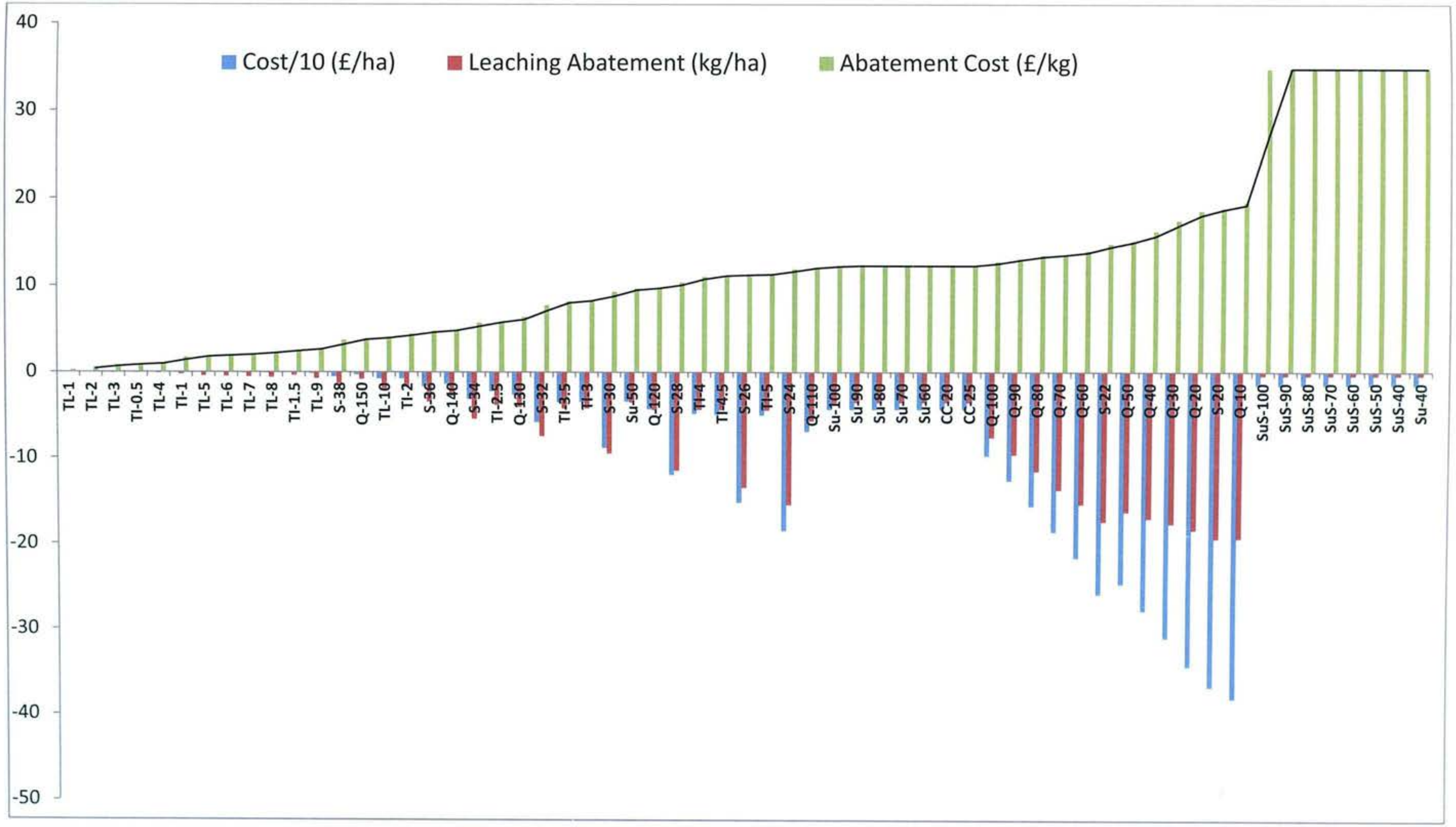

Fig. 6.6 Nitrate leaching abatement costs for CC1 (b)

6.2.2.2 Relationship between Water Quality Indicators

The relationship between N input, nitrate leaching, phosphorus inputs and losses slightly differs between scenarios.

Standards on leaching result in generally greater reductions of N use (Fig. 6.7). Greater similarities between the rates of reduction of nitrate leaching and N use are observed in the first leaching scenarios for all farm types. After a point however, N use reductions are significantly greater compared to those of nitrate leaching. In the case of CC2, nitrate leaching reductions are higher than N use reductions for some scenarios. The reverse effect is observed between phosphorus inputs and phosphorus losses, as the reduction in input use is smaller than the reduction of the pollutant.

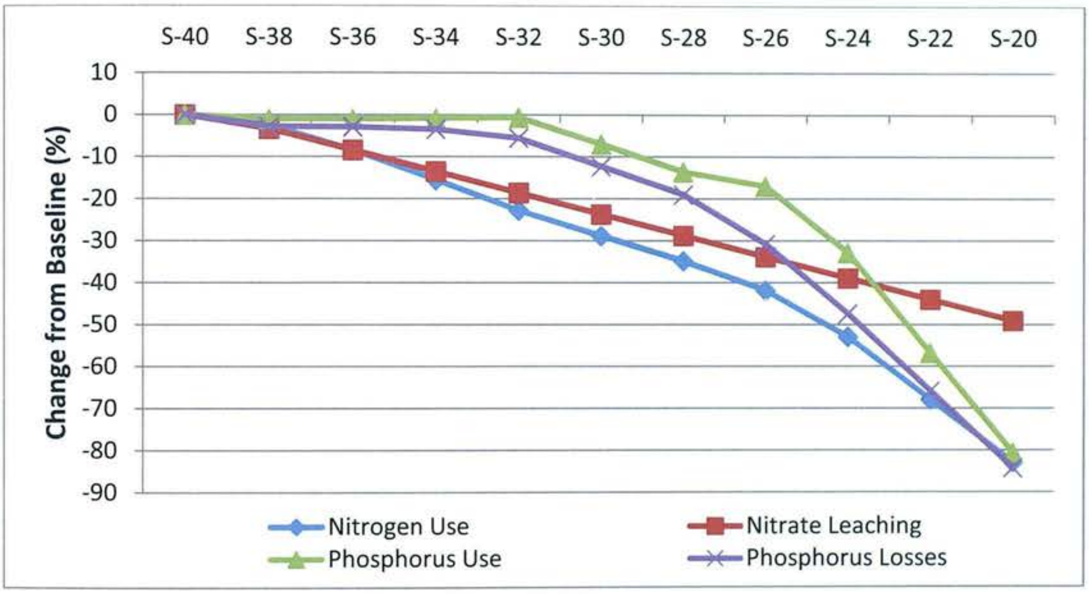

Fig. 6.7 Changes in water quality indicators of GC2 for leaching standards scenarios

For input quotas, N use reductions are consistently considerably greater than N leaching reductions. For one of the farm types (GC2), it is observed that phosphorus losses decrease in some scenarios, while phosphorus inputs increase.

Taxes on leaching have diverse effects depending on the farm type. For CC2 and GC2, per cent reductions in nitrate leaching are greater than per cent reductions in N inputs. The opposite is observed for GC1. For CC1, both effects occur depending on the scenario.

Taxes on inputs indicate how reductions in N inputs can result in only minor effects on nitrate leaching (Fig. 6.8). Also, between TI-3 and TI-3.5 nitrate leaching slightly increases with decreasing inputs. Effects of decreasing phosphorus losses for increasing inputs are also observed.

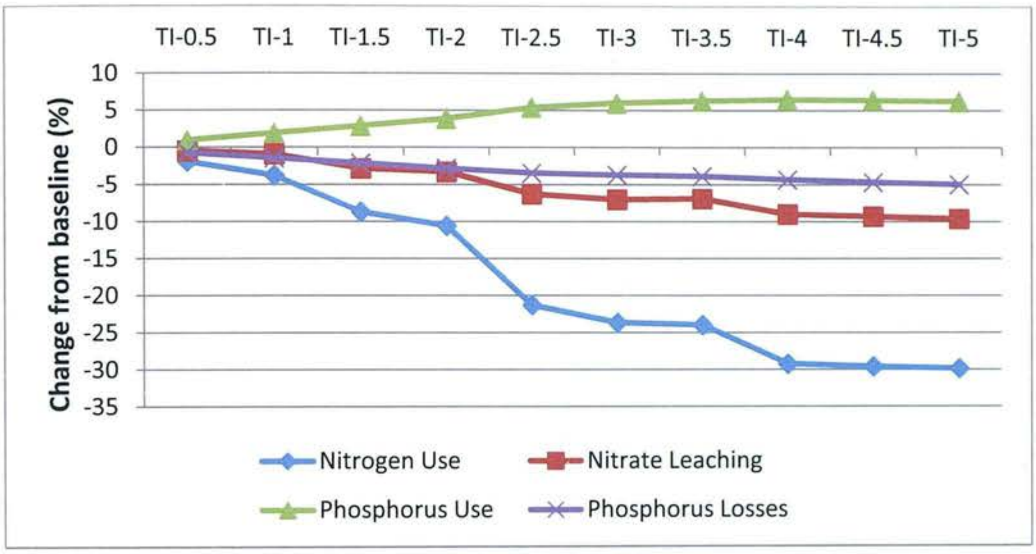

Fig. 6.8 Changes in water quality indicators of GC2 for input taxes scenarios

For the effective scenarios of subsidies and cross-compliance measures, decreases of average N input generally result in decreases of a lower magnitude of nitrate leaching (Fig. 6.9). However, for CC2, a N use reduction corresponds to a slight nitrate leaching increase in one of the scenarios. Additionally, phosphorus inputs and losses increase.

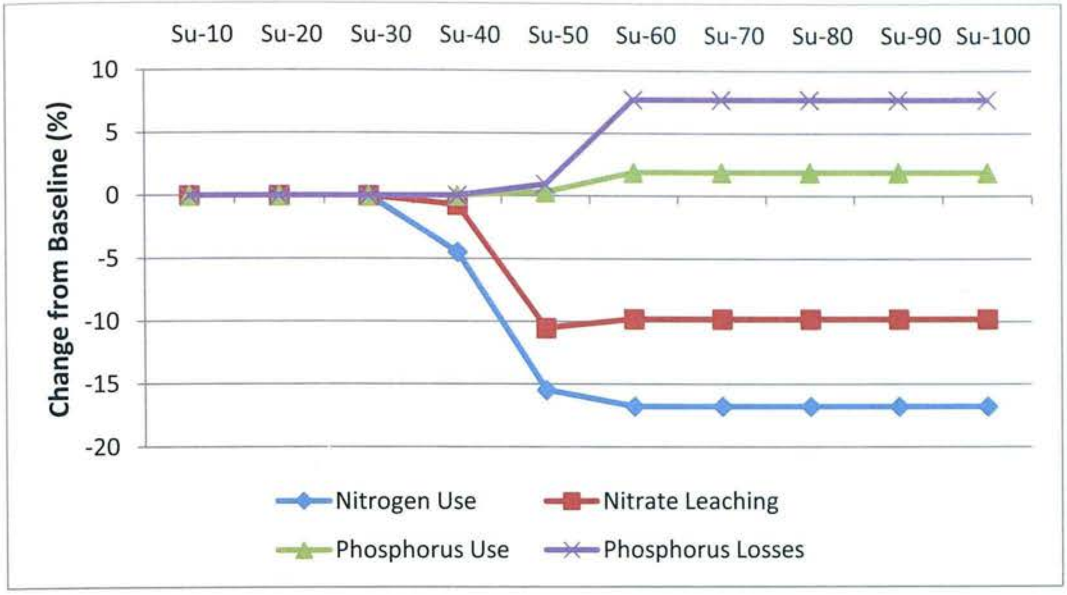

Fig. 6.9 Changes in water quality indicators of CC2 for subsidies scenarios

6.2.2.3 Land Use and Intensity Changes

Taxes on leaching cause minor changes in rotational patterns. In CC1, changes in the allocation of rotations on different soil types occur in the first tax scenarios (Fig. 6.10). Only in the last two scenarios there is a reduction in fertiliser intensity and changes in the areas devoted to different rotations. In CC2, the rotation with the highest leaching on Sc3 is reduced (R4-leaching 42.69) and substituted by a rotation with the lowest leaching for Sc3 (R19-leaching 32.43). Similar patterns are observed for farm types GC1 and GC2, where one of the high leaching rotations is gradually substituted by one of the lowest leaching rotations, all under Sc3.

Input taxes result overall in slight reductions of N intensive crops and fertiliser intensities, on both soil types (e.g. Fig. 6.11). Crops with low or zero fertiliser inputs (spring cereals, seed potatoes, peas) increase, while crops with high fertiliser input (winter barley, potatoes, oilseed rape, winter wheat) decrease. The only exceptions are i) spring barley that slightly reduces (0.01%) for GC1; and ii) winter wheat that slightly increases (0.08%) for GC2. Fertiliser levels decrease on both soils.

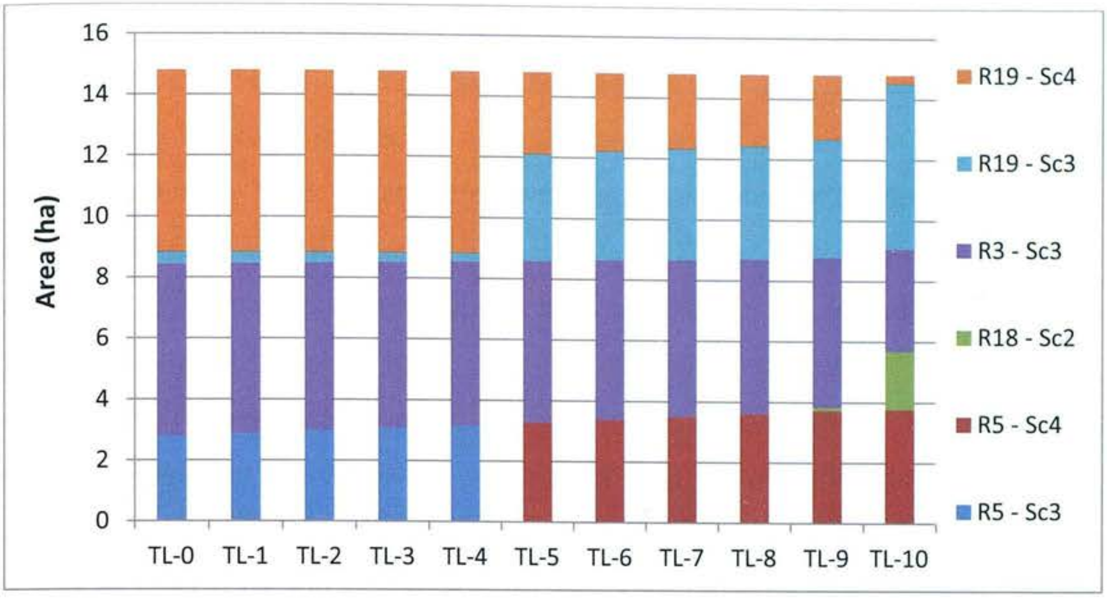

Fig. 6.10 Land use of CC1 for leaching taxes scenarios

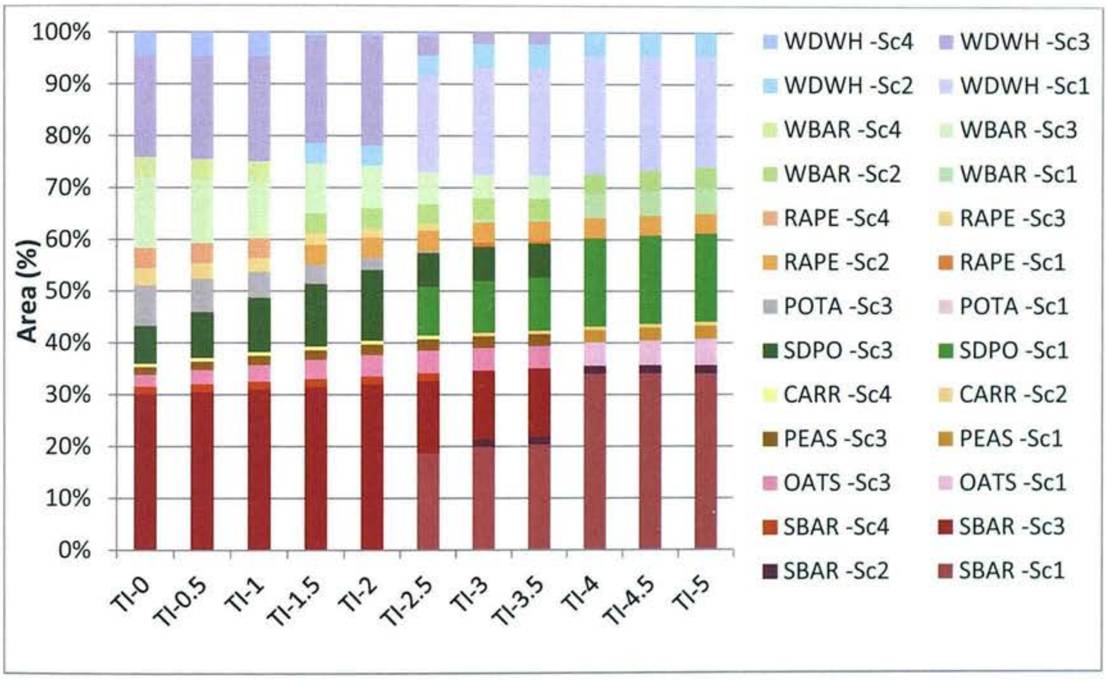

Fig. 6.11 Land use of GC2 for input taxes scenarios

The results of standards on leaching are changes in rotational patterns and fertilisation intensities. Crop changes across farm types and scenarios are not entirely consistent, as the key unit targeted for leaching reductions is the rotation as opposed to the crop. The continuous set-aside rotation increases after a certain standard level (S-32 for CC1 and GC2, S-28 for CC2, S-30 for GC1). The crop changes that are observed before set-aside is introduced in the rotational mix are: i) oats are increasing for all farm types and scenarios; ii) winter wheat decreases for all farm types and scenarios; iii) spring barley increases for all farm types except GC1; iv) winter barley increases for general cropping farms and decreases for CC1; v) oilseed rape decreases for GC2; vi) maincrop potatoes increase for GC2; vii) seed potatoes decrease for CC2 and GC2, viii) peas decrease for GC1. The combinations of crops and farm types not mentioned above are characterised by inconsistent patterns between scenarios. After the introduction of continuous set-aside, most crops start to decrease. Exceptions are observed for some crops in the general cropping farms (maincrop potatoes, winter barley and oats for GC1; all crops except winter wheat, winter barley, potatoes and carrots for GC2). Fertilisation intensity levels start to reduce in i) S-38 on soil C and S-36 on soil A for CC1; ii) S-36 for both soils for CC2; iii) S-34 on soil A for GC1, while on soil C crop rotations are abandoned for the continuous set-aside rotation; iv) S-36 for soil A and S-34 on soil C for GC2.

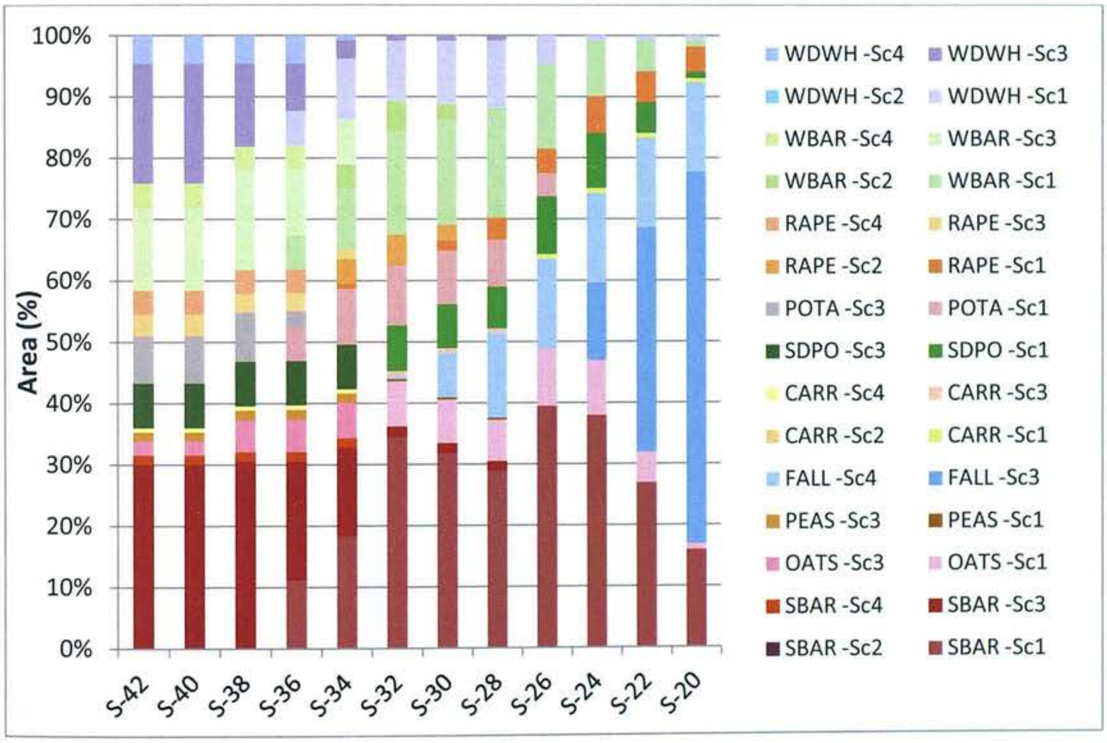

Fig. 6.12 Land use of GC2 for leaching standards scenarios

For the first levels of input quotas, the results are similar to those for input taxes (Fig. 6.13). However, as the quota decreases, the area of continuous set-aside constantly increases, and the areas of all crops, and in particular high N crops such as winter cereals and oilseed rape, decrease. The scenarios where set-aside starts to increase are Q-110 for CC1, Q-120 for CC2, and Q-100 for the general cropping farms.

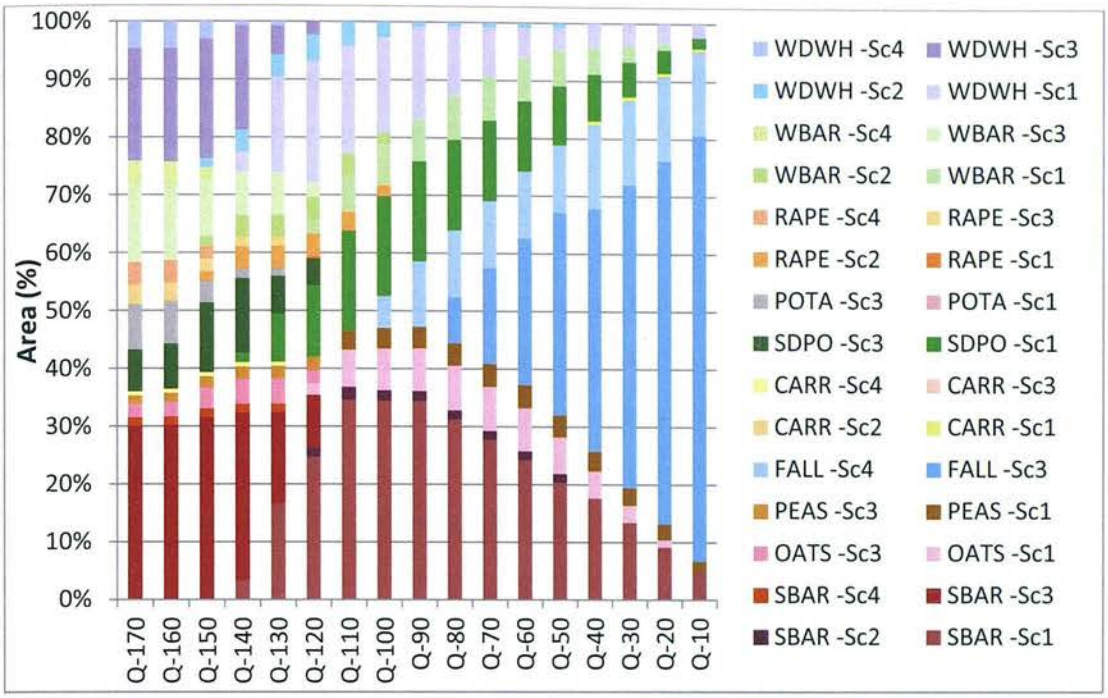

Fig. 6.13 Land use of GC2 for input quotas scenarios

The changes induced by cross-compliance measures are reductions in intensity for all activities. Slight land reallocation to different crops also occurs, as farmers adapt in order to minimise the effects of the measure. Generally, rotations where reductions in fertiliser intensity has significant impacts on incomes are substituted by rotations where such effects are milder. The same trends are observed for subsidies, only that those changes occur gradually through scenarios as the subsidy level increases.

6.2.2.4 Supply Responses

The supply outcomes of the different scenarios on an average per farm basis at the catchment level are shown in Fig. 6.14. The results encompass supply changes due to crop and intensity patterns, and the associated impacts of the latter on yields.

Taxes on leaching result in minor changes associated with decreases in the supply of winter wheat and oilseed rape, and increases in the supply of the rest of the crops. The same results are observed for the very first scenarios of standards on leaching.

Most crops decrease for standard levels lower than S-32 or S-30, as the continuous set-aside rotation is increasing. Before these scenarios (i.e. for scenarios that correspond to higher leaching standards), there are no consistent upward or downward trends for the majority of crops. The only exceptions are in relation to the supply of winter wheat and oilseed rape (with the exception of S-24), where continuous downward trends are observed. Inverse trends are observed for the supply of peas and oats.

Supply responses caused by taxes on inputs are more closely related to crop specific changes. Supply of peas slightly increases across all scenarios, and supply of oilseed rape, winter barley, and potatoes decreases across all scenarios. Supply of spring cereals and seed potatoes also increases in the first tax scenarios. Reductions associated to the supply of these crops in the last scenarios are related to changes in fertiliser intensity. Similar responses are observed in the first scenarios of the input quotas, which are further augmented in the middle scenarios. The only exception is winter barley, which first decreases but then slightly increases, to start decreasing again. After a point, as set-aside is increasing, supply starts to decrease gradually for all crops. These effects start to be observed at Q-110 or Q-100 for winter wheat, winter barley, spring barley, and seed potatoes, at Q-80 for carrots, Q-70 for oats, and Q-50 for peas.

The results for cross-compliance and subsidy measures are very similar, and indicate reductions in the supply of most products except peas and seed potatoes. Even though supplies of oilseed rape and potato generally decrease, some slight increases compared to the previous scenario are observed in the last scenario of subsidies.

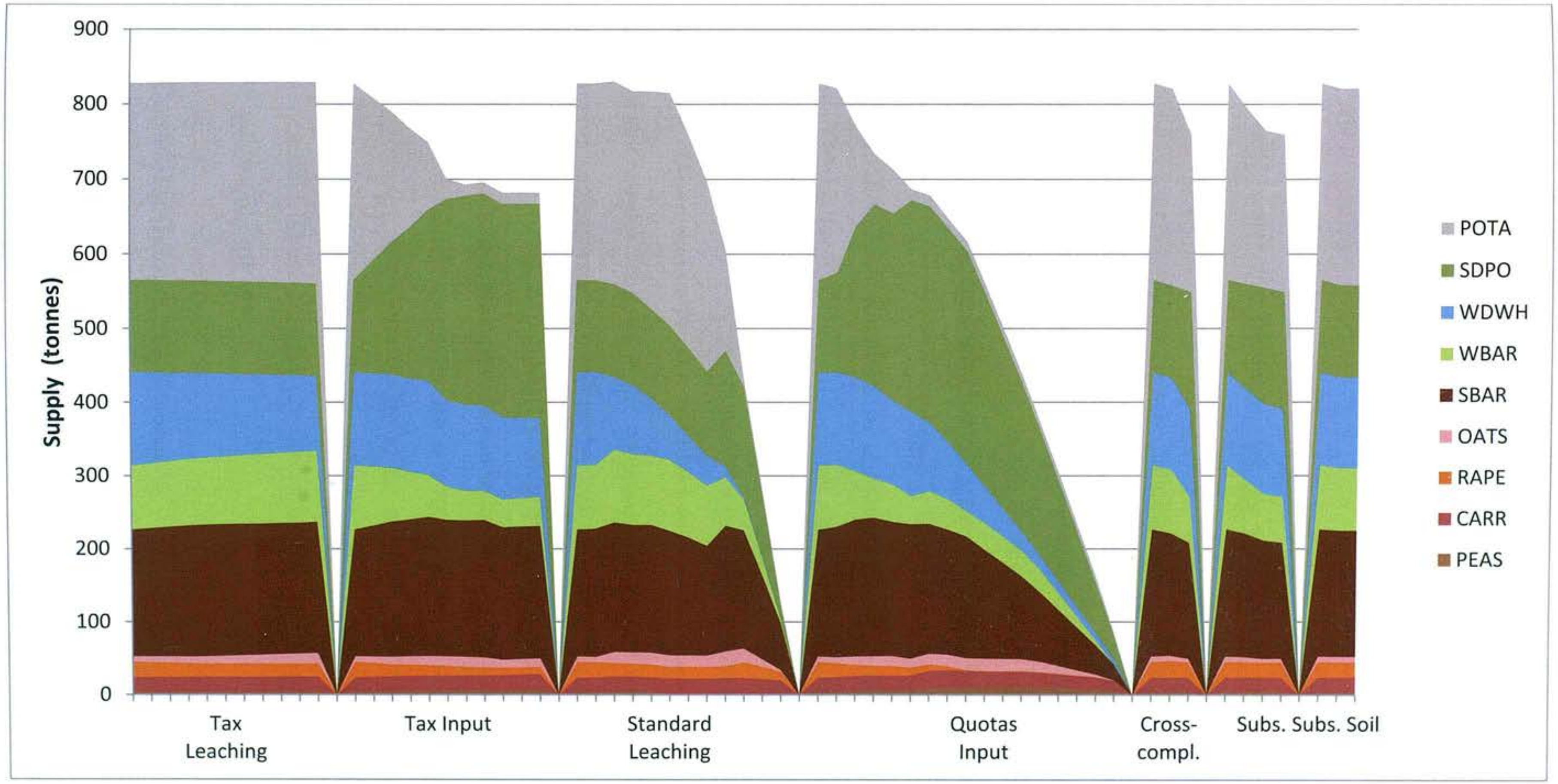

Fig. 6.14 Average supply per farm for all scenarios

7 Discussion and Conclusions

7.1 Summary and Discussion of the Results

7.1.1 CAP Impacts

The CAP Reform scenario results in minor changes in land use and subsequently economic and water quality indicators. A very small reduction in incomes is observed due to modulation. However, this reduction is lower than the reduction in premiums as farmers adapt to the new policy. Changes in N use and nitrate leaching are negligible in the case of small farms. Small N use reductions are observed for larger farms. However, the direction and magnitude of nitrate leaching effects differ between the two farm types, due to the corresponding changes in the selected rotations. The observed land use changes are partly driven by changes in the relative difference of premiums, such as increases in vegetable crops that became eligible for subsidy payments, and reductions in oilseed rape due to the relative reduction of premiums for this crop. Differential changes between farm types seem to be mainly caused by the initial crop mix per farm type, and thus the estimated PMP cost functions. Similar results were obtained by previous research in the context of this thesis (e.g. Mouratiadou *et al.*, 2011; Mouratiadou *et al.*, 2008), where results indicated only small changes in the cropping pattern and associated economic and water quality indicators as a result of the Reform, with the main changes in farmers' decision making being explained by crop price changes. As expected, the CAP Health Check leads to higher farm incomes due to the productive use of land that was previously kept under set-aside. As a consequence, N use increases but nitrate leaching decreases. The latter is due to the reduction of rotational set-aside, which corresponds to the rotations with the highest leaching. Set-aside is primarily replaced by winter cereals. These changes are driven by the relative profitability of crops and the PMP estimated cost terms.

7.1.2 Cost-effectiveness of Measures

The relative cost-effectiveness of measures differs depending on whether monetary transactions of farmers with the rest of the society (i.e. payments for subsidies and taxes) are considered. Subsidies for reducing fertiliser intensity result in increasing farmers' incomes. The amount of subsidy required for reducing intensity differs between farm types, but overall it ranges between 40-60 £/ha. The maximum leaching reduction achieved is about 10% compared to the baseline scenario, and it corresponds to a minor increase in farmers incomes (1-2 %). Soil specific subsidies are active when they reach 40-50 £/ha, depending on the farm type. The observed effectiveness is limited (below 2%) due to the low occurrence of the targeted soil. Income increases are negligible. The results of the cross-compliance measure, which also targets fertilisation intensity, are similar to the subsidy scenarios in terms of both effectiveness and costs. Premium reductions at the level at which farmers respect the measure (20-25 %) correspond to about 40 £/ha, which is equivalent to 8% of income forgone for cereal farms, and 5% for general cropping farms. Tax instruments impose significant costs on farmers, which represent mainly payments for taxes rather than opportunity costs due to changing land use and intensity patterns. This is due to the low elasticity of responses to the measures, which is nevertheless increasing as the tax is increasing. In order to achieve leaching reductions of about 10% the input tax needs to be set equal to 6-10 times the price of commercial fertiliser per kg of N used. As expected, standards on nitrate leaching are the most cost-effective measure, since they target directly nitrate losses. The cost-effectiveness of quotas on N inputs is very close to the one of leaching standards for small nitrate leaching reductions, but lower thereafter. This demonstrates the effectiveness of first-best over second-best measures. If payments for taxes are not considered, the cost-effectiveness of taxes coincides exactly with the cost-effectiveness of leaching standards and input quotas for achieving small nitrogen reductions.

When considering only opportunity costs incurred by farmers, leaching standards, input quotas, and taxes yield similar results between them and indicate a higher cost-effectiveness than measures that regulate fertiliser intensity, such as the simulated subsidy and cross-compliance measures. This was expected, because the second set of measures targets leaching indirectly through N inputs associated to technique specifications of fertiliser intensity. Input quotas and taxes also target the input as opposed to the output. However, these measures allow adaptation at the farm level where input reductions can be achieved by substitution between rotations, crops and/or fertiliser intensities, depending on what will have the least cost. On the other hand, fertiliser intensity reductions per activity, as modelled through the cross-compliance and subsidy measures, operate at the field level and target only the fertiliser intensity dimension.

Nevertheless, with the exception of standards and quotas, the rest of the measures achieve a relatively small reduction in nitrate leaching. In the case of taxes, this is due to the low elasticity of responses to the measure. In the case of measures targeting reductions in fertiliser intensity, it is observed that the relative reduction at the farm level is similar to the relative average reduction at the field level estimated using COUP results. Thus, this effect is in line with the supplied nitrate leaching input values. Additional fertiliser intensity scenarios can be simulated in order to explore the effects of such measures for further nitrate leaching reductions. However, there is limited scope for such an attempt, since it is unlikely that a reduction of more than 20% of the existing NVZ recommendations would be proposed as a policy measure.

7.1.3 Other Considerations for the Selection of Courses of Action

Overall, the cost-effectiveness results indicate that similar leaching reductions can be incentivised through a number of economic instruments. Beyond the relative cost-effectiveness of measures as modelled in our framework, further key considerations are relevant in order to determine the best set of measures for reducing nitrate pollution from nitrates. A first aspect is who should bear the costs of achieving these reductions. As demonstrated, taxes would impose important costs on farmers without yielding significant nitrate leaching results. Even though a strict enforcement of the *polluter pays* principle would advocate such a measure, its social and political acceptability is questionable. The extent to which these costs would be carried over to consumer prices, and thus still be imposed on the wider society, or incurred by farmers' due to price competition, would depend on the extent of the market of the considered agricultural products and the enforcement of environmental legislation in other countries. On the other hand, subsidies would directly impose the costs of environmental protection on the rest of the society. Cross-compliance would deliver environmental protection by imposing on farmers costs that are lower than those imposed by taxes. Additionally, it might result in cost savings for the rest of the society through subsidy reductions if farmers chose not to respect the measures. Command-and-control measures at the farm level are not associated with other costs except opportunity costs of changing land use and intensity, which are fully incurred by farmers.

Secondly, even though measures that operate at the farm level through farmers' adaptation appear to be more cost-effective than measures operating at the field level through net intensity reductions, a number of concerns are associated with this assertion. Firstly, farmers' or any human's cognition is unlikely to yield results that are as efficient as those obtained through an optimisation modelling framework. Thus, in practice, and given the similarity of the cost-effectiveness between the two types of measures, field level measures might be as cost-effective as not fully exploited farm level measures. Secondly, net percent reductions that have been chosen to represent the field level measures might not be appropriate, as N use reductions should not be uniform across crops, but tailored to the resilience of yields to N inputs per crop and soil. Thirdly, the results indicate that even though there is a trend of reduction in nitrate leaching at the farm level, which in most cases is analogous to decreases in N inputs, this relationship does not guarantee significant reductions in nitrate leaching through measures targeting N inputs at the farm level. This is demonstrated through the following effects: i) significant N input reductions are needed for small decreases in nitrate leaching; ii) in few of the scenarios it was observed that N use reductions resulted in nitrate leaching increases; iii) the rate of N use reductions for achieving nitrate leaching reductions is not uniform across scenarios and farm types. Previous work (Mouratiadou *et al.*, 2010; Belhouchette *et al.*, 2011; Mouratiadou *et al.*; forthcoming) has also showed that the relationship between N inputs and nitrate leaching at the farm level is not straightforward. Additionally, measures targeting farm level N use might skew supply responses against more N intensive crops, such as winter cereals, oilseed rape and potatoes.

Ideally, standards on leaching would provide the optimal pathways towards achieving nitrate leaching reductions. Even though this measure provided indications that leaching reductions can be achieved through changes in rotations, N inputs at the farm level, and fertilisation intensities at the field level, no specific recommendation about the exact pattern to be followed in order to achieve similar cost-effectiveness can be extracted from these scenarios. Indeed, this in reality is not a straightforward task as leaching effects are rotation specific and associated with unexpected weather events. Nevertheless, as farmers are in direct interaction with the agricultural environment, training and education of farmers in relation to the processes that trigger nitrate pollution and ways that this can be minimised at the field level, might assist in understanding the implications of their actions and controlling pollution at source.

Finally, assuming that nitrate leaching losses at baseline conditions are close to actual ones, the results indicate that considerable leaching reductions through changes in inputs can only be achieved at a significant cost. Thus, farm infrastructure measures, such as buffer strips, can provide a viable alternative solution.

7.1.4 Comparison with other Studies

Comparing the results of studies on the integrated assessment of policy measures is not trivial as the results are usually shaped by the combination of various causal relationships that have determined the outcomes of the simulations. These relationships involve the set of considered agricultural activities determined by geographical locations and farm types, intermediate variables such as yields or nitrate leaching for different agricultural activities, and their interactions with varying policy environments. As the starting points of integrated assessment studies on the above three features rarely coincide, the direct comparability of the results of different studies is reduced. Nevertheless, some general conclusions can be drawn.

Regarding the efficiency of policy instruments, Belhouchette *et al.* (2010) find that current levels of cross-compliance penalties are not sufficient to induce reduction of applied fertilisers, and the measure is only found to be respected when the penalty is significantly increased. Percentage reductions in incomes and nitrate leaching when the measure is respected are inline with our results. Specifically, when fertilisation intensity is lowered for all activities, a 10% reduction of nitrate leaching is observed. Gibbons *et al.* (2005) find that increases in fertiliser costs that are below 50% have little effect on nitrate losses, while some nitrate leaching reductions are observed for higher costs. Even though their results are more sensitive to increasing fertiliser costs compared to our results induced by taxes on nitrogen inputs, in both cases it is implied that significant increases in fertiliser costs are required for achieving nitrate leaching reductions. Indeed, low price elasticity of nitrogen fertiliser consumption is reported in numerous studies (e.g. Semaan *et al.*, 2007). Martinez and Albiac (2006), in accordance to our results, suggest that standards incur lower economic losses for farmers compared to taxes. However, contrary to our study, the authors observe significant leaching reductions (about 50%) accompanied by relatively small economic losses for farmers (7%). This demonstrates how the results of different studies might yield contrasting results on absolute or relative pollution abatement potentials, as these depend largely on initial assumptions on nitrogen use and crop-specific responses to input reductions. Finally, the consideration of cost-sharing between farmers and society is also recognised by Semaan *et al.* (2007) as a decision-making attribute on the selection of measures. The authors note that taxes charge the full cost of abatement to farmers, while subsidies share the costs between society and farmers.

7.2 Discussion of the Methodology

7.2.1 Economic Component: FSSIM-REG

The use of FSSIM-REG was suited to the needs of this study due to a number of model characteristics. FSSIM-REG allowed considering farmers' reactions to policy change, taking into account both the socio-economic and environmental outcomes of agricultural production, and representing in a comprehensive manner the complexity of the agricultural system. The primal representation of technology permitted the simulation of measures related to production activities rather than products and the efficient linkage with output from COUP simulations. The model enabled the simulation of a wide range of economic incentive measures, and showed a reasonable response to the simulated scenarios. Additionally, previous work (Mouratiadou *et al.*, 2011; Mouratiadou *et al.*, 2008) has demonstrated the model's capacity to represent farmers' decision making in a realistic manner, through comparison of model predictions with observed land use patterns.

However, the employed methodology is not free of assumptions and limitations. First, FSSIM-REG is a comparative static mono-periodic model. This implies that the model only compares different equilibrium states representing the modelled scenarios. The motion towards equilibrium or the process of change are not studied themselves, as the results of the simulations represent one point in time. In the case of FSSIM-REG, this point in time represents the average over a number of years as the model is set up with multi-periodic rotations rather than crops. Thus, some temporal effects are implicitly incorporated through the definition of activities as crop rotations. These are in principle the effects simulated by the bio-physical model, i.e. crop growth, fertilisation patterns, and leaching effects through the course of a rotation. As discussed in section 3.2.3, such an implicit representation of time seems to be sufficient for the objectives of this study. However, it can be argued that it under-represents nitrate leaching hotspots and variability between different years.

Model calibration to crop levels, while using the rotation as the basic simulation unit, creates an inflexible dependence between i) the farm typology and corresponding observed crop levels of the relevant farm types; and ii) the rotations to be modelled by both the bio-physical and the economic models. As discussed in section 5.3.3.5, in order to achieve model calibration it is likely that the modelled rotations need to be altered in order to match the observed crop pattern of the modelled farm types. Any change in the values of observed activity levels, due to changes in the farm typology and/or the baseyear period, require changing the set of modelled rotations and imply further bio-physical simulations for these additional rotations.

Although the definition of the activities per rotation, crop, and technique, allows a direct link with bio-physical modelling scenarios and is consistent with natural patterns, it imposes limitations on the number of activities that can be considered and the substitution possibilities between crops and techniques. The combinations of crops into rotations and their corresponding levels of fertilisation need to be defined in the outset of the simulations. As these combinations are infinite, their simulation without a fully automated modelling framework is not feasible in practice. The consequence is a rigid and limited representation of the actual farmer's feasibility set that might result in overly constrained solutions.

The risk specification of the model was not used in this study, because it was found to interfere with the solution of the binary variable used for the simulation of cross-compliance measures. This issue was not solved in time for the purposes of this thesis, and as a consequence risk neutrality for all farm types has been assumed. Further, it can be suggested that a risk specification that takes into account all levels of the agricultural activity, and in particular techniques in relation to fertilisation levels, would be more appropriate than a risk specification that assesses only crop-specific risk.

Even though the development of FSSIM-REG is overall based on well-grounded theoretical and integrated modelling considerations, model application has been subject to a number of operational limitations. This was caused by the aspiration for the model to operate as part of the SEAMLESS-IF, and therefore the need to communicate with other models, operate within a broader modelling chain subject to specific programming requirements, and function with specific data sets. The above dictated an intricate model structure with a programming code that is disproportionate to the algebraic structure of the model. Thus, model transparency is questionable and navigation across the code to identify/alter model specifications related to both data and equations is challenging. To illustrate this with a simple example, the inclusion of the factor representing voluntary modulation, overshoot of base areas, and the national reserve mentioned in section 5.3.3.4 implied changes in ten different model files.

Additionally, the model was subject to a number of dependencies within the SEAMLESS-IF. A key dependency was related to data management procedures, that although they were very well-developed within SEAMLESS-IF, they were specific to model use within this framework. The stand-alone model version corresponded to a model requiring a considerable amount of data (mainly due to the specification of discrete production and pollution functions), but with no defined procedures to feed these data into the model. Using an example from this study, the simulation of only about 30 rotations required input files that corresponded to about 10 columns by 1000 rows. This problem has been overcome with the creation of the DMF and other operational procedures described in section 5.5, without which model use would have been impossible.

Another important FSSIM-REG dependency is caused by the model links to the FSSIM-livestock feed-module, which provides key inputs for the rest of the model livestock component. As mentioned in section 5.3.2, this model component was not operational in an effective manner within the lifetime of this thesis. The alternative option for producing outputs from the feed module would have been to use directly the model code that is written in JAVA[40], select the parts of the model that would be relevant to the specific application, and manually introduce all the livestock related data. This option was deemed infeasible within the time span of the thesis, due to the time required for manual introduction of all the data and for familiarisation with another programming language.

Finally, the fact that the model was in development and has thus been continuously updated during the composition of this thesis, posed some practical difficulties. As it would be expected, the release of every model version implied new model bugs and getting acquainted with altered/new specifications. Additionally, as these specifications impacted also in the specifications of the DMF, each model version release required scanning the whole model for differences in the specifications.

7.2.2 Bio-physical Component: COUP

The lack of a generic ready-to-use bio-physical model that would be able to adequately represent bio-physical conditions in Scotland posed significant constraints to the achievement of the objectives of this research. The COUP model

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[40] http://www.java.com/en/

was chosen on the basis of its ability to sufficiently represent Scottish natural conditions. Indeed, the model provided satisfactory results regarding absolute and relative values of yields of cereal crops under different soil and fertiliser scenarios, and relative differences in leaching. However, this was not the case for non-cereal crops. The flexibility of the plant growth sub-model in terms of the type of plant that can be simulated is a significant model advantage. However, a drawback is that several assumptions and compromises need to be made prior to full model implementation, which might simplify or exclude some of the more plant specific processes or physiological characteristics, or lead to misspecification of the associated parameters. This reinforces the argument for extensive testing of models prior to their utilisation, particularly when a model is applied in a new environment. However, a serious limiting factor for this task is the limited amount of experimental information on both yield and nitrate leaching associated with different levels of inputs and soils against which model predictive capacity can be assessed. Such data sets are truly scarce, and even when they do exist they are hardly traceable beyond the teams that conducted the experiments. For progress to be made regarding model testing and validation, the gaps between experimental and mechanistic approaches should be narrowed. The creation of databases where experimental data could be publicised would certainly be a valuable asset.

Additionally, this work emphasises the necessity of striking the appropriate balance between model complexity and practicality in implementation in a bio-economic modelling framework, and at the same time the need for generic and user-friendly tools. COUP complexity caused significant dependencies on bio-physical simulation expertise. This resulted in delays in the provision of inputs for FSSIM-REG and in the assessment of a limited number of agricultural activities and measures. Further, bio-economic modelling requires i) a considerable number of simulations per rotation, soil and technique, for a long-term sequence, and ii) easily obtainable outputs from bio-physical simulations. Clearly, there are very few models that are generic enough so as to accurately reproduce most plant and soil systems. Additionally, the majority of bio-physical models, including COUP, have not initially been intended for bio-economic modelling use and are thus subject to severe operational limitations regarding procedures to import the required parameters, use of rotations rather than crops as model objects, output extraction time, and format and time scale of the generated output. This comes at a significant cost regarding time requirements per simulation scenario, that may lead to simplifying assumptions regarding the number of agricultural activities considered.

Additionally, the lack of rules for the set-up of the bio-physical model misrepresents some key elements of farmers operations regarding the timing and quantities of applied fertilisers, which might have significant effects on leaching. Farmers make these decisions in relation to weather and crop growth. However, in COUP fertiliser applications are specified as fixed dates at the outset of the simulations. This could be avoided by the implementation of inherent rules built in the bio-physical model, as for example rules applying fertiliser according to the stage of crop development and/or requirements, or shifting application dates according to rainfall patterns. Additionally, a simple rule allowing the user to specify fertilisation doses and timing per crop, and then allowing these doses to be applied in a yearly sequence according to the corresponding crop across the long term simulation period, as opposed to specifying each individual fertiliser dose, would be advisable.

7.2.3 System Representation and Data Availability

A significant challenge in bio-economic modelling applications is the successful integration across systems and scales in the absence of a complete set of appropriate data. In this study, this was demonstrated by lack of sufficient information for separating the farms of the catchment from the farms of the broader area of the parishes, difficulties associated with estimating the soil distribution per soil type within farms and eventually farm types, and insufficiency of information for characterising farm types and agricultural activities in terms of their intensity levels in physical inputs and outputs. Further, established farm classification schemes disregard some aspects of importance, such as variables that successfully represent the essential inputs and outputs of agricultural production (Kostrowicki, 1977), differences in the proportions of resource endowments and size, yields, and technologies (Hazell & Norton, 1986) and criteria for assessing the environmental performance of farms (Andersen *et al.*, 2007). The source of the above limitations is threefold. Firstly, data on farms have been typically collected for administrative regions. Integrated analysis requires overlaying administrative and natural boundaries. This implies that perhaps an approach that respects natural boundaries and collects information on the natural characteristics of farms is more appropriate when considering that the farm should no longer be considered as a business unit that operates regardless of its surrounding environment. Secondly, strict confidentiality agreements exist for existing but not publicly available data. Thirdly, the economic efficiency of agricultural production and farms has for long been the centre of attention, and thus farm data are typically collected in economic as opposed to physical units. Current policies, and as a consequence research priorities, focus on multi-functionality and environmental efficiency of agriculture. For relevant policy questions and research endeavours to be meaningfully explored, the nature and focus of public statistics also need to move towards this direction.

Ideally, for drawing conclusions at an aggregate level, all potential farm types should have been simulated. However, the simulation of livestock activities has been hindered by significant delays regarding the development of the FSSIM-livestock feed-module, leaving no obvious alternative for simulating livestock within the time-scale of this project.

One would wish to simulate a significant number of rotations and fertiliser levels for each of the crops in a rotation, and additionally the interactions of inorganic fertilisation with tillage practices, irrigation, and manure applications. This was hindered by the severe time requirements imposed by the COUP model and the lack of a procedure allowing a large number of batch simulations in an automatic or semi-automatic manner. Considering only two scenarios of fertilisation assumes that farmers operate only within the application space defined by these two points, and imposes linearity between these extreme two points and any intermediate point. Nevertheless, a comparison of the BSFP figures (Annex VIII) and the figures used for the simulations (Table 5.2) provide no evidence that farmers apply fertiliser quantities that considerably diverge from the simulated ones.

A simultaneous exploration of the effects of agricultural and environmental policies on other pollutants, such as greenhouse gases, would also be possible within the employed framework. Indeed it would be desirable for, as Belhouchette *et al.* (2010) showed that a policy aimed at the resolution of one environmental problem may result in counter intuitive effects on others. Similar effects were also observed in some of the scenarios between nitrate and phosphorus losses, and thus a more detailed representation of phosphorus losses and subsequently a more informed representation of the potential of pollution swapping would have been advantageous.

In this study, nitrate leaching at the catchment level is essentially estimated through aggregation of leaching at individual fields. This does not capture the three-dimensional flow of nitrate and the effects of water transport at the catchment scale. Capturing these effects would require hydrological modelling, and this was considered to lie outside the scope of this thesis. Additionally, such an attempt would require detailed information about the location of farms which was not available.

7.2.4 Policy Scenarios and Measures

This thesis focuses on the use of economic instruments for the reduction of N diffuse pollution, mainly through measures relating to land use changes and fertiliser management on arable cropping systems. Therefore, a wide range of measures, such as those shown in Table 3.1 in relation to soil management, manure management, livestock management and farm infrastructure, have not been assessed. Specifically, i) livestock and manure measures (e.g. manure quotas, limit levels of organic manure on land, manure incorporation, sludge application, manure markets, reduce stocking rates, reduce grazing, animal feeding) would require a readily available alternative for simulating livestock systems in lack of the SEAMLESS-IF feed module component; ii) the majority of measures on farm infrastructure (e.g. hedgerows, buffer zones, wetlands) are best modelled by a spatially-explicit modelling framework; and iii) a number of other measures relating to soil management (e.g. cover crops, minimal cultivation systems, spring cultivation, ploughing obligations, split fertilisation) theoretically could have been simulated by COUP. However, this would require additional model parameterisation and testing, that was not feasible within the time-scale of this thesis.

Some of the above mentioned measures are specified as cross-compliance measures under the reformed CAP, and as a consequence the cross-compliance implications of the Reform have not been fully taken into account. Out of these measures the ones that could have been considered by the employed methodological framework relate to GAECs 1, 2 and 5, and SMR 4. GAEC 1 on post-harvest management of land and GAEC 2 on wind erosion, both require crop cover in cases where soil conditions after harvest allow. GAEC 5 requires maintenance of field drainage systems. Although COUP is one of the few models that allows modelling the quality of field drainage systems, this measure has not been taken into account due to uncertainties regarding the quality of the existing field drainage systems and ambiguous definition of drainage modelling within COUP. SMR 4 stipulates that farmers with land in NVZs follow the rules set out in the Action Programme for NVZs. In our scenario set-up, we are assuming that farmers were respecting the NVZ regulations even before these were enforced, i.e. in the baseyear scenario. Adding a third fertilisation level beyond the NVZ regulations would allow estimating the costs associated with this cross-compliance measure. Nevertheless, a comparison of recommended fertiliser levels and average fertiliser use in Scotland (Annex VIII) and in South East Scotland (DEFRA & SEERAD, 2004) shows that farmers were applying fertilisers around or below the recommended levels even before the regulation was put into place. Even though the Lunan Water Catchment is thought to be an intensive agricultural area, there was little evidence, from this data and lack of case-study specific data, supporting an assumption that farmers were applying higher fertiliser levels. Therefore, the simulation of such a measure would be based on *ad hoc* assumptions of fertiliser use and estimates of costs with potentially low validity.

7.3 Key Messages and Further Research

This thesis analysed the problem of nitrate water pollution from agricultural sources, with a focus on arable cropping systems. The impact of agricultural and water management policies on farmers' decision making and the resultant economic and nitrate pollution effects were investigated, using the Lunan Water catchment in Scotland as a case study. This was achieved with the use of a bio-economic modelling approach, which combines bio-physical and mathematical programming modelling. A number of scenarios were simulated including CAP scenarios, per unit taxes on nitrogen fertiliser inputs and nitrate leaching, per hectare nitrate leaching standards and nitrogen fertiliser quotas at the farm level, and subsidies and cross-compliance measures aiming at the reduction of fertiliser intensity.

The decoupling of subsidies under the CAP reform scenario resulted in minor changes regarding land use and subsequently economic and water quality indicators. This is due to the small changes in relative differences of premiums prior and after the Reform for the typically grown Scottish crops. The abolition of set-aside under the CAP Health Check scenario led to increases in farm incomes associated primarily with the substitution of set-aside by profitable winter cereal crops. Even though these changes resulted in increased fertiliser use, the results indicate that this does not necessarily imply increased nitrate leaching due to rotational effects associated to the nature of nitrate losses. The nitrate pollution control scenarios on subsidies and cross-compliance measures provided indications of how CAP instruments can be utilised to achieve water quality objectives.

An analysis of the relative cost-effectiveness of measures demonstrated that similar leaching reductions can be incentivised through a number of economic instruments. However, a central consideration is who should bear the costs of water protection, which is an issue to be determined not solely by cost-effectiveness criteria, but also by political and social sovereignty. Taxes impose considerable costs on farmers without resulting in significant nitrate leaching reductions. On the other hand, subsidies impose the costs of environmental protection on the rest of the society, while cross-compliance can deliver water quality improvements at a lower cost compared to taxes. Cross-compliance instruments can either be used for the enforcement of measures at the farm level, such as nitrogen quotas, or measures at the field level, such as crop and soil specific reductions in fertiliser inputs. Even though farm level measures appear to be more cost-effective, field level measures targeting fertiliser levels in relation to crops and soils might be as efficient due to i) the similarity of the cost-effectiveness between the two types of measures; ii) the ability of farmers' to adapt in a way as efficient as predicted by an optimisation model; iii) uncertainties related to the level of nitrate leaching reductions achieved by N use reductions at the farm level; and iv) potential negative supply distortions related to high N input crops. However, the results indicate that considerable leaching reductions through changes in inputs can only be achieved at a significant cost. Thus, farm infrastructure measures, such as buffer strips, and training and education of farmers in relation to the processes that trigger nitrate pollution, could further assist in achieving water quality objectives.

The bio-economic modelling methodology used provided a consistent framework for water policy assessment in the agricultural sector, as it allowed integrating agronomic, environmental and economic information in a single framework. This was achieved at three spatial scales: the field scale capturing agronomic and environmental diversity, the farm scale that offers a better representation of farmers' actual behaviour, and the catchment scale that allows consideration of the aggregate policy impacts. A key advantage of the methodology is that it enables the simulation of potential farmers' reactions to water and agricultural policy change, and the associated water quality and economic impacts of these reactions. It therefore allows the exploration of the combined costs and effectiveness of measures, while considering likely distributional effects on different farm-types.

The thesis also demonstrated the complexity of the issues involved, and highlighted the challenges to be overcome by future research. These are related to the lack of truly generic ready-to-use bio-physical simulation models, operational limitations imposed by insufficient procedures for model communication, and limitations of publicly available data. Additionally, livestock production systems, and a more extended system representation through the inclusion of a greater number of rotations, fertiliser levels, and the interactions of inorganic fertilisation with tillage practices, irrigation, and manure applications, would be desirable. This would allow exploring a wider range of measures such as measures related to soil, manure, livestock, and irrigation management. A simultaneous exploration of the effects of agricultural and environmental policies on other pollutants, such as greenhouse gases and a more sophisticated representation of phosphorus losses, would also be interesting to explore within the employed framework.

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Annexes

Annex I - Report on Review of Calibration Approaches

The contribution of the author of the thesis in this report was provision of editing and general comments.

Model Calibration: a Review of Approaches and the Description of the FSSIM-REG Calibration Procedure

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1.1 Calibration and Validation in Optimization Models

An important part of the modeling process is the evaluation of an acquired model. *How do we know if a mathematical model describes the system well?* This is not an easy question to answer. Usually the engineer has a set of measurements from the system which are used in creating the model. Then, if the model was built well, it will adequately show the relations between system variables for the available observed information. The question then becomes: *How do we know that the observed data are a representative set of possible values?* Does the model describe well the properties of the system inside the observed range of data? Does the model describe well events outside the observed range of information?

In mathematical programming, a common methodology consists of splitting model evaluation into two parts: calibration and validation. Calibration is a process of adjusting model parameters in order to reproduce the observed reality of a base period. It can be understood as a way to find the best parameters that characterize a given model and as a method to maximize the similarity between the output of the model and the observed data (Santillana, 2005). According to Howitt (2005), the calibration process is one of using a hypothesized function and data on input and output levels in the base year to derive specific model parameter values that "close" the model. By closing the model, we mean that the calibration parameters lead to the objective function being optimized for the base year conditions at the observed base year values. The calibration process can be done against a base year or an average over several years.

The calibration process is necessary, but insufficient, to ensure the robustness of a model, that is why models should also be validated. Validation consists of testing calibrated models with respect to an additional set of input data, preferably under different conditions or policies, to further examine the validity of the model (Thomann *et al.*, 1982). It checks whether the calibrated model, when applied for an *ex-post* analysis, is able to track, as closely as possible, a historical situation. According to Hazell and Norton (1986), validation is a process that leads to (i) numerical report of the model's fidelity to the historical data set; (ii) confirmation that the calibrated model is applicable over the limited range of conditions defined by the calibration and validation data sets; (iii) improvements of the model as a consequence of imperfect calibration; (iv) a qualitative judgement on how reliable the model is for its stated purposes; and (v) a conclusion for the kinds of uses that it should not be used for. Validation does not mean validating a model as "generally useful" or even as "generally useful over an extensive range of conditions for the area of interest". It is important that the validation exercise, and hence the collection of calibration and validation data, focus on the range of conditions over which predictions are desired. Also, the data should be such that the calibration parameters are fully independent from the validation data (Himesh, 2000).

Data uncertainties, typographical errors, or mismatched structural assumptions can cause models to malfunction. Moreover, the larger a model becomes, the greater are the probabilities to introduce errors. Therefore, model calibration and validation are issues that require special attention in order to substantially reduce such errors and carry out agricultural policy analysis.

This report will focus on the calibration methodology for farm models. Model validation requires a large amount of data, which are not easily available. However, in the future it may be necessary to come back to the validation issue. The following section exposes different methods of calibrating the supply side of optimization models, updated on recent methodological developments and discussing some recent applications. A short overview and critique of each of these methods is also developed in order to facilitate the choice of the appropriate approach for our work. After this, the principal specificities required for the calibration methodology of FSSIM will be briefly exposed.

1.2 Review of Calibration Methodologies in Optimization Models

The idea of evaluating optimization models is not new. The path of development of this idea will be clearly documented in this section, by firstly analysing the linear programming (LP) calibration problems, later moving to the explanation of approaches that have been used to substantially reduce these problems (approximate calibration) and finishing with a review of the methods that have been developed to calibrate exactly optimisation models (exact calibration).

1.2.1 The calibration problem in linear programming models

Traditional optimization models, such as LP models, are often based on *normative* assumptions, aiming at identifying the "best" production combination under the hypothesis that the initial situation is not binding in terms of production choices (De Wit, 1992). This assumption induces a wide divergence between base period model outcomes and observed production patterns, and hence is unacceptable. This is the main reason why the *normative* LP approach is being replaced by *positive* type models where the main objective is not to reach the first-order optimality conditions, which is inaccessible, but to precisely reproduce the observed production situation. This way farmers' behaviour can be simulated under varying parameters expressing the agricultural policy intervention. However, in order to reproduce the observed situation, an LP model has to be calibrated.

LP relies on data based on observed average conditions (e.g., average production costs, yields, and prices), which are expressed as fixed coefficients. As a result, LP models tend to select crops with highest average returns until resources (land, water, and capital) are exhausted. The predicted crop mix is therefore less diverse than observed in reality, and overspecialisation of the solution occurs. The most widespread reason for overspecialisation is that the basis matrix of valid empirical constraints has a rank less than the number of observed base year activities. Since the number of nonzero activities in an LP framework is upper bounded by the number of resource constraints, overspecialisation occurs by definition (Heckelei, 2002). In cases where the modeller is fortunate enough to have empirical data to specify, *a priori*, a realistic constraint set that reproduces the optimal base year solution, additional model calibration may be redundant.. But even if the model has enough realistic constraints that allow avoiding overspecialisation (this is usually the case for FSSIM), there are always other sources of errors that may lead to solutions far from the observed activities in the base year.

Two broad approaches have been developed for calibrating optimization models: approximate and exact calibration methods. Based on some of the theoretical and methodological aspects of mathematical programming, these approaches try to make a model more able to represent the production choices made by farmers, and to provide greater capacity to analyse the problems of agricultural policy.

1.2.2 The approximate calibration approaches

The common point between the approaches known as "approximate calibration approaches" is that they do not seek to calibrate exactly optimisation models, but rather to fit model's predictions to observed data accepting a residual deviation between simulation and reality. They include all traditional calibration methods, which require more complicated constraint structures to reproduce the observed cropping pattern. Among these methods, we have those based on the use of rotational constraints or step functions over multiple activities to curtail the overspecialization (Meister et al., 1978), those imposing upper and lower bounds on certain production activities as constraints in a recursive procedure (Day, 1961), etc. The principal limitation of these methods is that the used constraints determine the optimal solution not only for the base year, for which they are appropriate, but they also affect policy simulation runs that attempt to predict the outcome of changed prices, costs or resource availability. The solution of the model under policy runs is therefore significantly restricted by the base year solution constraints.

This approach includes also all the methods which are based on the addition of risk and uncertainty to the linear programming model such as MOTAD, Target MOTAD, Mean-Variance, Safety first, etc (Hazell and Norton, 1986). Most of these risk methods presume that a non-correspondence between model results and observed situation is related to one of these two factors: (i) omission of some important element of the cost structure, such as specialized management skills in growing high-value crops; (ii) inadequate specification of the risk associated with different activities and farmers' risk aversion (*ibid*). To capture this last factor adequately the objective function should include the risk associated cost, as well as represent behaviour related to risk-aversion. Some of the proposed risk approaches treat risk in the objective function (e.g. MOTAD, Mean-standard deviation, Mean-Variance, Safety first) and others in the constraint set (e.g. Discrete stochastic programming, Chance constrained programming).

A frequently used risk approach is the mean-standard deviation one, which assumes that farmer's preferences among alternatives farm plans [$U = E\text{-}\phi\sigma$] are based on expected income [E] and its standard deviation [σ] multiplied by a risk aversion parameter [ϕ]. For the estimation of the risk aversion parameter, the most common method is to parameterize the model for different values of the parameter, and then to choose the value that gives the best fit between the model's predicted crop pattern and the actual values observed in some base period (i.e. this parameter is used for calibrating the model). These models take into account risk and uncertainty associated to income variability, attributed to yield variability due to climatic conditions, and/or prices and subsidies variability. The risks in resources supplies, for example, seasonal labour, water for irrigation, and forage supplies for livestock feed, are generally neglected, with the exception of discrete stochastic programming and chance constrained programming. Such methods have been applied to different agricultural systems, under various agro-ecological conditions, and at different levels of analysis (i.e. farm, region, sector, country) (Boussard, 1988; Boussemart *et al.*, 1996).

Another range of methods that can be classified in this broad approach are multi-criteria approaches, such as the weighted goal programming (WGP) and the Min-Max goal programming (MINMAX GL). These two approaches minimize the deviation of each objective from the observed value of the same objective. The unwanted deviations (either positive or negative or both) are weighted, so as to indicate the importance attached to each objective. To allow for summation, the deviations are normalised by dividing them by the expressed range of their respective objectives (Charnes *et al.*, 1955; Simon, 1979; Rehman & Romero, 1993; Tamiz *et al.*, 1998; Ballestero & Romero, 1998). The steps in applying the methodology can be described as follows: (i) determine a tentative set of objectives aimed for by the farmers; (ii) obtain a pay-off matrix in which element a_{ij} represents the value achieved by the *ith* objective when the *jth* objective is optimized; (iii) calculate the weight of each objective that minimizes the distance from the observed value of the same objective; (iv) normalize the previous weights dividing by the range of their respective objectives (in the pay-off matrix, the best and worst values); (v) compose the additive utility function using the normalized weights.

The mathematical structure of a WGP model is given by:

$$\min Z = \mathbf{w1}_i \frac{\mathbf{n}_i}{\mathbf{t}_i} + \mathbf{w2}_i \frac{\mathbf{p}_i}{\mathbf{t}_i}$$

$$\text{S.t.} \quad \mathbf{f}_i(\mathbf{x}) + \mathbf{n}_i - \mathbf{p}_i = \mathbf{t}_i$$

$$\mathbf{x} \geq \mathbf{0}; \mathbf{n} \geq \mathbf{0}; \mathbf{p} \geq \mathbf{0};$$

Where ***w1*** and ***w2*** measure the relative importance that the decision-maker attaches to each goal; $\mathbf{f}_i(\mathbf{x})$ represents the mathematical expression of the *ith* attribute; $\boldsymbol{t_i}$ shows its target level; $\boldsymbol{n_i}$ and $\boldsymbol{p_i}$ are negative and positive deviations, respectively.

The mathematical structure of a MinMax GP model is given by:

$$\min \quad \mathbf{d}$$

$$\text{S.t.} \quad `_i \frac{\mathbf{n}_i}{\mathbf{t}_i} + \%\varphi_i \frac{\mathbf{p}_i}{\mathbf{t}_i} \leq \mathbf{d}$$

$$\mathbf{f}_i(\mathbf{x}) + \mathbf{n}_i - \mathbf{p}_i = \mathbf{t}_i$$

$$\mathbf{x} \geq \mathbf{0}; \mathbf{n} \geq \mathbf{0}; \mathbf{p} \geq \mathbf{0};$$

Where **d** is the maximum deviation; $\mathbf{f}_i(\mathbf{x})$ represents the mathematical expression of the *ith* attribute; $\boldsymbol{t_i}$ shows its target level; $\boldsymbol{\lambda_i}$ and $\boldsymbol{\beta_i}$ coefficients play the following role: when $\boldsymbol{n_i}$ is the unwanted deviational variable then β_i

takes the value zero and λ_i measures the relative importance attached by the decision maker to the *ith* goal. In the opposite case, that is, when $\boldsymbol{p_i}$ is the unwanted deviational variable then λ_i takes the value zero and β_i is the preferential weight.

As discussed above, the common point between all these calibration approximate approaches is that they reduce the calibration problem, but they cannot calibrate the model exactly and thus substantial calibration problems remain in many cases. Furthermore, even if all observed production activities are nonzero in the optimal solution, deviations in optimal levels from observed levels will occur. Another problem that appears in this case relates to defining how credible a model is and determining the level of confidence that can be placed on model predictions. There is no consensus on the statistic measure to be used in evaluating the fit of predictions, but in most cases simple measures, such as the mean absolute deviation[1] (MAD) or the percentage absolute deviation[2] (PAD), are used. The Theil index[3] and the Nash coefficient[4] have also been suggested. However, clearly and objectively defined

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[1] Mean absolute deviation:

$$d = \frac{1}{n}\left|\sum_i (\ddot{X}_i - X_i)\right|^2$$

Where $\ddot{X}_i$ is the observed value of the variable *i*, X_i is the simulated value (the model prediction) and *n* is the number of samples..

[2]
$$PAD\ (\%) = \frac{\sum_{i=1}^{n} |\ddot{X}_i - X_i|}{\sum_{i=1}^{n} \ddot{X}_i} . 100$$

Where $\ddot{X}_i$ is the observed value of the variable *i* and X_i is the simulated value (the model prediction). The best calibration is reached when PAD is close to 0.

[3] The Theil index:

$$\frac{\left[\frac{1}{n}\sum_i (\ddot{X}_i - X_i)\right]^{1/2}}{\left(\left[\frac{1}{n}\sum_i (\ddot{X}_i)^2\right]^{1/2} + \left[\frac{1}{n}\sum_i (X_i)^2\right]^{1/2}\right)}$$

Where $\ddot{X}_i$ is the observed value of the variable *i*, X_i is the simulated value and *n* is the number of samples.

[4] The Nash coefficient (widely used in hydrology):

threshold values of the different measures that clearly determine acceptance or rejection of a model do not seem to be available in the literature. For example, Hazell and Norton (1986) suggest that for sector models a PAD for production and acreage below 10% is good, equal to 5% is exceptional and more than 15% indicates that the model may need improvement before it can be used. These thresholds are always subjective. Hazell and Norton (1986) suggest also six tests to improve model calibration. First, a capacity test checks whether the model constraint set allows the base year production. Second, a marginal cost test ensures that the marginal costs of production, including the implicit opportunity costs of fixed inputs, are equal to the output price. Third, they suggest a comparison of the dual value on land with actual rental values. Three additional comparisons of input use, production level, and product price are also advocated (Howitt, 2005).

Another serious disadvantage of approximate calibration approaches is the *ad hoc* calibration process. The calibration procedure is generally manual and if a model is manually calibrated, the objective may be stated qualitatively: fits may be obtained by eye and intuition then play a part in choosing appropriate calibrated parameter sets.

Alternatively to the approximate calibration approaches, another range of approaches has been proposed in the last few years, in order to exactly calibrate optimization models making use of information on the observed behaviour of economic agents. A brief overview of these approaches and their extensions will be developed in the following sections.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(X_i - \ddot{X}_i)^2}{\sum_{i=1}^{n}(X_i - \overline{X}\ )^2}$$

Where $\ddot{X}_i$ is the observed value of the variable *i*, Xi is the simulated value, $\overline{X}$ is the mean of the measured values and n is the number of samples.

1.2.3 The exact calibration approaches

An alternative solution for model calibration, based on a new methodological approach called "Positive Mathematical Programming" (PMP), was proposed in the late 1980's by Richard Howitt (1995). . The formulation of the PMP standard approach was first published by Howitt (1995), but the technique had also been previously employed by a series of pragmatic, policy oriented modelling exercises - following Howitt yet non published proposal in a well recognized journal - (e.g. House, 1987; Kasnakoglou & Bauer, 1988; Horner *et al.*, 1992). The term "positive" that qualifies this method implies that, like in econometrics, the parameters of the non-linear objective function are derived from observations of economic behaviour that is assumed to be rational, given all the observed and non-observed conditions that generate the observed activity levels (De Frahan, 2005). This approach stipulates that a divergence between model's predictions and observed reality of a base period means that both some technical constraints and cost (or yield) specifications were not taken into account. Consequently, they need to be included in the objective function via a nonlinear cost (or production) function (Gohin & Chantreuil, 1999). The principal advantages of PMP, compared to *ad hoc* calibration procedures, are (i) automatic and exact calibration of optimization models based on information on the observed behaviour of economics agents, (ii) lower data requirements, and (iii) continuous changes in exogenous variables (Röhn and Dabbert, 2003).

According to Howitt (2005), two conditions should be fulfilled in order to exactly calibrate optimization models: the nonlinear and the dimension calibration conditions.

1) *The nonlinear calibration condition:* if the number of observed nonzero crop activities (k) exceeds the number of binding constraints (m), then the profit function is a nonlinear function of land for most crop activities, and the observed crop allocations are a result of a mix of unconstrained and constrained optima. The equilibrium conditions for this case are satisfied if some of, or all, the cropping activities have decreasing returns to land as the crop acreage is increased. The most common reasons for decreasing returns per acre are declining yields due to heterogeneous land quality, risk aversion,

or increasing costs due to restricted management or machinery capacity (Howitt, 2005). This condition is necessary but not sufficient, because many models have some nonlinear terms in the objective function reflecting endogenous price formations or risk specifications, but still they do not result in exact model calibration.

2) *The calibration dimension condition:* The number of calibration terms in the objective function must be equal to, or greater than, the number of independent variables to be calibrated. The ability to adjust some nonlinear parameters in the objective function, such as the typically used risk aversion coefficient, can improve model calibration. However, if there are insufficient independent nonlinear terms the model will be unable to calibrate exactly.

The PMP approach involves three phases: calibration, estimation and simulation.

1) *The calibration phase:* it consists of writing a usual LP model, but also adding to the set of limiting resource constraints a set of calibration constraints that bind the activities to the observed levels of the base year period. The sole purpose of this phase is to obtain an accurate and consistent measure of the vector of dual values associated with the calibration constraints. As pointed by Heckelei and Wolff (2003), this phase can be integrated in the estimation phase by means of Lagrangean multipliers. Paris and Howitt (1998) interpret this vector as capturing any type of model mis-specification, data errors, risk behaviour and price expectations. In other words, as a revealed error term.

   $$\max Z = \mathbf{p}'\mathbf{x} - \mathbf{c}'\mathbf{x} \qquad \text{Subject to } \mathbf{A}\mathbf{x} \leq \mathbf{b}\,[\lambda], \quad \mathbf{x} \leq \mathbf{x}_0 + \varepsilon\,[\rho], \quad \mathbf{x} \geq \mathbf{0} \qquad (1)$$

   Where **Z** is the objective function value; **p, x** and **c** are (n x 1) vectors of product prices, non-negative activity levels, and accounting costs per unit of activity, respectively; **A** represents an (m x n) matrix of coefficients of resource constraints; **b** and **λ** are (m x 1) vectors of resource availability and their corresponding shadow prices; $\mathbf{x_o}$ is a non-negative (n x 1) vector of observed activity levels; **ε** is an (n x 1) vector of small positive numbers for preventing linear dependency between the structural and the calibration constraints; $\boldsymbol{\rho}$ is an (n x 1) vector of duals associated with the calibration constraints.

To account for greater competitiveness among closed competitive activities that can be viewed as variant activities from a generic activity, Röhm and Dabbert (2003) add less restrictive calibration constraints for these variant activities compared to the calibration constraints for the generic activities.

2) *The estimation phase:* it consists of employing the dual values $\boldsymbol{\rho}$ delivered by the first phase to specify additional non-linear terms in the objective function, so as to allow reproducing the observed activity levels without calibration constraints. These terms mostly refer to increasing marginal costs (Arfini & Paris, 2000), and/or decreasing marginal yields (Howitt, 1995; Barkaoui & Butault, 1998), or a *neutral* form[5] (Röhm & Dabbert, 2003). Often the parameters of a variable cost function $\mathbf{C^v(x_0)}$ are calibrated in a way that the *variable marginal* cost $\mathbf{MC^v}$ of the activities is equal to the sum of the known cost $\mathbf{c}$ and the *non-specified* marginal cost $\boldsymbol{\rho}$**.** When a quadratic functional form is used [6], the following condition for calibration is implied:

$$\mathbf{MC}^{v} = \frac{\partial\, \mathbf{C}^{v}(\mathbf{x})}{\partial\, \mathbf{x}} = \mathbf{d} + \mathbf{Qx}_{0} = \mathbf{c} + - \qquad (2)$$

Where **d** is an (n x 1) vector of parameters of the cost function and **Q** is an (n x n) symmetric, positive (semi-) matrix.

To solve this system of n equations for [N+(N+1)/2] parameters, the literature suggests many solutions, which include simple *ad hoc* procedures with some parameters set a priori (Howitt, 1995), the use of supply elasticities (Hemling *et al.*, 2001), the direct derivation of the unknown parameters from the Kuhn-

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[5] For neutral form: $= \rho_i * X_i * (1 - \frac{X_i}{\ddot{X}_i})$ where ρ_i is the dual value associated with the calibration constraint of activity i, $\ddot{X}_i$ is the observed level of activity *i*, and X_i is the simulated activity level.

[6] Other functional forms are possible. The generalized Leontief and the weighted-entropy variable cost function (Paris and Howitt, 1998) and the constant elasticity of substitution (CES) production function (Howitt, 1995) in addition to the constant elasticity of transformation production function (Graindorge *et al.*, 2001) have also been used. A von Neumann-Morgenstern expected utility approach has been used to account for a constant absolute risk aversion to price volatility (Paris, 1997).

Tucker conditions (Judez et al., 2001), and the employment of the maximum entropy criterion (Paris & Howitt, 1998).

3) *The simulation phase*: it consists of adding the estimated non-linear terms (cost (production) function) to the LP objective function in order to simulate farmers' behaviour when some conditions change, such as prices, yields, policy, etc.

During the last decade, PMP has become a popular method for farm, regional and sector models. It has been established as a widely used approach for the specification of programming models designed for the analysis of agricultural and environmental policies, and it has generated numerous applications and extensions. Some noteworthy works using PMP include the models of the University of Bonn (Heckelei & Britz, 2000), INRA-Nancy (Barkaoui & Butault, 1998), the University of Madrid (Judez et al., 2001), the FAL model (Kleinhanss, 2002) and the CAPSET model (Paris et al., 2002). Some other applications are shown in Howitt and Gardner (1986), House (1987), Kasnakoglu and Bauer (1988), Arfini and Paris (1995), and Helming *et al.* (2001).

Also, several expanded frameworks of the PMP methodology have been developed in order to overcome some of the critics against the original version. Some of these include: (i) the new approaches developed for the estimation of the parameters of the non-linear functions (Hemling *et al.*, 2001; Paris & Howitt, 1998; Judez *et al.*, 2001); (ii) approaches used to solve the problem of the exclusion of crops that are not present in the base year (self-selection problem)[7] (Paris and Arfini, 2000); (iii) approaches dealing with the problems of zero marginal product (cost) for one of the calibrating constraints (Gohin & Chantreuil, 1999; Paris & Howitt, 2001; Röhm & Dabbert, 2003); (iv) approaches to overcome the PMP shortcoming regarding the inclusion of greater competitiveness among close competitive activities whose requirements for limiting resources are more similar compared to other activities (Röhm & Dabbert, 2003);(v) approaches for solving the issues of fixed coefficient

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[7] They add to the *F* PMP models a supplementary PMP model for the whole farm sample and calibrate a frontier cost function for all the activities included in the whole farm sample.

technology, and also the use of data based on many observations (Paris and Howitt, 2001). To deal with the last two problems, Paris and Howitt (2001) suggested a new PMP version that takes on the structure of a Symmetric Positive Equilibrium Problem (SPEP). The advantage of the approach is that it removes the last vestige of normative programming represented by the need for an explicit optimization. This new version appears substantially different from the original specification, but it follows the same inspiration and goals.

In spite of the attractiveness and popularity of PMP, it is associated with several important problems:

(i) Any version of a PMP method will always exactly calibrate the model to the observed situation, but under different scenarios model behaviour may be different and not in line with theoretical expectations (Röhm and Dabbert, 2003);

(ii) With only one set of observations it is possible to construct an infinite number of non-linear curves that "calibrate" the model, and hence any economic interpretation placed on these functions becomes unjustified (Yates and Rehman, 2002);

(iii) The PMP approach can be applied only if the microeconomic optimum conditions can be assumed to be a reasonable approximation of reality. That is, this approach is not suitable if there are, for example, binding constraints in the baseline situation that limit the possibility of the farmers receiving payments (i.e. Mixed Integer Linear Programming (MILP) models), as it is not easy to find the dual values associated with the calibration constraints;

(iv) The approach cannot take explicitly into account technology, and it treats the same crop grown under two technologies as two separate crops. This may lead to unsatisfying results (Röhm and Dabbert, 2003);

(v) The PMP approach cannot resolve the self-selection problem when it is applied at the farm level (e.g. alternative activities which are not observed in the base year can not be captured by the PMP approach).

Alternatively to PMP, another less popular approach to calibrate programming models has been proposed by McCarl (1982) and Önal and McCarl (1989; 1991). In effect, this approach was initially developed in order to correct aggregation errors, and thus it is very common in regional and sector models. However, it can be also used to calibrate programming models making use of the Dantzig-Wolfe (1961) decomposition.. According to this decomposition, any feasible solution of the production possibility set, i.e., the bounded set defined by the resource constraints, can be expressed as a convex combination of the extreme points. Like PMP, this aggregation procedure also is positive in the sense that its empirical applications are based on the observed behaviour of economic agents (De Frahan, 2005).

By exploiting the extreme point representation of a linear system, the problem:

$$\max Z = \mathbf{p'x - c'x} \qquad \text{Subject:to } \mathbf{Ax \leq b}\,[\,] \;;\quad \mathbf{x \geq 0} \tag{3}$$

can be equivalently stated as:

$$\max Z = p'x - c'x \qquad \text{Subject to } x - \sum \ddot{x}_i \varphi_i \;;\; \sum_i \varphi_i = 1 \;;\; x \geq 0 \tag{4}$$

Where the (w x 1) vector contains the convex combination weights **φi** and the (n x w) matrix $\ddot{X}$ contains the extreme points of the linear system of the initial model constraints.

To sum up, Table 1 shows a comparative summary of the characteristics of approximate and exact calibration approaches.

Table 1. Comparison between exact and approximate calibration approaches

The Approximate Calibration Approaches	The Exact Calibration Approaches: PMP
- Approximate model calibration (allows a residual deviation between observed and simulated behaviour). - Generally manual calibration procedure. - Transparent and does not include any doubtful terms, parameters or constraints. - Difficult to evaluate model credibility. The level of confidence that can be placed on model predictions and any threshold values of acceptable deviations of model results from observations remain subjective.	- Exact model calibration. - Automatic calibration procedure. - Lower data requirements. - Continuous changes in model results in response to continuous changes in exogenous variables. - An excellent intermediary between (positive) econometric approaches and traditional (normative) optimization models. - The introduced PMP term locks the model's result to the observed data for a base period. Even if this term has often a straightforward economic and agronomic interpretation, it is often criticized by economists because it supports the activities observed in the base year to the detriment of those which have zero level, even in policy scenarios. - Any PMP version will always exactly calibrate the model to the baseline situation, but different methods will produce different solutions in simulation runs. It is impossible to say which version is globally the best.

1.3 Calibration Methodology for FSSIM-REG

1.3.1 Criteria for designing the calibration methodology

This part presents certain criteria that need to be taken into account for the selection of the calibration methodology for FSSIM. These criteria will also assist in the definition of the assumptions of the calibration process.

The main desired specificities of the calibration methodology for FSSIM are the following:

- It should be easily applicable to all farm types and regions, transparent and calibrate the model automatically or semi-automatically (i.e. at least parts of the procedure are automatic).
- It can be either exact or approximate, even if exact calibration seems more desirable. The priority is not to build models which are simply able to reproduce exactly the observed data, but rather develop models that describe the system adequately and produce more realistic results both in the calibration and the simulation phase. What is important is that the model describes the system in more detail and produces, in the calibration phase, results that are not very different to observed data. However, the challenge with an approximate calibration approach is the selection of a statistical method for the evaluation of the fit and of criteria for acceptance or rejection of the model.
- It should be extremely transparent[8] and it should not add parameters, terms or constraints binding the model, which have no clearly defined economic or technological justification. Each additional parameter, term or constraint, which on the one hand is able to calibrate the model but one the other hand rigidly restricts model results under policy runs (simulation phase), should be avoided.
- It should satisfy technical requirements and take into account easily the substitution between production activities, as in FSSIM-REG each crop (animal) will be grown under a large number of production techniques each of them representing a different production activity.

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[8] When we write "transparent" it is opposed to "black box", it means avoiding terms that are just residuals or accepting residuals if they are small.

- It should calibrate the model for a number of key variables, such as rotation and crop levels, production levels, and income, rather than focusing on only one variable such as activity levels.
- It's preferable that the calibration procedure can be applied to both farm and regional models, because FSSIM-REG can be applied at farm and aggregate (village or regional) levels.

1.3.2 Methods for calibrating FSSIM-REG

FSSIM uses the calibration approaches of risk and/or PMP. As discussed, the first approach calibrates the model approximately and the latter calibrates it exactly using information on observed farmers' behaviour. The user can select between three different PMP variants, that are implemented in FSSIM, according to data availability: (i) the standard PMP approach (Howitt, 1995), (ii) the Rhöm and Dabbert's PMP approach (Röhm and Dabbert, 2003) and the (iii) Heckelei' s PMP approach (PD 3.3.2) and the quasi-linear PMP approach (developed in 1.3.2.5).

1.3.2.1 The risk approach

FSSIM uses the mean-standard deviation approach, as described in section 1.2.2. for calibrating the model with the risk approach. The risk aversion coefficient is estimated by parameterizing the model for different values of the coefficient and then choosing the value that gives the best fit between the model's predicted crop allocation and the observed values. The difference between observed and predicted values is assessed statistically by the measure of PAD. For judging model quality, we have adopted Hazell and Norton's suggestion, i.e a PAD for production and acreage below 10% is good, equal to 5% is exceptional and more than 15% indicates that the model may need improvement before it can be used.

1.3.2.2 The standard PMP approach

The standard PMP approach has been extensively described, and its limitations thoroughly discussed, in section 1.2.3. Due to these limitations FSSIM also uses two more PMP variants which overcome some of these limitations, namely the Rhöm and Dabbert's PMP approach (2003) and the Heckelei's PMP approach.

1.3.2.3 The Röhm and Dabbert's PMP approach

As explained above, the Röhm and Dabbert (2003) approach was developed to solve the problem of considering the same activity grown under different variants (e.g. different agro-managements) as two separate activities. To handle this problem, they add in the first step of PMP a set of additional calibration constraints which restrict the level of each variant activity to its observed level. In other words, they divide the slope of the cost function of each activity into two parts: one part depends on the different variants of a certain activity and the other part depends on the activity.

$$MaxZ = p^{'}x - c^{'}x, S.t. Ax \leq b[\lambda] x_{C} \leq x_{C}^{0} + \varepsilon_{1}[\rho_{1}] x_{C,T} \leq x_{C,T}^{0} + \varepsilon_{2}[\rho_{2}] x \geq 0 \qquad (5)$$

Where, **C** denotes the set of crops and **T** the set of management type. The first calibration constraint is related to crop specified by management type and the second one is related only to crop. As in the PMP standard approach, the dual values **ρ1** and **ρ2** are used to estimate the linear and the non-linear PMP terms. The application of this approach for FSSIM requires data availability on the observed crop levels as well as the observed level per crop, soil type and management type.

1.3.2.4 The Heckelei's PMP approach

The Heckelei's PMP approach was developed to handle the problems of zero-marginal cost for one of the calibrating constraints and the unequal treatment of the marginal and preferable activities. Because the differential marginal costs of the marginal activities captured by the dual vector **ρ** are zero, the actual marginal costs of supplying these activities are independent of their levels. The calibrated marginal costs are equal to average costs and marginal profits are equal to average profits. At the same time, the marginal costs of supplying the preferable activities are not under the average cost approach of calibration. Gohin and Chantreuil (1999) show that an exogenous shock on a preferable activity would uniquely modify the levels of this activity and the levels of the marginal activities, but not those of the other preferable activities.

One *ad hoc* solution for obtaining an increasing marginal cost function for these marginal activities consists of retrieving some share of one limiting resource dual value λ and adding it to the calibration dual vector **ρ** to obtain a modified calibration dual vector **ρ_M** (Rohm & Dabbert, 2003). A more radical solution skips the first step of PMP altogether. The solution proposed by Heckelei is based on the use of the land rental values to estimate the non-linear cost term of marginal activities. It adds the values of rented land and a set of calibration constraints in the first step of PMP (PD 3.3.2).

$$MaxZ = p^{'}x - c^{'}x - gl, S.t. Ax \le b[\lambda], x \le l, x \le x^{0} + \varepsilon_{1}[\rho_{1}], x \ge x^{0} - \varepsilon_{2}[\rho_{2}], x \ge 0 \qquad (6)$$

Where, **g** denotes the average gross margin and **l** the rented land in ha. As in the PMP standard approach, the dual values **ρ1** and **ρ2** are used to estimate the linear and the non-linear PMP terms.

1.3.2.5 The quasi-linear PMP approach

The quasi-linear PMP approach (new approach that will be tested in BECRA project) seems appropriate for bio-economic models as FSSIM-REG, where a single product is produced by a number of different activities. For example, assume that in a specific region wheat can be produced with four different management techniques (e.g. extensive rainfed, intensive rainfed, fully irrigated, complementary irrigated) and on three soil types, thus wheat can be the product of up to 12 activities. If wheat is treated as a product, the usual representation of increasing average costs with increasing produced quantity, and also increasing marginal costs, can be applied. In this case the assumption of increasing marginal costs, inherent in all PMP variants, is consistent. However, if an activities' perspective is adopted[9], there is no logical justification for assuming increasing marginal costs per activity, as average and marginal costs should be equal and constant for any activity level. For example, the costs of producing a unit of wheat on a certain soil and weather with a certain management should be the same regardless of the quantity produced. The assumption of increasing costs is justified by resources heterogeneity and varying management practices. However, in an activity based model as FSSIM-REG, these factors are explicitly accounted for, since the definition of an activity encompasses the soil and

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[9] This means that wheat produced on a certain soil and weather and with a certain management is seen as one production activity. Following from the previous example, wheat would be represented by up to 12 activities.

management dimensions. Nevertheless, PMP can be a useful procedure for the estimation of "revealed" costs, solving problems of reasonably low data errors or insufficient constraint specification due to lack of full information.

Given the above considerations, the quasi-linear approach seems an attractive alternative. The approach consists of calibrating the model using a high weight for the linear part of the PMP term and a low weight to the non-linear one; hence the name "quasi-linear" PMP approach. This approach bares some similarity to the Heckelei's approach in the sense that the PMP term is specified by a linear and a non linear term. An important advantage of this procedure is that it can be applied in a consistent way to alternative activities that are not present in the base year period or to marginal activities without having to use *ad hoc* criteria for the specification of the non-linear parts of the PMP term. A practical disadvantage is that it can only be applied if sufficient technical information is available for the definition of a relatively high number of activities per product.

The quasi-linear PMP approach will be tested in BECRA. Also, depending on data availability the different PMP approaches can be tested and compared in an ex-post validation exercise.

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Annex II - Report on Data Management and Integration Procedures

The contribution of K. Louhichi and G. Flichman in this report was provision of general comments.

A Data Management Facility for FSSIM-REG

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1 Introduction

Databases and data integration procedures are increasingly important in Mathematical Programming Modelling (MPM) applications, especially in the case of generic models which have been designed to assess numerous scenarios. The manual introduction of data either directly in the model or in text files is particularly error prone, difficult, and user hostile, and therefore infeasible for large models or multiple scenario simulations. FSSIM-MP, created under the project SEAMLESS[1], has been developed as a generic model, aiming at increased model re-usability and applications of different case studies and scenarios. This is also the case for FSSIM-REG, the extended version of FSSIM-MP developed for BECRA, which includes as well the national, regional, and farm type dimensions and allows interaction between farms when these do not work as completely independent units. For the use of FSIM-REG, and FSSIM-MP[2] as a standalone model (outside the SEAMLESS-Integrated Framework (SEAMLESS-IF)), a model-specific data management system is required for entering, storing, editing and importing in the model the required data. This report briefly reviews a number of approaches available for data management and data integration into economic modelling and describes the data management facility (DMF) that was created against this aim.

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[1] See http://www.seamless-ip.org/.

[2] In what follows, for ease of expression we will be referring only to FSSIM-REG, simultaneously implying also previous versions of FSSIM-MP, unless a distinction is made between the two in the text.

2 Data Management and Integration Approaches

2.1 Database and Data Import Procedures

A number of approaches are available regarding data management and data integration into economic modelling. Typically used data management approaches for Mathematical Programming Models (MPMs) written in General Algebraic Modeling System (GAMS)[3] involve the use of Microsoft Excel (MS Excel), Microsoft Access (MS Access), and My Structured Query Language (SQL). My SQL is a well-established and free of charge database management system, but it requires higher user specialisation than MS Access or MS Excel. MS Excel is a very widely used tool, lacking however the data management properties of a specialised database product. These include 1) easier and faster data control, 2) possibility of using structured procedures for database population, 3) maintenance of data integrity, and 4) possibility of linking the database tool to other external databases and/or models. MS Access is a user-friendly easily accessible database management system, offering the above capabilities.

Additionally, the use of MS Access, as opposed to MS Excel, is advantageous for the retrieval of the data and their writing into text files. GAMS offers the xls2gms and mdb2gms utilities, operating with MS Excel and MS Access respectively (Kalvelagen, 2004)[4]. The loading of files into GAMS is significantly faster when using MS Access and the mdb2gms utility, compared to using MS Excel and xls2gms (Carroll, 07). The system is also more generic and re-usable, since with xls2gms one has to specify the range of cells to be imported. This means that for each application the range of data to be imported would have to be re-specified, depending on the number of records of each input file. In mdb2gms, the same SQL queries are used for retrieving the data regardless of the number of records.

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[3] Given that FSSIM-MP is written in GAMS and that there exist a very large number of alternative modelling software products for economic modelling, here we will focus on reviewing only approaches for models written in GAMS.

[4] See http://interfaces.gams-software.com/doku.php

2.2 Database Design

One of the most popular models[5] for database implementation is the relational model (Date, 1990). The relational model, as initially defined by Codd (1970; 1979), was developed seeking to address the issues of data independence, derivability, redundancy and consistency of relations, which were often not sufficiently dealt with in network models (Codd, 1970). Relational database design is strongly associated with normalization (Lee, 1995), which has been defined by Codd as a very simple elimination procedure of non simple domains[6] (Codd, 1970). This process follows a set of data dependency rules, so that data are grouped into well structured relations free of anomalies, such as update anomalies, insertion anomalies, and deletion anomalies (Lee, 1995). A simple guide to database normalisation and explanations of the meaning of the various normal forms can be found in William (1983). The normalisation guidelines are biased towards the assumption that there are frequent updates of the non key fields, while they tend to penalize retrieval in the sense that data which may be retrievable from one record in an unnormalised design may have to be retrieved from several records in the normalised form (William, 1983). Thus, given such performance trade-offs it is not obligatory to fully normalize all records of a database (*ibid*).

Another important characteristic of the relational model are the two base integrity rules, namely the entity integrity and referential integrity rules:

1) *Entity integrity rule*: "No primary key value of a base relation is allowed to be null or to have a null component".
2) *Referential integrity rule*: "Suppose an attribute A of a compound (i.e. multi-attribute) primary key of a relation R is defined on a primary domain D. Then, at all times, for each value v of A in R there must exist a base relation

---

[5] We use Codd's definition of a data model, being a combination of the following three components: 1) "a collection of data structure types (the building blocks of any database that conforms to the model)"; 2) "a collection of operators or inferencing rules, which can be applied to any valid instances of the data types listed in (1), to retrieve or derive data from any parts of those structures in any combinations desired"; 3) "a collection of general integrity rules, which implicitly or explicitly define the set of consistent database states or changes of state or both - these rules may sometimes be expressed as insert-update-delete rules" (Codd, 1981).

[6] Simple domains are those whose elements are atomic (non decomposable) values (Codd, 1970).

(say S) with a simple primary key (say B) such that v occurs as a value of B in S" (Codd, 1979).

The primary key in a database table is an important row identifier that ensures row uniqueness. Often primary keys are established as foreign keys to other tables, enforcing referential integrity constraints between the two tables. Through these constraints, the values of a foreign key are limited to the primary key values in the corresponding table (Kroenke, 2006). Keys can be "surrogate" or "natural". A surrogate key is an artificial column added to a relation, while a natural key is formed of attributes that already exist in the real world. Surrogate keys are often used to substitute for natural keys, especially when these consist of more than one attributes (compound keys).

Auto-generated auto-incrementing integer surrogate primary keys are supported by the products of most database management systems. The main advantage of using surrogate versus natural keys is that surrogate keys are generally treated more efficiently by database management optimizers (Haughey, 2004). A single column surrogate key takes up much less space than multiple-columns compound keys. Also, by being system generated keys they are guaranteed to be unique and they exhibit implicit temporal ordering. Finally, cascading updates procedures are not required. This is not the case with natural keys, where if the value of an attribute of the natural key changes then all the foreign keys that contain this value need to be updated.

On the other hand, the use of surrogate keys does not automatically guarantee referential integrity through uniqueness of the natural keys. As Pascal (2003) argues "It may be possible to insert two logically identical items in a multivalued file - the multivalued file manager will generate two item-IDs for them and, thus, consider them unique". If a natural key needs to be unique, then an extra index will have to be defined and this increases database size. Additionally as artificial numerical surrogate keys mean nothing to the user, tables need to contain both the surrogate and natural keys increasing essentially database size, or alternatively forms and reports need to be established for data entry and data retrieval.

2.3 Database and Model Integration

The mdb2gms utility is a tool that retrieves data from an MS Access database into GAMS text files or GAMS Data Exchange (GDX) files (Kalvelagen, 2004) through SQL queries which can be written directly in GAMS modules. In the code, one needs to specify the source database, an SQL query for each data field to be extracted, and the data destination files. The utility can be used in "interactive" or "batch mode", and with single-query or multi-query commands. Some examples of single-query or multi-query pieces of code for creating include files can be seen in Fig. 1.

Figure 1. Example of mdb2gms utility code

```
SINGLE QUERY BATCH USE
$set commandfile Database\commands.txt
$onecho > %commandfile%
I=%system.fp%Database.mdb
Q="select distinct (Crop_gms) from GS_Crop"
O=FSSIM-DM\INPUTDATA\Global_set\Crops.inc
M
$offecho
$call =mdb2gms @%commandfile%


MULTI QUERY BATCH USE
$setlocal DataRepository ..\FSSIM-DM\INPUTDATA
$setlocal commandfiles temporary.txt
$onecho > %commandfiles%
I=%system.fp%Database.mdb
Q1="SELECT distinct(Crop_gms) from GS_Crop UNION SELECT distinct(Animal_gms) from
GS_D_Animal_Data"
O1="%DataRepository%\Global_set\PACT.inc"
Q2="SELECT distinct(Crop_gms) from GS_Crop"
O2="%DataRepository%\Global_set\Crops.inc"
M
$offecho
$call =mdb2gms @%commandfiles%
```

The mdb2gms utility can effectively retrieve the sets/parameters definitions contained in an MS Access database and write them in gdx or text files. However, one disadvantage of the utility is that it does not allow writing additional text such as set/parameter declarations in text files, since it is not possible to embed in the utility code other GAMS commands, as for example the "put" command that allows writing text. An alternative approach uses two steps through GDX files for writing text files that include both data declarations and data definitions (Blanco, 2008). First, the mdb2gms utility commands are used for retrieving the data from the database and storing them in GDX files. Subsequently standard GAMS commands are used for writing the include files: 1) the "put" command is used for writing the declaration; and 2) the "loop" command combined with the "put" command are used for looping and writing the members of sets and the parameter values (Fig. 2).

Even though this approach offers significant functionality, it is associated with complications when the values of a set of parameters are all equal to zero, and with duplication of effort for controlling the output. Specifically, although the contents of the GDX files correspond exactly to the contents of the database, the use of the loop and put command result in combining the members of sets in all possible combinations, rather than transferring in the text files only the data contained in the GDX files. This can be resolved with the use of conditional statements with the GAMS dollar operator, specifying that only the existing combinations are imported in the text file. However, when the value of a parameter is zero for all its instances, and given than in GAMS parameter values equal to zero are equivalent to nulls, the use of conditional statements results in nothing being imported into the respective text file and the model crashes. Other disadvantages of this approach include that the mdb2gms utility is not working consistently with GDX files in some older versions of GAMS, and that the numbers of decimals per parameter need to be re-specified even if they have already been specified in the database.

Other approaches for writing set/parameter declarations in text files involve 1) using Visual Basic for Applications (VBA) to write to text or GDX files directly or 2) using the mdb2gms utility to write to GDX files and then use the GDXDUMP utility to create the text files (Kalvelagen, 2008). The former requires significant amount of VBA programming, while using the GDXDUMP utility causes a similar problem to the approach described above, as it does not import parameter values that are equal to zero.

Figure 2. Example of code using mdb2gms and GAMS commands

```
$onecho > command.txt
I=%system.fp%Database.mdb
X=%system.fp%Database.gdx
Q1="select distinct (Crop_gms) from GS_Crop"
S1=Pact
Q2="select distinct (Crop_gms) from GS_Crop"
S2=Crops
$offecho
$call =mdb2gms @command.txt

SET Pact, CROPS(Pact);

File GPACT/FSSIM-DM\INPUTDATA\Global_set\PACT.inc/;
put GPACT
put 'SET PACT /';
loop(PACT,put PACT.tl/;)
put '/;';
putclose;
```

3 FSSIM-REG and the Data Management Facility

The DMF for FSSIM-REG serves two specific purposes. It is used as a database for storing, manipulating and interfacing the FSSIM-REG data (database module – DM), and also as a tool for retrieving the data from the DM and transforming them into a readable by FSSIM-REG format (integration code module - ICM). The development of the DMF followed the development of FSSIM-MP and therefore a number of versions are available. The first prototype version (Jan 08), dealing only with crop model components, has been used for a number of applications (e.g. Majewski *et al.*, 2009; Traoré *et al.*, 2009; Mouratiadou *et al.*, 2008; Mouratiadou *et al.*, 2009). This first version has been continuously updated following the FSSIM-MP model changes until the development of the version described in this report (Aug 09), which includes also the livestock components and the additional national, regional and farm type dimensions of FSSIM-REG. The Aug 09 version is the one that will be used for the purposes of BECRA.

3.1 FSSIM-REG Data Requirements and Structure

The inputs required by FSSIM-REG can be distinguished into data concerning the definition and specification of the agricultural system, and into data describing characteristics of this system. These data correspond to set elements or parameter values within the model. There is a clear analogy between the two types of data and what is specified as a set or a parameter in the model. The sets usually act as the data on system definition, while the parameters associated to the sets act as the data on the description of characteristics of this system. In a MPM written in GAMS, sets are defined as "the basic building blocks of a GAMS model, corresponding exactly to the indices in the algebraic representations of models" (Rosenthal, 2008). Sets can be one-dimensional or multi-dimensional. The parameters are the core data of a model and they can be scalars or dimensional parameters. A scalar is a parameter of zero dimensionality, thus there are no associated sets and there is exactly one number associated with it (*ibid*). The dimensional parameters are associated to one or more sets of the model.

The fact that FSSIM-MP has been developed as a generic model, which uses however specific sources of data and that is part of the SEAMLESS-IF, has significant implications on the model data requirements. First, the potential occurrences of some of the data on system definition are given in a predefined list that is meant to be applicable to all case studies. The user specifies the occurrences that apply to his case-study by providing the value of the associated parameters only for the appropriate occurrences. One reason for predefining these data is that FSSIM-MP uses different definitions of a specific entity, depending on the data source of this entity. For example, for the entity "crop", the FSSIM-MP labels need to be linked to crop labels for data that come from the Farm Accountancy Data Network (FADN), or to crop labels for data that come from the partial equilibrium model CAPRI. By predefining the FSSIM-MP crop list, these linkages could also be predefined within the SEAMLESS-IF system. Effectively, it is possible to add a new occurrence to some of the predefined lists, given that all the cross-linkages established between the different data types are updated.

Second, as FSSIM-MP is part of the SEAMLESS-IF it uses already defined procedures for importing the data. The data are delivered to the model in the form of GAMS include files, which are essentially text files that can be read by GAMS. These data files include both data declarations and data definitions and are included in FSSIM-MP by using the "$include" command, that inserts the contents of the specified text file at the location of the call. These specified characteristics for the data import into FSSIM-MP need to be respected for the model to be operational both within and outside SEAMLESS-IF.

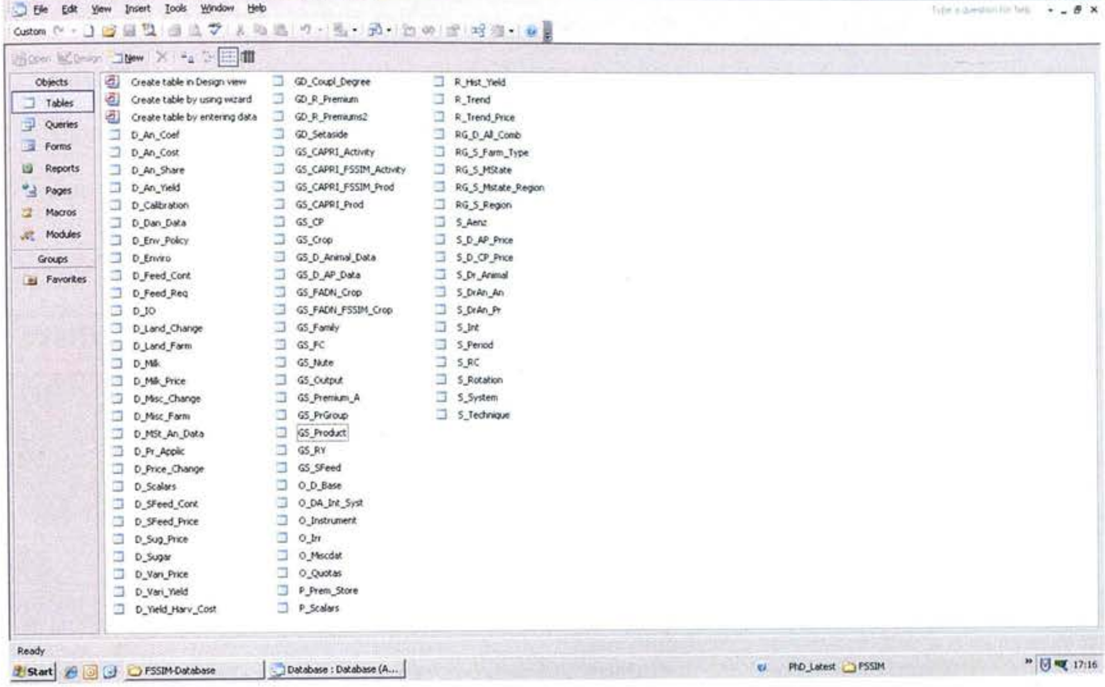
Finally, some of the required data are outputs of other models linked to FSSIM-MP. Some of these model-generated data can be obtained from other sources, when the model is used outside SEAMLESS-IF. The data generated by the bio-physical model APES can be obtained by using other bio-physical models with similar specifications or statistical information. On the other hand, the data generated from CAPRI or the feed-module of FSSIM-AM, are not that easily obtainable from other sources as they correspond to complex model estimations.

3.2 Database Structure

The DM data model follows closely the data structure of FSSIM-REG. Specifically, the actual relationships between sets and parameters that exist in FSSIM-REG have been used for establishing the relationships between the different DM fields. Also, it draws from the "relational model" for database implementation (Date, 1990) regarding normalisation and integrity rules.

The building blocks of any database are the database tables. Each table is characterised by 1) a table name - a unique identifier for the relation defined in the table; 2) a primary key - a unique identifier assigned to one of the table attributes, enforcing that no row will be duplicated; 3) columns with their headings and value types - each column represents an attribute which should be related to the primary key and it is assigned a specific value type e.g. string, numerical, boolean, etc. The Aug 09 version of the DM contains 78 tables (Fig. 3).

Figure 3. Database table contents



Create table in Design view
Create table by using wizard
Create table by entering data
D_An_Coef
D_An_Cost
D_An_Share
D_An_Yield
D_Calibration
D_Dan_Data
D_Env_Policy
D_Enviro
D_Feed_Cont
D_Feed_Req
D_IO
D_Land_Change
D_Land_Farm
D_Milk
D_Milk_Price
D_Misc_Change
D_Misc_Farm
D_MSt_An_Data
D_Pr_Applic
D_Price_Change
D_Scalars
D_SFeed_Cont
D_SFeed_Price
D_Sug_Price
D_Sugar
D_Vari_Price
D_Vari_Yield
D_Yield_Harv_Cost
GD_Coupl_Degree
GD_R_Premium
GD_R_Premiums2
GD_Setaside
GS_CAPRI_Activity
GS_CAPRI_FSSIM_Activity
GS_CAPRI_FSSIM_Prod
GS_CAPRI_Prod
GS_CP
GS_Crop
GS_D_Animal_Data
GS_D_AP_Data
GS_FADN_Crop
GS_FADN_FSSIM_Crop
GS_Family
GS_FC
GS_Nute
GS_Output
GS_Premium_A
GS_PrGroup
GS_Product
GS_RY
GS_SFeed
O_D_Base
O_DA_Int_Syst
O_Instrument
O_Irr
O_Miscdat
O_Quotas
P_Prem_Store
P_Scalars
R_Hist_Yield
R_Trend
R_Trend_Price
RG_D_All_Comb
RG_S_Farm_Type
RG_S_MState
RG_S_Mstate_Region
RG_S_Region
S_Aenz
S_D_AP_Price
S_D_CP_Price
S_Dr_Animal
S_DrAn_An
S_DrAn_Pr
S_Int
S_Period
S_RC
S_Rotation
S_System
S_Technique

The table names signal the contents of the table in terms of type of data and specific relation. Specifically, the name consists of a prefix, which identifies the data type, and a root which describes the relation contained in the table[7] (Table 1). The type of data can be classified into the following categories:

1) Global Sets: Sets that are predefined in SEAMLESS-IF;
2) User-defined Sets: Sets directly defined by the user on a case-study basis;
3) Global Parameters: Parameters that are predefined in SEAMLESS-IF;
4) User-defined Parameters: Parameters defined by the user on a case-study basis;
5) Regional Parameters: Parameters that vary per region (in the original versions of FSSIM-MP prior to FSSIM-REG). Their majority are CAPRI outputs, but they can be related to other regional features, e.g. regional historic yield for CAP;
6) Farm-type Parameters: Parameters that vary per farm type (in the original versions of FSSIM-MP prior to FSSIM-REG);

---

[7] When a table contains more than one type of data and relations, the name is a combination of what the individual table names would be.

7) User Policy Parameters: Parameters that can be altered by the users for the policy scenario;

8) FSSIM-REG Parameters: Sets and parameters that are only in use by the FSSIM-REG model version.

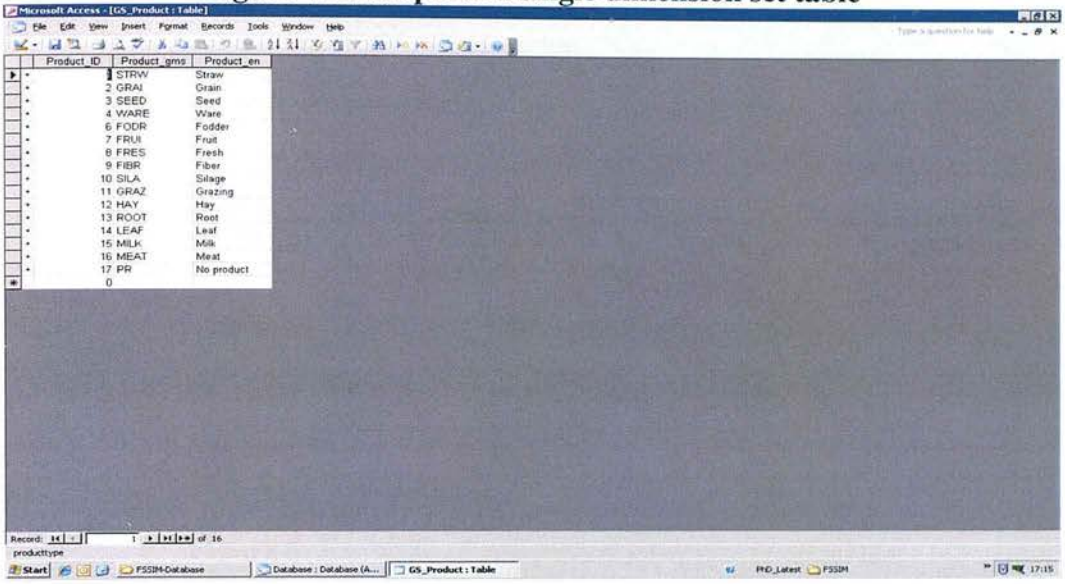
9) Other: Data that do not fall in any of the above categories. These can be either data that are not used in the model, e.g. data on farm type characteristics, or data that refer to sets that are defined in FSSIM-MP but are also included in the DM for the maintenance of the integrity of the related data.

Table 1. Table Names Prefixes

Prefix	Data Type	Example
GS	Global Sets	GS_Crops
S	User-defined Sets	S_Rotation
GD	Global Parameters	GD_Basic_Premium
D	User-defined Parameters	D_Yield
R	Regional Parameters	R_Hist_Yield
Spec	Farm-type Parameters	Spec_Calibration
P	User Policy Parameters	P_Prem_Store
RG	FSSIM-REG Parameters	RG_S_Region
O	Other data	O_Instrument

The main type of information contained in each database table are (i) the primary key, (ii) the respective unique natural key, and (iii) any data associated with the keys. Regarding the use of surrogate or natural primary keys a mixed procedure has been used. Surrogate keys have been used as primary keys however the single or compound natural keys, revealing the actual set/parameter domains, are also contained in the tables and indexed as unique. The surrogate primary keys are numeric for the majority of sets, and auto-numbers for some multi-dimensional sets and the parameters that are populated by queries. The unique natural keys reveal the GAMS labels of the sets that are used in FSSIM-MP, hence defining the model domains for sets and parameters. These natural keys are compound when they refer to multi-dimensional sets and parameters. The data associated to the keys are effectively describing these domains. For domains of one dimension the data column gives the definition of the meaning of the domain (Fig. 4). For multi-dimensional domains the data columns provide the values of each of the parameters that are associated to this domain. The values of all the parameters that are defined over a specific domain are included in separate columns of the same table (Fig 5).

Figure 4. Example of a single dimension set table



Product_ID	Product_gms	Product_en
1	STRW	Straw
2	GRAI	Grain
3	SEED	Seed
4	WARE	Ware
6	FODR	Fodder
7	FRUI	Fruit
8	FRES	Fresh
9	FIBR	Fiber
10	SILA	Silage
11	GRAZ	Grazing
12	HAY	Hay
13	ROOT	Root
14	LEAF	Leaf
15	MILK	Milk
16	MEAT	Meat
17	PR	No product
0		

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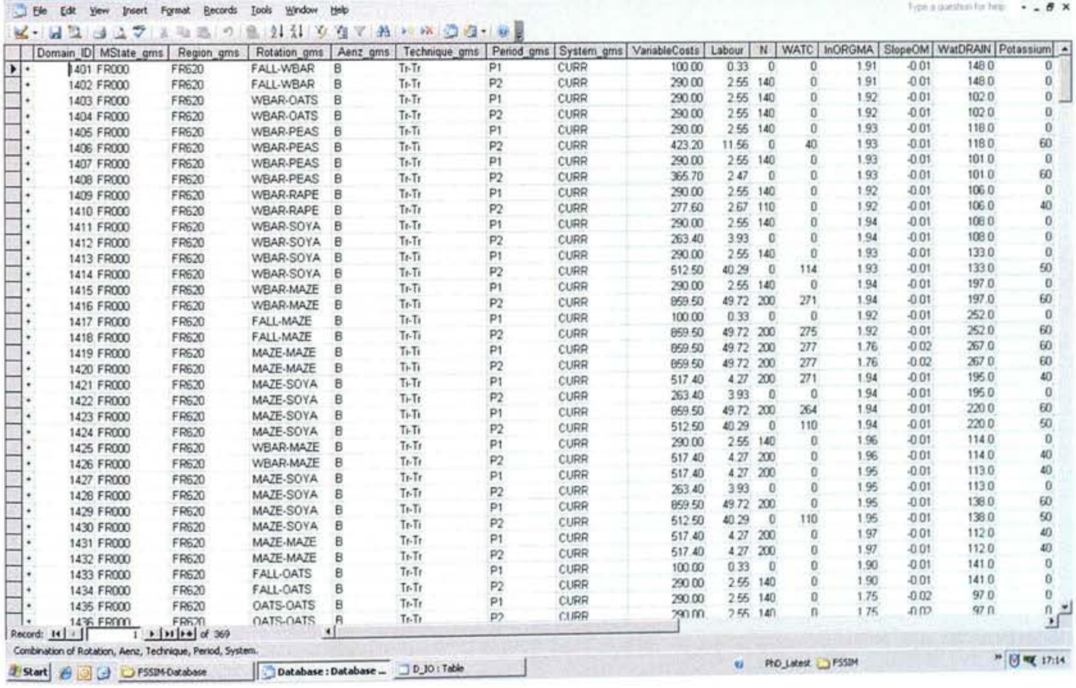
producttype

Figure 5. Example of a multi-dimensional parameter table



Domain_ID	MState_gms	Region_gms	Rotation_gms	Aenz_gms	Technique_gms	Period_gms	System_gms	VariableCosts	Labour	N	WATC	InORGMA	SlopeOM	WatDRAIN	Potassium
1401	FR000	FR620	FALL-WBAR	B	Tr-Tr	P1	CURR	100.00	0.33	0	0	1.91	-0.01	148.0	0
1402	FR000	FR620	FALL-WBAR	B	Tr-Tr	P2	CURR	290.00	2.55	140	0	1.91	-0.01	148.0	0
1403	FR000	FR620	WBAR-OATS	B	Tr-Tr	P1	CURR	290.00	2.55	140	0	1.92	-0.01	102.0	0
1404	FR000	FR620	WBAR-OATS	B	Tr-Tr	P2	CURR	290.00	2.55	140	0	1.92	-0.01	102.0	0
1405	FR000	FR620	WBAR-PEAS	B	Tr-Ti	P1	CURR	290.00	2.55	140	0	1.93	-0.01	118.0	0
1406	FR000	FR620	WBAR-PEAS	B	Tr-Ti	P2	CURR	423.20	11.56	0	40	1.93	-0.01	118.0	60
1407	FR000	FR620	WBAR-PEAS	B	Tr-Tr	P1	CURR	290.00	2.55	140	0	1.93	-0.01	101.0	0
1408	FR000	FR620	WBAR-PEAS	B	Tr-Ti	P2	CURR	365.70	2.47	0	0	1.93	-0.01	101.0	60
1409	FR000	FR620	WBAR-RAPE	B	Tr-Tr	P1	CURR	290.00	2.55	140	0	1.92	-0.01	106.0	0
1410	FR000	FR620	WBAR-RAPE	B	Tr-Tr	P2	CURR	277.60	2.67	110	0	1.92	-0.01	106.0	40
1411	FR000	FR620	WBAR-SOYA	B	Tr-Tr	P1	CURR	290.00	2.55	140	0	1.94	-0.01	108.0	0
1412	FR000	FR620	WBAR-SOYA	B	Tr-Tr	P2	CURR	263.40	3.93	0	0	1.94	-0.01	108.0	0
1413	FR000	FR620	WBAR-SOYA	B	Tr-Ti	P1	CURR	290.00	2.55	140	0	1.93	-0.01	133.0	0
1414	FR000	FR620	WBAR-SOYA	B	Tr-Ti	P2	CURR	512.50	40.29	0	114	1.93	-0.01	133.0	50
1415	FR000	FR620	WBAR-MAZE	B	Tr-Ti	P1	CURR	290.00	2.55	140	0	1.94	-0.01	197.0	0
1416	FR000	FR620	WBAR-MAZE	B	Tr-Ti	P2	CURR	859.50	49.72	200	271	1.94	-0.01	197.0	60
1417	FR000	FR620	FALL-MAZE	B	Tr-Ti	P1	CURR	100.00	0.33	0	0	1.92	-0.01	252.0	0
1418	FR000	FR620	FALL-MAZE	B	Tr-Ti	P2	CURR	859.50	49.72	200	275	1.92	-0.01	252.0	60
1419	FR000	FR620	MAZE-MAZE	B	Ti-Ti	P1	CURR	859.50	49.72	200	277	1.76	-0.02	267.0	60
1420	FR000	FR620	MAZE-MAZE	B	Ti-Ti	P2	CURR	859.50	49.72	200	277	1.76	-0.02	267.0	60
1421	FR000	FR620	MAZE-SOYA	B	Ti-Tr	P1	CURR	517.40	4.27	200	271	1.94	-0.01	195.0	40
1422	FR000	FR620	MAZE-SOYA	B	Ti-Tr	P2	CURR	263.40	3.93	0	0	1.94	-0.01	195.0	0
1423	FR000	FR620	MAZE-SOYA	B	Ti-Ti	P1	CURR	859.50	49.72	200	264	1.94	-0.01	220.0	60
1424	FR000	FR620	MAZE-SOYA	B	Ti-Ti	P2	CURR	512.50	40.29	0	110	1.94	-0.01	220.0	50
1425	FR000	FR620	WBAR-MAZE	B	Tr-Tr	P1	CURR	290.00	2.55	140	0	1.96	-0.01	114.0	0
1426	FR000	FR620	WBAR-MAZE	B	Tr-Tr	P2	CURR	517.40	4.27	200	0	1.96	-0.01	114.0	40
1427	FR000	FR620	MAZE-SOYA	B	Tr-Tr	P1	CURR	517.40	4.27	200	0	1.95	-0.01	113.0	40
1428	FR000	FR620	MAZE-SOYA	B	Tr-Tr	P2	CURR	263.40	3.93	0	0	1.95	-0.01	113.0	0
1429	FR000	FR620	MAZE-SOYA	B	Tr-Ti	P1	CURR	859.50	49.72	200	0	1.95	-0.01	138.0	60
1430	FR000	FR620	MAZE-SOYA	B	Tr-Ti	P2	CURR	512.50	40.29	0	110	1.95	-0.01	138.0	50
1431	FR000	FR620	MAZE-MAZE	B	Tr-Tr	P1	CURR	517.40	4.27	200	0	1.97	-0.01	112.0	40
1432	FR000	FR620	MAZE-MAZE	B	Tr-Tr	P2	CURR	517.40	4.27	200	0	1.97	-0.01	112.0	40
1433	FR000	FR620	FALL-OATS	B	Tr-Tr	P1	CURR	100.00	0.33	0	0	1.90	-0.01	141.0	0
1434	FR000	FR620	FALL-OATS	B	Tr-Tr	P2	CURR	290.00	2.55	140	0	1.90	-0.01	141.0	0
1435	FR000	FR620	OATS-OATS	B	Tr-Tr	P1	CURR	290.00	2.55	140	0	1.75	-0.02	97.0	0
1436	FR000	FR620	OATS-OATS	B	Tr-Tr	P2	CURR	290.00	2.55	140	0	1.75	-0.02	97.0	0

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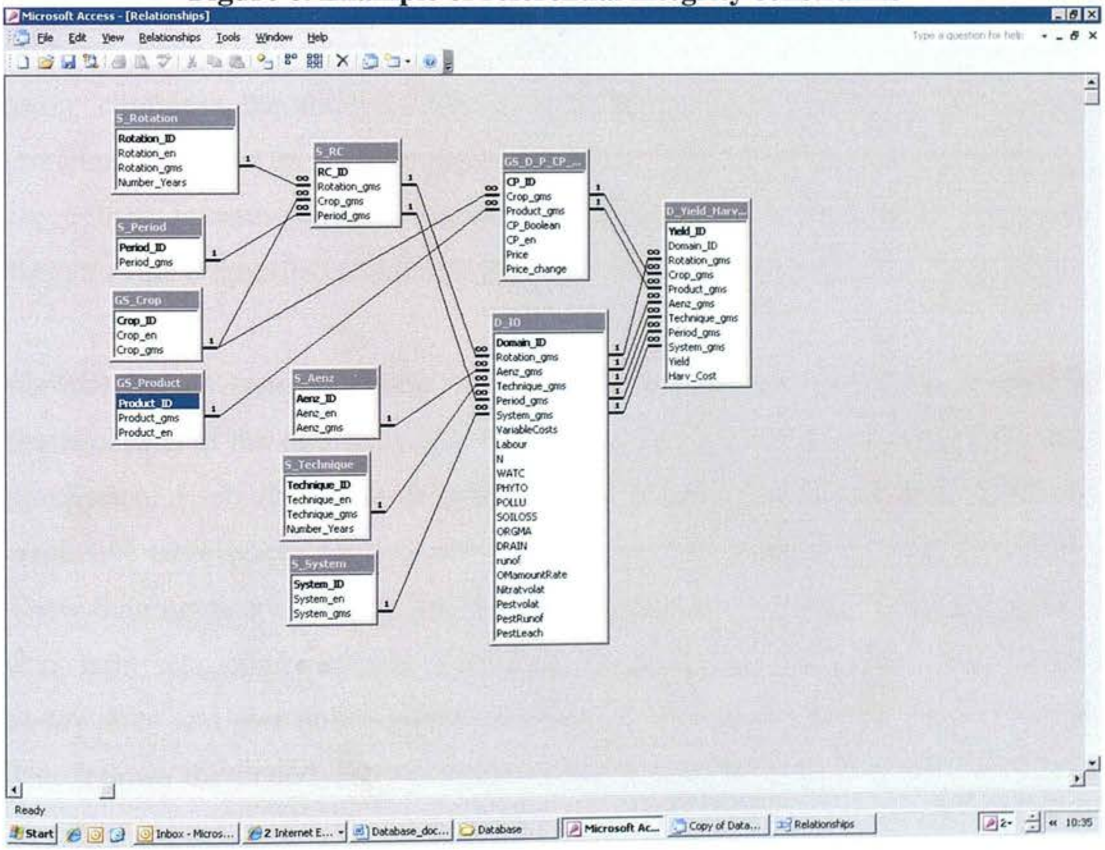
Combination of Rotation, Aenz, Technique, Period, System.

The referential integrity constraints follow the conceptual and technical links of the FSSIM-REG input data for the establishment of one-to-many relationships, as implicitly established by the dimensions of the set and parameter domains in the model. Hence, referential integrity is enforced using the indexed unique natural keys which are used as foreign keys in subsequent tables. The natural keys of one-dimensional tables for sets are foreign keys to multi-dimensional set or parameter tables. The combination of these foreign keys forms then the unique natural key of the multi-dimensional set or parameter tables. For example, as shown in Fig.6, the natural keys of the single dimension set tables GS_Crop and GS_Product are foreign keys to the table GS_D_CP, where the two-dimensional set CP is defined over the domain of crop-product. The combination of crop-product forms the indexed unique natural key of the table GS_D_CP. Subsequently this two-dimensional compound key is a foreign key to the table D_Yield_Harvest, along with the 5-dimensional natural key of the table D_IO. The natural key of the table D_Yield_Harvest will be the combination of these 7 dimensions.

Figure 6. Example of referential integrity constraints



3.3 Database Population, Queries and Interface

The database tables corresponding to global sets and parameters have been populated with the respective data contained in the SEAMLESS Database. The rest of the tables are populated by the users on a case-study basis. For the facilitation of the entering of information regarding natural keys, a number of SQL append queries have been developed. These queries combine information on natural keys that have already been entered in other tables and import these combinations on the dependant table, so that the user does not need to manually re-enter all this information. For example, in the example provided in the previous section, the user needs to run a query that populates the natural key fields of the table D_Yield_Harvest with the corresponding fields entered in the tables GS_D_CP and D_IO, instead of manually filling in these data fields.

A SQL query has been developed for each table that its natural key is a combination of two or more foreign keys, with at least one of them being a user-defined set[8]. The names of the queries are identical to the names of the tables to be populated (starting with the prefix *Q*) in order to easily identify to which table they correspond. Each query combines the different foreign keys of the related table in all possible combinations based on the information contained in the tables where each of the keys are defined. In cases where the combination of the keys is subject to a standard rule, then this rule is specified within the query. The Aug 09 version contains 34 queries.

An MS Access form has been developed to facilitate DM navigation. The form displays each of the data items that the user needs to fill in and their corresponding description. Each data item is associated to a command button that opens the respective table where the data are stored using event procedures written in VBA. These data items are grouped into 8 specific categories under different tabs: global sets, farm sets, combined sets, farm data, IO production data, animal data, trend policy data, and user policy parameters (Fig. 8). The grouping and ordering of the data follows the underlying hierarchical relationships between sets and parameters

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[8] When all the foreign keys are global sets, there is no need for the user to run a query as all the possible combinations are already contained in the database.

and the associated referential integrity rules. This means that the user is first prompted to insert the data of lower dimensionality (e.g. one-dimensional sets) and gradually continue towards filling in the data of higher dimensions. Between the different steps there are command buttons that allow 1) using the SQL append queries to populate the natural keys of the tables, or 2) deleting the data contained in the tables. The command buttons are associated to macros containing the queries that correspond to the specific data groups. In total 8 append and 5 delete macros were developed and linked to the form command buttons. Additionally, a command button allows the user to access a form with specific instructions on how to fill in the data, and another command button to close the database.

Figure 7. Database query contents

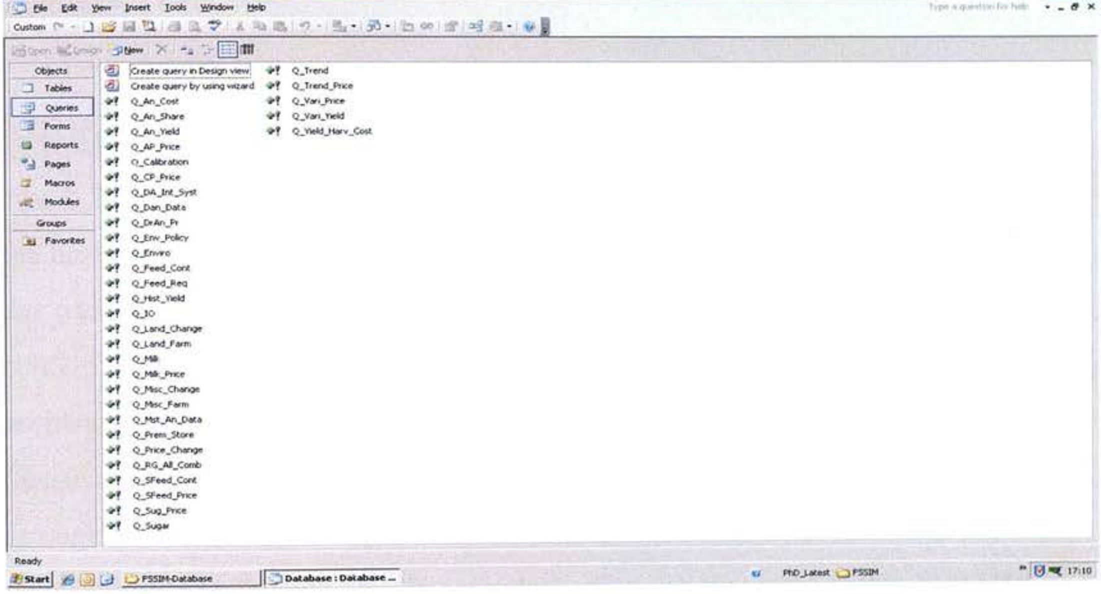
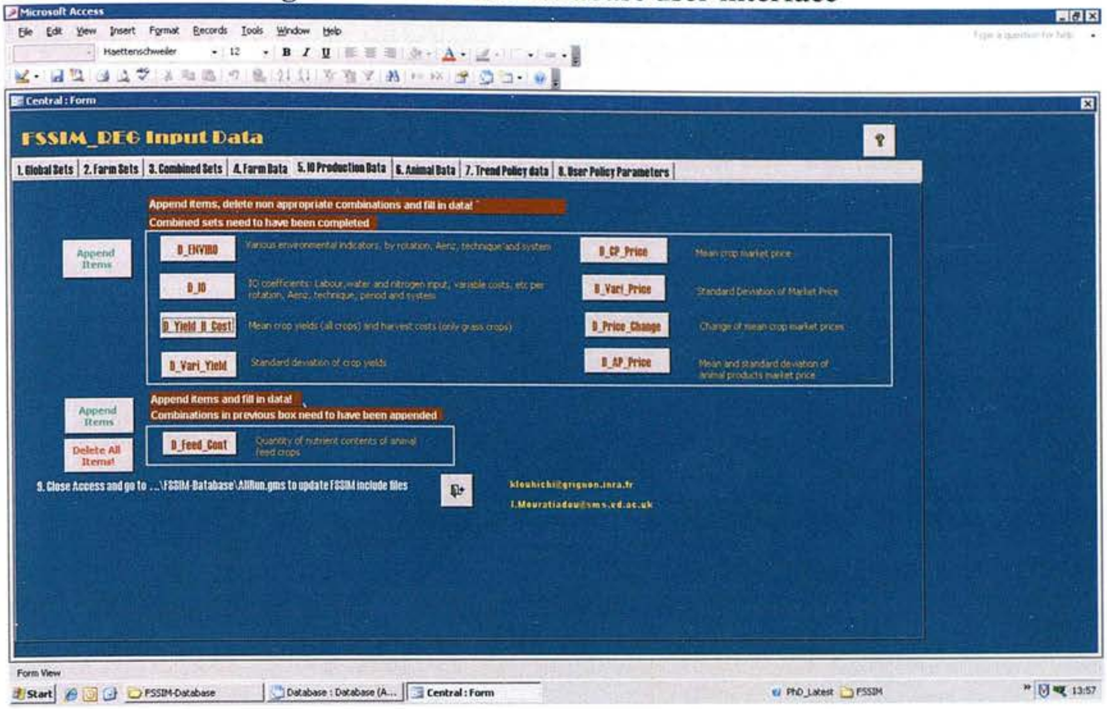


Figure 8. Tab of the database user interface



Append items, delete non appropriate combinations and fill in data!

Combined sets need to have been completed

D_ENVIRO: Various environmental indicators, by rotation, Aenz, technique and system

D_IO: IO coefficients: Labour, water and nitrogen input, variable costs, etc per rotation, Aenz, technique, period and system

D_Yield_H_Cost: Mean crop yields (all crops) and harvest costs (only grass crops)

D_Vari_Yield: Standard deviation of crop yields

D_CP_Price: Mean crop market price

D_Vari_Price: Standard Deviation of Market Price

D_Price_Change: Change of mean crop market prices

D_AP_Price: Mean and standard deviation of animal products market price

Append items and fill in data!

Combinations in previous box need to have been appended

D_Feed_Cont: Quantity of nutrient contents of animal feed crops

9. Close Access and go to ...\FSSIM-Database\AllRun.gms to update FSSIM include files

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3.4 The Integration Code Module

The ICM has been developed for writing the data into GAMS include files. It uses the batch multi-query approach, since it is considerably faster and it does not require the user to be present while the utility is running. The FSSIM-MP include files contain both the declarations and the definitions of sets/parameters, therefore the problem of writing declarations in the include files with the use of mdb2gms (discussed in the review section) has been a challenge. The two-step approach through GDX files (Blanco, 2008) offers significant functionality, mainly because it allows producing include files that are identical to the ones used within SEAMLESS-IF and therefore it does not require any changes in the FSSIM-MP code. However, due to the generic nature of FSSIM-MP there are a number of parameters that are likely to have all their instances equal to zero (e.g. water availability or crop water requirements). Therefore, use of this approach would involve that the user deactivates in the model any parameters that all their instances are equal to zero. This demands high user familiarity with the model code and to an extent compromises the generic nature of the model.

Consequently, only the data definitions have been included in the include files, and additional GAMS modules have been created for embedding the data declarations at the point where the include files are included. The ICM comprises of: a) 5 modules retrieving the data from the DM and transferring them into the respective include files - these modules can be run independently of the rest of the FSSIM-REG code for the creation of the include files; b) 1 module that includes the 5 data modules previously described - this can be used for updating all the data files; c) 12 modules for the data declaration - these are called into the existing FSSIM-REG code with the use of include commands at the point where the previous data include commands were located.

4 Discussion and Conclusions

The DMF allows the use of FSSIM-REG and FSSIM-MP as a standalone model, providing a consistent approach for data management and integration. The approach used appears the most efficient overall, among a number of other approaches, against the following criteria: 1) time-requirements for data input, 2) user-friendliness, 3) speed of creation of the FSSIM-REG data input files, 4) error minimisation, 5) tools reusability, and 6) minimisation of changes in the actual FSSIM-MP code and include files.

Following from the above criteria, the overall advantageous features of the DMF can be summarised as follows:

1) The referential integrity constraints ensure data integrity, consistency of the existing relationships between FSSIM-MP sets and parameters, and minimisation of errors that could halt model execution;
2) The use of indexed natural keys ensures no errors due to record duplication;
3) The appearance of the natural keys in the database tables allows direct user interaction with the stored data. Also the user can easily import data stored in other databases or in MS Excel, and edit or download their data;
4) The use of surrogate primary keys offers the advantages of temporal ordering and a straightforward fast record identifier;

5) The queries to automatically generate the dimensions of the multidimensional sets/parameters minimise data entry requirements. Additionally they allow domain checking and implementation of rules for the combination of the different dimensions;
6) The user interface, the map of relationships, and the table naming according to data type encourage user familiarisation with the structure of the FSSIM-MP input data and facilitate database navigation;
7) The user interface allows grouping of the data and display of instructions. These features guide the user through the different stages of the data entry process, respecting the hierarchical relationships between sets and parameters and the associated referential integrity rules, and taking advantage of queries and macros.
8) A relatively easy transition to one of the two systems (use of only surrogate primary keys or use of only natural primary keys) can be implemented at a later stage of the database development;
9) The ICM allows the use of include files for importing the data without significant changes in the code and structure of FSSIM-MP, hence the switch from the standalone to the SEAMLESS-IF version of the model is very easy.

A number of improvements for the DMF can be suggested. First, the use of surrogate primary keys, as opposed to multiple-columns compound keys, as foreign keys can significantly reduce database size and increase database efficiency. It can be ensured that this does not compromise user-friendliness by constructing forms and reports so that the users can enter/retrieve/view data. It should be noted however that this improvement implies considerable changes in the DM table structure, DM queries and ICM queries, and also the development of a significant number of data views so that the user is able to view the tables in a meaningful way. Effectively both the DM and ICM queries would be substantially more complex as they would have to follow all the relational constraints backwards. Alternatively database size can also be reduced by using directly the natural keys as primary keys and eliminating any surrogate keys.

Additionally, some DM tables that have similar structure but are linked to either crop or animal activities could be merged into one table linked to a field that contains both crop and animal activities, so as to reduce the number of tables. Also, even though the ICM requires minimal changes in the code and include files of FSSIM-MP, an approach that requires no changes is much more efficient when switching from standalone to non standalone model use. This could be facilitated by VBA programming. Finally, it would be beneficial to develop procedures that allow simulating only one farm type/region/member state at the time in FSSIM-REG, while the data for all of them are contained in the DM.

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Annex III - Soil Leaching Potential Classification

High Soil Leaching Potential

Soils with little ability to attenuate diffuse source contaminants. Non-adsorbed diffuse contaminants and liquid discharges have the potential to move rapidly to underlying strata or to shallow groundwater. Four subclasses are recognised:

H1 Soils that readily transmit liquid discharges because they are either shallow or susceptible to rapid by-pass flow directly to rock, gravel or groundwater.

H3 Soils with a moderate adsorption capacity due to the presence of organic matter and/or clay. Non-adsorbed contaminants and liquid discharges can be readily transmitted as these soils overlie rock or gravel at relatively shallow depths.

H2 Soils with a low attenuation capacity due to low clay and/or organic matter contents and with the ability to drain rapidly but have limited potential for by-pass flow.

HU Soils over current and restored mineral workings and in urban areas are often disturbed or absent and the interpretation is based on fewer observations than elsewhere. A worst case vulnerability classification (equivalent to H1) is therefore assumed for these areas, until proved otherwise.

Intermediate Soil Leaching Potential

Soils with a moderate ability to attenuate diffuse source contaminants but it is possible that some non-adsorbed diffuse-source contaminants and liquid discharges could penetrate the soil layer. Two subclasses are recognised:

I1 Soils with a moderate ability to attenuate a wide range of potential contaminants due to their thickness, moderate levels of both clay and organic matter. These soils have only a limited potential for by-pass flow.

I2 Soils that can possibly transmit non- or weakly-adsorbed diffuse contaminants and liquid discharges, but are unlikely to transmit adsorbed contaminants. These soils have a high topsoil organic matter content but relatively porous subsoils. In some cases the soils are shallow.

Low Soil Leaching Potential (L)

Soils in which contaminants are unlikely to penetrate the soil layer due to both the presence of a slowly permeable horizon and the ability of the soil to attenuate contaminants. Water and contaminant movement is, therefore, largely horizontal and the lateral flow from these soils may contribute to groundwater recharge elsewhere in the catchment.

Source: Lewis *et al.* (2000)

Annex IV - HOST Classes Present in the Lunan Water Catchment

Substrate Hydrogeology	**Mineral Soils**				**Peat Soils**
	Groundwater or aquifer	No impermeable or gleyed layer within 100cm	Impermeable layer within 100cm or gleyed layer at 40-100cm	Gleyed layer within 40cm	
Strongly consolidated, non or slightly porous, by-pass flow common	Normally present and at >2m	4			
Unconsolidated, macroporous, by-pass flow very uncommon		5			
Unconsolidated, microporous, by-pass flow common		6			
Unconsolidated, microporous, by-pass flow common	Normally present and at ≤ 2m	8		10	12
Slowly Permeable	No significant groundwater or aquifer	16	18	24	

Source: Boorman *et al.* (1995)

Annex V - Description of Soil Types used in SAC Technical Note T516

Shallow soils (SS)	All mineral soils which are less than 40cm deep, between soil surface and underground rock.
Sands (S)	Soils which are sand and loamy sand textures to a depth more than 40cm.
Sandy loams (SL)	Soils which are sandy loam texture to a depth of more than 40cm.
Other mineral soils (OMS)	Soils with less than 15 percent organic matter that do not fall into the sandy or shallow soil category i.e. silty and clay soils.
Humose soils (HS)	Soils with between 15 and 35 percent organic matter. These soils are darker in colour, stain the fingers black or grey, and have a silky feel.
Peaty soils (PS)	Soils that contain more than 35 percent organic matter.

Source: Sinclair (2002)

Annex VI - Numbers of Farms per Robust, Main and UK Farm Types

Robust	Main	UK Type	2000	2001	2002	2003	2004	2005	2006	2007
Cereals	Cereals	Cereals	31	33	34	32	38	33	28	28
		Cereals, oils. rape, peas, beans, setaside	7	9	8	10	10	10	11	7
		Oil. rape, linseed	*	*						
G. Cropping	G. Cropping	Cereals, root veget.	59	61	72	56	57	61	59	56
		Crops, mixed other	*	*	*					
		General crops	78	76	68	80	70	66	69	79
		Mixed crops, fruit		*						
		Mixed crops, veget.					*	*	*	
		Peas, beans, veget.	*	*	*	*	*		*	*
		Potatoes	11	11	13	12	11	10	5	*
Cattle & Sheep	Cattle & sheep (Lowland)	Beef cows	*	*	5	*	*	7	7	8
		Beef cow, milk-calf	*	6	5	5	5	5	*	5
		Cattle and ewes	*							*
		Cattle general	*							
		Ewes	5	*	5	5	*	*	5	6
		Goats					*	*	*	*
		Mixed cattle-sheep	*	*	*	*	*	*	*	
Mixed	Cropping and Dairy	Crops, dairy cattle		*	*	*	*	*	*	*
		Dairy cattle, crops	*	*	*	*		*		*
	Cropping and mixed livestock	Cropping and mixed livestock					*			
	Cropping, cattle and sheep	n/a	*	*	*	*	*	5	*	*
		Rough graz., fodder	15	10	7	12	10	10	16	11
	Cropping, pigs and poultry	Crops, pigs and poultry	*	*	*		*	*	*	*
	Mixed Livestock	Mixed poultry and non-dairy cattle			*	*	*	*	*	*
Other	Non-classifiable fallow	Bare, fallow land	5	5	*	*	*	5	8	6
	Non-classifiable other	Other	5	9	10	11	9	9	13	11
	Specialist goats	Goats	*	*	*	*				
	Specialist grass and forage	Fodder and rough grazing	5	6	6	8	9	8	6	8
		Grass and rough grazing	38	40	41	45	48	49	50	63
		Grass under 5 years, crops and root veg. for fodder	5	*	*	*	*	*	*	6
		Rogh grazing and (less) fodder	*	*	*					*
	Specialist horses	Horses	22	24	25	25	20	21	14	
	Spec. set-aside	Set-aside	*	*	*	*	*	*	6	8

Source: own elaboration from JCD

Annex VII - Modelled Rotations

Rotation	CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6
1	WDWH	WBAR	RAPE			
2	WDWH	SBAR	RAPE			
3	WBAR	SBAR	SBAR	RAPE		
4	WDWH	WDWH	SBAR	RAPE		
5	SBAR	SBAR	OATS			
6	WDWH	SBAR	SETA			
7	WBAR	SBAR	SBAR	SETA		
8	SBAR	SBAR	SBAR	SETA		
9	SBAR	SBAR	RAPE	OATS		
10	WDWH	SBAR	WDWH	SBAR	SDPO	
11	SBAR	SBAR	SETA	SBAR	SDPO	
12	SBAR	SBAR	SETA	SBAR	POTA	
13	RAPE	WDWH	SETA	SBAR	SBAR	SDPO
14	WDWH	SBAR	SBAR	WBAR	POTA	
15	OATS	WDWH	SBAR	SETA	WBAR	SDPO
16	WDWH	WBAR	SETA	WBAR	SBAR	POTA
17	WDWH	WBAR	SBAR	WBAR	SBAR	SDPO
18	SBAR	SBAR	SBAR	RAPE		
19	WDWH	SBAR	SBAR			
20	WDWH	SBAR	SBAR	SBAR	POTA	
21	WDWH	SBAR	SBAR	SBAR	SDPO	
22	WDWH	SBAR	PEAS	SBAR	POTA	
23	WDWH	SBAR	PEAS	SBAR	SDPO	
24	WDWH	SBAR	SBAR	OATS	SDPO	
25	WDWH	WBAR	OATS	SBAR	POTA	
26	WDWH	OATS	SBAR	SBAR	POTA	
27	WBAR	OATS	SBAR	SBAR	SDPO	
28	SBAR	OATS	SBAR	SBAR	POTA	
29	WDWH	SBAR	SBAR	CARR		
30	FALL					

Crop Codes:

WDWH: Winter Wheat	WBAR: Winter Barley
SBAR: Spring Barley	OATS: Spring Oats
RAPE: Winter Oilseed Rape	SDPO: Seed Potatoes
POTA: Main Crop Potatoes	SETA: Set-aside
PEAS: Peas	CARR: Carrots
FALL: Fallow land	

Annex VIII - Additional Information on Fertiliser Use and Recommendations

This annex assembles the available information on fertiliser use and recommendations using the data sources of the FMH (Chadwick, 2000, 2001, 2002), the RB209 (MAFF, 2000), the Guidelines for Farmers in Nitrate Vulnerable Zones (Scottish Government, 2008b) and the BSFP (DEFRA, 2002; 2003; 2004). The five different sources of information take into account different agricultural system attributes related to fertilisation: i) the FMH provides figures per crop, ii) the BSFP provides the frequency of different field application rates per crop, and average field rates per crop, and iii) the RB209 recommendations, the SAC Technical Note T516 recommendations, and the Scottish Government Guidelines take into account crop, soil and previous crop in the rotation.

The crop groups of the Scottish Government Guidelines are ordered in ascending order of residual available N. The crops that are included in our analysis are classified into the different residual crop groups as follows: 1: cereals, carrots; 2: winter oilseed rape, vining peas, seed potatoes, maincrop potatoes, and set-aside[1]. The indexes of residual groups in RB209 are related to previous crop groups and soil type. Using the *high rainfall areas* indexes for areas with over 700mm annual rainfall, as the Lunan Water catchment, the different crops grown in the case study area are classified in the following residual crop groups in combination with soils: 0: all crops on light sands, 1: all crops on medium soils.

The BSFP, except from average and overall field rates for the whole of Scotland, provides this information also for the South East of Scotland. These values, however, are not provided for all crops due to smaller farm sample. A comparison of the available values for Scotland and South East Scotland for the years 2002 and 2003 showed no significant differences or specific trends between the two.

---

[1] The classification for set-aside does not appear in the Scottish Government Guidelines, but in SAC Technical Note T516.

The first table shows the doses recommended by Scottish Government Guidelines and the RB209. The second table shows figures given in the FMH and the BSFP.

Fertilisation figures in the Scottish Government guidelines and RB209 (kg/ha)

	Scottish Government Guidelines			RB209		
	Soil*	**1**	**2**	**Soil*****	**0**	**1**
W. Wheat	S	220	210	LSS	160	
	SL/O	200	190	M		220
W. Barley	S	200	190	LSS	150	
	SL/O	180	170	M		170
S. Barley	S	150	140	LSS	110	
	SL/O	130	120	O		140
S. Oats	S	120	110	LSS	90	
	SL/O	100	90	O		110
W. Oils. Rape	S/SL	230	210	A	250	220
	O	230	210			
Seed Pot. **	S	110	100	A	depending on variety	
	SL/O	90	80			
Maincrop Pot.	S	245	235	A	depending on variety	
	SL/O	225	215			
Peas		n/a	n/a	A	0	0
Carrots		n.a.	n.a.	A	100	70

Source: Scottish Government (2008b); MAFF (2000);
*For description see Annex V;
** Information in Sinclair (2002), as not available in Scottish Government (2008b)
***LSS: Light sand soils; M: Medium soils, O: Other mineral soils; A: All soils;

Fertilisation figures in the FMH and the BSFP (kg/ha)

Crop	FMH	FMH	FMH	BSFP					
	2001	2002	2003	Av. 2002	Av. 2003	Rate 1 2002	Rate 1 2003	Rate 2 2002	Rate 2 2003
W. Wheat	200	200	200	214	201	200-225	200-225	225-250	225-250
W. Barley	180	180	180	194	173	150-175	150-175	175-200	175-200
S. Barley	100	100	100	113	107	75-100	75-100	100-125	100-125
S. Oats	80	80	80	102*	98*	50-75*	50-75*	75-100*	100-125*
W. Oils. Rape	185	185	185	221	225	175-200	200-225	225-250	225-250
Seed Pot.	100	90	100	110	131**	50-75	n.a.	100-125	n.a.
Maincrop Pot.	180	220	180	96	181	0-25	125-150	50-75	200-225
Peas	0	0	0	72**	0	n.a.	0	n.a.	n/a
Carrots	50	50	50	?	?	?	?	?	?
Set-aside	0	0	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Source: FMH (2000, 2001, 2002); BSFP (2002, 2003, 2004)
*Corresponds to both spring and winter oats.
** Corresponds to value for Great Britain, n.a. for Scotland.

Annex IX – Visual C# Code for Transformation of COUP Outputs into FSSIM-REG Inputs

```
using System;
using System.Collections.Generic;
using System.Text;
using System.IO;

using Excel;

namespace readXLS
{
    class Program
    {
        static void Main(string[] args)
        {
            #region local variables declaration
            Excel.Application ExcelObj;
            Excel.Workbook theWorkbook;
            Excel.Sheets sheets;
            Excel.Worksheet worksheet;
            Excel.Range range;
            System.Array myvalues;
            System.Double Final;
            System.Double Initial;

            double[] VarArray;
            string[] NameArray;
            double mean_Yield=0;
            double mean_Yield2 = 0;
            double sd_Yield=0;
            double mean_Lix=0;
            double mean_Leach = 0;
            double sd_Leach = 0;
            double mean_Drain = 0;
            #endregion

            #region generate file names and path
            string path =
@"I:\Ioanna\PhD_Latest\My_Project\COUP\Output\TOUSE\";

            int simNbr = 29;

            string[] filePath = new string[simNbr];
            filePath[0] = "WDWH_WBAR_RAPE____";
            filePath[1] = "WDWH_SBAR_RAPE____";
            filePath[2] = "WBAR_SBAR_SBAR_RAPE___";
            filePath[3] = "WDWH_WDWH_SBAR_RAPE___";
            filePath[4] = "SBAR_SBAR_OATS____";
            filePath[5] = "WDWH_SBAR_SETA____";
            filePath[6] = "WBAR_SBAR_SBAR_SETA___";
            filePath[7] = "SBAR_SBAR_SBAR_SETA___";
            filePath[8] = "SBAR_SBAR_RAPE_OATS___";
            filePath[9] = "WDWH_SBAR_WDWH_SBAR_SDPO__";
            filePath[10] = "SBAR_SBAR_SETA_SBAR_SDPO__";
            filePath[11] = "SBAR_SBAR_SETA_SBAR_POTA__";
            filePath[12] = "RAPE_WDWH_SETA_SBAR_SBAR_SDPO_";
            filePath[13] = "WDWH_SBAR_SBAR_WBAR_POTA__";
            filePath[14] = "OATS_WDWH_SBAR_SETA_WBAR_SDPO_";
```

```
filePath[15] = "WDWH_WBAR_SETA_WBAR_SBAR_POTA_";
filePath[16] = "WDWH_WBAR_SBAR_WBAR_SBAR_SDPO_";
filePath[17] = "SBAR_SBAR_SBAR_RAPE___";
filePath[18] = "WDWH_SBAR_SBAR____";
filePath[19] = "WDWH_SBAR_SBAR_SBAR_POTA__";
filePath[20] = "WDWH_SBAR_SBAR_SBAR_SDPO__";
filePath[21] = "WDWH_SBAR_PEAS_SBAR_POTA__";
filePath[22] = "WDWH_SBAR_PEAS_SBAR_SDPO__";
filePath[23] = "WDWH_SBAR_SBAR_OATS_SDPO__";
filePath[24] = "WDWH_WBAR_OATS_SBAR_POTA__";
filePath[25] = "WDWH_OATS_SBAR_SBAR_POTA__";
filePath[26] = "WBAR_OATS_SBAR_SBAR_SDPO__";
filePath[27] = "SBAR_OATS_SBAR_SBAR_POTA__";
filePath[28] = "WDWH_SBAR_SBAR_CARR___";
#endregion

#region open output text file stream & header for leaching and
drainage
StreamWriter fs;
fs = new StreamWriter("Rot_Leaching_Drainage.txt", false);
string header = "Rotation\tAverage Leaching (kg/ha)\tAverage
Drainage (kg/ha)";
fs.WriteLine(header);
#endregion

#region open output text file stream & header for yield
StreamWriter fs2;
fs2 = new StreamWriter("Yield.txt", false);
string header2 = "Rotation\tCrop\tAverage Yield (t/ha)\tStD Yield
(t/ha)";
fs2.WriteLine(header2);
#endregion

#region open output text file stream & header for crop leaching
StreamWriter fs3;
fs3 = new StreamWriter("Crop_Leaching.txt", false);
string header3 = "Rotation\tCrop\tAverage Leaching (kg/ha)";
fs3.WriteLine(header3);
#endregion

#region loop for all simulations folders
for (int i = 0; i < simNbr; i++)
{
    #region Leaching and Drainage

    #region open simulation outputs xls file
    ExcelObj = new Excel.Application();
    theWorkbook = ExcelObj.Workbooks.Open(path + filePath[i] +
    "\\annual", 0, true, 5, "", "", true,
    Excel.XlPlatform.xlWindows, "\t", false, false, 0, true);
    sheets = theWorkbook.Worksheets;
    worksheet = (Excel.Worksheet)sheets.get_Item(1);
    #endregion

    #region read xls values leaching
    range = worksheet.get_Range("C11326");
    Final = (System.Double)range.Cells.Value;
    range = worksheet.get_Range("C2560");
    Initial = (System.Double)range.Cells.Value;
    #endregion
```

```
#region Average Leaching
mean_Lix = Final;
mean_Lix -= Initial;
mean_Lix /= 24;
mean_Lix *= 10;
#endregion

#region read xls values drainage
range = worksheet.get_Range("B2561", "B11326");
myvalues = (System.Array)range.Cells.Value;
VarArray = ConvertToDoubleArray(myvalues);
#endregion

#region Average Drainage
mean_Drain = 0;
for (int j = 0; j<VarArray.Length; j++)
mean_Drain += VarArray[j];
mean_Drain /= 24;
#endregion

#region write a new line in output text file & console
fs.WriteLine("{0}\t{1}\t{2}", filePath[i], mean_Lix,
mean_Drain);
#endregion

#endregion

#region Yield
#region open simulation outputs xls file
ExcelObj = new Excel.Application();
theWorkbook = ExcelObj.Workbooks.Open(path + filePath[i] +
"\\harvest", 0, true, 5, "", "", true,
Excel.XlPlatform.xlWindows, "\t", false, false, 0, true);
sheets = theWorkbook.Worksheets;
worksheet = (Excel.Worksheet)sheets.get_Item(1);
#endregion

#region read xls values & average
//read crop names
range = worksheet.get_Range("B11", "B34");
myvalues = (System.Array)range.Cells.Value;
NameArray = ConvertToStringArray(myvalues);
//read values
range = worksheet.get_Range("C11", "C34");
myvalues = (System.Array)range.Cells.Value;
VarArray = ConvertToDoubleArray(myvalues);
//list of the different crops
List<string> CropNames=new List<string>();
CropNames.Clear();
CropNames.Add(NameArray[0]);
for (int j = 1; j < NameArray.Length; j++)
    if (!CropNames.Contains(NameArray[j]))
        CropNames.Add(NameArray[j]);
#endregion

//loop for all crops in rotation
foreach (string NameCrop in CropNames)
{
```

```
 #region Average and Standard deviation
     mean_Yield = 0;
     int count = 0;
     for (int j = 0; j < NameArray.Length; j++)
         if (NameArray[j] == NameCrop)
         {
             mean_Yield += VarArray[j];
             count++;
         }
     mean_Yield /= count;
     mean_Yield *= 0.025;

     mean_Yield2 = 0;
     count = 0;
     for (int j = 0; j < NameArray.Length; j++)
         if (NameArray[j] == NameCrop)
         {
             mean_Yield2 += VarArray[j];
             count++;
         }
     mean_Yield2 /= count;

     sd_Yield = 0;
     count = 0;
     for (int j = 0; j < NameArray.Length; j++)
         if (NameArray[j] == NameCrop)
         {
            sd_Yield += Math.Pow(VarArray[j] - mean_Yield2, 2);
             count++;
         }
     sd_Yield /= count - 1;
     sd_Yield = Math.Sqrt(sd_Yield);
     sd_Yield *= 0.025;
 #endregion

 #region write a new line in output text file & console
 fs2.WriteLine("{0}\t{1}\t{2}\t{3}",   filePath[i], NameCrop,
 mean_Yield, sd_Yield);
 #endregion
}
 #endregion

 #region Crop Leaching
 #region open simulation outputs xls file
 ExcelObj = new Excel.Application();
 theWorkbook = ExcelObj.Workbooks.Open(path + filePath[i] +
 "\\harvest", 0, true, 5, "", "", true,
 Excel.XlPlatform.xlWindows, "\t", false, false, 0, true);
 sheets = theWorkbook.Worksheets;
 worksheet = (Excel.Worksheet)sheets.get_Item(1);
 #endregion

 #region read xls values & average
 //read crop names
 range = worksheet.get_Range("B12", "B34");
 myvalues = (System.Array)range.Cells.Value;
 NameArray = ConvertToStringArray(myvalues);
 //read values
 range = worksheet.get_Range("D12", "D34");
 myvalues = (System.Array)range.Cells.Value;
```

```
        VarArray = ConvertToDoubleArray(myvalues);
        //list of the different crops
        List<string> CropNames2 = new List<string>();
        CropNames2.Clear();
        CropNames2.Add(NameArray[0]);
        for (int j = 1; j < NameArray.Length; j++)
            if (!CropNames2.Contains(NameArray[j]))
                CropNames2.Add(NameArray[j]);
        #endregion

        //loop for all crops in rotation
        foreach (string NameCrop in CropNames2)
        {
            #region Average and Standard deviation
            mean_Leach = 0;
            int count = 0;
            for (int j = 0; j < NameArray.Length; j++)
                if (NameArray[j] == NameCrop)
                {
                    mean_Leach += VarArray[j];
                    count++;
                }
            mean_Leach /= count;
            mean_Leach *= 10;
            #endregion

            #region write a new line in output text file & console
             fs3.WriteLine("{0}\t{1}\t{2}\t{3}", filePath[i], NameCrop,
             mean_Leach, sd_Leach);
            #endregion
        }
        #endregion
       Console.WriteLine(filePath[i]);

        ExcelObj.Quit();
    }
    #endregion

    #region Ending Leaching
    fs.Close();
    #endregion

    #region Ending Crop Leaching
    fs3.Close();
    #endregion

    #region Ending Yield
    fs2.Close();
    Console.WriteLine("\nFinished, \npress enter to close.");
    Console.ReadLine();
    #endregion
}
```

Annex X - Example of COUP Fertilisation File

```
1974-03-15 12:00    5.6
1974-04-15 12:00    8.4
1975-03-05 12:00    5
1975-03-25 12:00    5
1976-03-15 12:00    5.6
1976-04-15 12:00    8.4
1977-03-05 12:00    5
1977-03-25 12:00    5
1978-05-10 12:00    3.4
1978-05-30 12:00    3.4
1979-04-05 12:00    6.24
1979-05-05 12:00    9.36
1980-03-15 12:00    5.6
1980-04-15 12:00    8.4
1981-03-05 12:00    5
1981-03-25 12:00    5
1982-03-15 12:00    5.6
1982-04-15 12:00    8.4
1983-03-05 12:00    5
1983-03-25 12:00    5
1984-05-10 12:00    3.4
1984-05-30 12:00    3.4
1985-04-05 12:00    6.24
1985-05-05 12:00    9.36
1986-03-15 12:00    5.6
1986-04-15 12:00    8.4
1987-03-05 12:00    5
1987-03-25 12:00    5
1988-03-15 12:00    5.6
1988-04-15 12:00    8.4
1989-03-05 12:00    5
1989-03-25 12:00    5
1990-05-10 12:00    3.4
1990-05-30 12:00    3.4
1991-04-05 12:00    6.24
1991-05-05 12:00    9.36
1992-03-15 12:00    5.6
1992-04-15 12:00    8.4
1993-03-05 12:00    5
1993-03-25 12:00    5
1994-03-15 12:00    5.6
1994-04-15 12:00    8.4
1995-03-05 12:00    5
1995-03-25 12:00    5
1996-05-10 12:00    3.4
1996-05-30 12:00    3.4
1997-04-05 12:00    6.24
1997-05-05 12:00    9.36
1998-03-15 12:00    5.6
1998-04-15 12:00    8.4
1999-03-05 12:00    5
1999-03-25 12:00    5
2000-03-15 12:00    5.6
2000-04-15 12:00    8.4
2001-03-05 12:00    5
2001-03-25 12:00    5
```

```
2002-05-10 12:00    3.4
2002-05-30 12:00    3.4
2003-04-05 12:00    6.24
2003-05-05 12:00    9.36
2004-03-15 12:00    5.6
2004-04-15 12:00    8.4
2005-03-05 12:00    5
2005-03-25 12:00    5
2006-03-15 12:00    5.6
2006-04-15 12:00    8.4
2007-03-05 12:00    5
2007-03-25 12:00    5
2008-05-10 12:00    3.4
2008-05-30 12:00    3.4
```

Annex XI - Additional COUP Output

Original and corrected yield absolute (tonnes/ha) and relative (%) values

Rotation	Crop	Sc1	Sc2	Sc3	Sc4	RD Sc1-Sc2	RD Sc3-Sc4	RD Sc1-Sc3	RD Sc2-Sc4
OATS_WDWH_SBAR_SETA_WBAR_SDPO_	WDWH	6.83	8.21	8.17	8.79	-18.29	-7.35	17.82	6.87
WDWH_SBAR_PEAS_SBAR_POTA__	WDWH	4.36	5.17	5.16	6.98	-17.02	-30.00	16.90	29.87
WDWH_SBAR_SBAR_OATS_SDPO__	WDWH	4.70	5.79	6.02	7.54	-20.82	-22.38	24.67	26.22
WDWH_SBAR_SBAR_SBAR_SDPO__	WDWH	5.17	6.25	6.34	7.88	-18.76	-21.60	20.27	23.10
WDWH_SBAR_SBAR_SBAR_POTA__	WDWH	4.36	5.16	5.18	6.24	-16.93	-18.60	17.19	18.85
WDWH_SBAR_SBAR____	WDWH	6.84	8.16	8.07	8.99	-17.67	-10.75	16.52	9.60
WDWH_WBAR_OATS_SBAR_POTA__	WDWH	4.40	5.21	5.22	6.30	-16.93	-18.87	17.03	18.97
WDWH_WBAR_SBAR_WBAR_SBAR_SDPO_	WDWH	5.44	6.59	7.09	8.43	-19.15	-17.36	26.37	24.59
WDWH_SBAR_PEAS_SBAR_SDPO__	WDWH	4.96	6.19	6.06	7.86	-22.08	-25.91	20.00	23.84
WDWH_OATS_SBAR_SBAR_POTA__	WDWH	4.38	5.19	5.20	6.27	-17.00	-18.63	17.13	18.77
WDWH_WBAR_SETA_WBAR_SBAR_POTA_	WDWH	4.57	5.76	5.56	6.01	-23.09	-7.64	19.68	4.19
WDWH_SBAR_SBAR_WBAR_POTA__	WDWH	4.40	5.20	5.21	6.25	-16.67	-18.24	16.87	18.44
RAPE_WDWH_SETA_SBAR_SBAR_SDPO_	WDWH	6.05	7.91	7.57	9.48	-26.56	-22.42	22.22	18.06
WDWH_SBAR_WDWH_SBAR_SDPO__	WDWH	5.09	6.38	6.45	7.90	-22.46	-20.25	23.55	21.34
WDWH_SBAR_SETA____	WDWH	5.51	6.48	6.61	7.67	-16.18	-14.85	18.15	16.82
		(6.48)	(5.61)	(6.47)	(5.61)				
WDWH_WDWH_SBAR_RAPE___	WDWH	7.26	8.17	8.44	9.03	-11.68	-6.76	14.91	10.00
WDWH_SBAR_RAPE____	WDWH	7.09	7.75	8.05	8.84	0.00	0.00	0.00	0.00
WDWH_SBAR_SBAR_CARR___	WDWH	4.14	4.72	4.86	5.56	-13.28	-13.42	16.07	16.22
WDWH_WBAR_RAPE____	WDWH	6.79	8.15	8.56	9.06	-18.11	-5.77	22.95	10.66
WBAR_SBAR_SBAR_SETA___	WBAR	7.44	8.19	7.72	8.49	0.00	0.00	0.00	0.00
OATS_WDWH_SBAR_SETA_WBAR_SDPO_	WBAR	6.66	7.81	6.88	8.01	-15.83	-15.18	3.17	2.52

WDWH_WBAR_SETA_WBAR_SBAR_POTA_	WBAR	6.85	7.44	7.44	7.94	-8.23	-6.56	8.21	6.55
			(7.74)		(7.64)				
WDWH_WBAR_SBAR_WBAR_SBAR_SDPO_	WBAR	6.40	6.75	7.05	7.28	-5.29	-3.19	9.56	7.46
WBAR_SBAR_SBAR_RAPE___	WBAR	7.38	7.72	8.04	8.17	-4.46	-1.71	8.47	5.73
WDWH_WBAR_RAPE____	WBAR	6.16	6.41	6.64	7.14	-3.94	-7.19	7.51	10.76
WDWH_SBAR_SBAR_WBAR_POTA__	WBAR	7.91	8.18	8.47	8.55	-3.37	-0.95	6.89	4.47
WBAR_OATS_SBAR_SBAR_SDPO__	WBAR	7.49	8.05	7.74	8.15	0.00	0.00	0.00	0.00
WDWH_WBAR_OATS_SBAR_POTA__	WBAR	5.95	6.70	6.81	7.46	-11.94	-9.12	13.55	10.74
WDWH_SBAR_SETA____	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WBAR_SBAR_SBAR_SETA___	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SBAR_SBAR_SBAR_SETA___	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SBAR_SBAR_SETA_SBAR_SDPO__	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SBAR_SBAR_SETA_SBAR_POTA__	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAPE_WDWH_SETA_SBAR_SBAR_SDPO_	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OATS_WDWH_SBAR_SETA_WBAR_SDPO_	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WDWH_WBAR_SETA_WBAR_SBAR_POTA_	SETA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WDWH_SBAR_PEAS_SBAR_SDPO__	SDPO	11.72	9.74	11.80	9.75	18.51	19.04	0.66	0.13
WBAR_OATS_SBAR_SBAR_SDPO__	SDPO	12.10	11.20	12.18	11.20	7.73	8.36	0.64	0.00
WDWH_SBAR_WDWH_SBAR_SDPO__	SDPO	12.14	10.85	11.87	10.85	11.24	8.98	-2.22	0.05
SBAR_SBAR_SETA_SBAR_SDPO__	SDPO	10.53	9.51	10.57	9.51	10.15	10.60	0.45	0.01
RAPE_WDWH_SETA_SBAR_SBAR_SDPO_	SDPO	8.72	9.41	9.63	9.41	-7.54	2.33	9.88	0.01
WDWH_SBAR_SBAR_SBAR_SDPO__	SDPO	10.83	9.75	10.89	9.76	10.50	11.00	0.57	0.07
OATS_WDWH_SBAR_SETA_WBAR_SDPO_	SDPO	9.52	9.39	9.61	9.40	1.39	2.17	0.94	0.15
WDWH_WBAR_SBAR_WBAR_SBAR_SDPO_	SDPO	9.73	9.64	9.92	9.67	0.96	2.60	1.96	0.32
WDWH_SBAR_SBAR_OATS_SDPO__	SDPO	10.66	9.93	10.81	9.94	7.09	8.39	1.40	0.10
		(18.28)	(18.29)	(18.64)	(18.39)				
WBAR_OATS_SBAR_SBAR_SDPO__	SBAR	5.22	5.87	5.90	6.60	-11.71	-11.23	12.23	11.75

WDWH_SBAR_SBAR_SBAR_POTA__	SBAR	5.99	6.66	6.80	7.38	-10.59	-8.16	12.66	10.23
WDWH_SBAR_SBAR____	SBAR	6.07	6.40	6.71	6.93	-5.30	-3.20	10.00	7.91
WDWH_SBAR_PEAS_SBAR_POTA__	SBAR	6.78	7.26	7.59	7.82	-6.78	-2.98	11.20	7.41
SBAR_SBAR_SETA_SBAR_SDPO__	SBAR	6.08	6.70	6.76	7.27	0.00	0.00	0.00	0.00
SBAR_SBAR_SETA_SBAR_POTA__	SBAR	5.82	6.75	6.66	7.54	-14.75	-12.27	13.53	11.05
SBAR_SBAR_RAPE_OATS___	SBAR	5.45	6.12	6.15	6.77	-11.64	-9.68	12.05	10.09
SBAR_SBAR_SBAR_RAPE___	SBAR	5.70	6.37	6.39	6.91	-11.19	-7.78	11.46	8.05
WBAR_SBAR_SBAR_SETA___	SBAR	6.11	7.01	6.52	7.61	-13.70	-15.37	6.47	8.14
WDWH_SBAR_SETA____	SBAR	6.54	7.55	7.10	8.08	-14.39	-12.90	8.28	6.78
SBAR_SBAR_OATS____	SBAR	5.48	6.13	6.18	6.73	-11.14	-8.54	11.90	9.30
WDWH_WDWH_SBAR_RAPE___	SBAR	6.08	6.25	6.76	6.83	-2.73	-0.98	10.60	8.85
SBAR_OATS_SBAR_SBAR_POTA__	SBAR	5.20	6.02	6.03	6.84	-14.58	-12.49	14.82	12.73
WBAR_SBAR_SBAR_RAPE___	SBAR	5.40	6.03	6.43	6.71	-11.15	-4.38	17.40	10.65
WDWH_SBAR_RAPE____	SBAR	6.08	6.45	6.63	7.00	-5.88	-5.45	8.66	8.23
WDWH_SBAR_SBAR_CARR___	SBAR	4.78	5.69	5.70	6.46	-17.35	-12.51	17.56	12.72
SBAR_SBAR_SBAR_SETA___	SBAR	6.08	6.92	6.75	7.55	-13.01	-11.30	10.43	8.72
OATS_WDWH_SBAR_SETA_WBAR_SDPO_	SBAR	6.74	6.80	7.32	7.37	-0.79	-0.69	8.16	8.05
WDWH_WBAR_SETA_WBAR_SBAR_POTA_	SBAR	5.62	6.25	6.31	6.89	-10.58	-8.86	11.46	9.74
			(7.21)		(6.62)				
WDWH_SBAR_SBAR_OATS_SDPO__	SBAR	5.65	6.10	6.33	6.73	-7.71	-6.16	11.41	9.86
WDWH_WBAR_OATS_SBAR_POTA__	SBAR	6.02	6.63	6.97	7.43	-9.72	-6.44	14.60	11.34
WDWH_SBAR_WDWH_SBAR_SDPO__	SBAR	6.57	6.76	7.21	7.38	-2.86	-2.42	9.20	8.77
WDWH_SBAR_SBAR_SBAR_SDPO__	SBAR	5.66	6.15	6.37	6.80	-8.20	-6.43	11.79	10.03
WDWH_SBAR_PEAS_SBAR_SDPO__	SBAR	6.42	6.63	7.15	7.21	-3.29	-0.85	10.72	8.29
WDWH_WBAR_SBAR_WBAR_SBAR_SDPO_	SBAR	5.85	6.25	6.57	6.90	-6.61	-4.88	11.70	9.97
WDWH_SBAR_SBAR_WBAR_POTA__.	SBAR	6.02	6.65	6.81	7.34	-9.93	-7.53	12.22	9.82
WDWH_OATS_SBAR_SBAR_POTA__	SBAR	5.66	6.32	6.44	7.09	-10.88	-9.51	12.86	11.50

RAPE_WDWH_SETA_SBAR_SBAR_SDPO_	SBAR	5.59	6.69	6.25	7.39	-17.97	-16.74	11.12	9.88
		5.88	6.49	6.60	7.14	-9.86	-7.86	11.54	9.54
WDWH_WDWH_SBAR_RAPE___	RAPE	3.92	3.59	3.95	3.62	8.77	8.74	0.69	0.72
WDWH_WBAR_RAPE____	RAPE	3.79	3.57	3.94	3.62	6.09	8.47	3.76	1.37
		(8.46)							
WBAR_SBAR_SBAR_RAPE___	RAPE	3.92	3.59	3.95	3.62	8.77	8.74	0.68	0.71
SBAR_SBAR_SBAR_RAPE___	RAPE	3.87	3.55	3.92	3.59	8.63	8.77	1.35	1.20
		(8.48)	(9.47)						
SBAR_SBAR_RAPE_OATS___	RAPE	3.71	3.38	3.75	3.38	9.29	10.34	1.06	0.00
WDWH_SBAR_RAPE____	RAPE	3.43	3.43	3.79	3.45	0.00	9.30	9.75	0.46
RAPE_WDWH_SETA_SBAR_SBAR_SDPO_	RAPE	3.75	3.51	3.88	3.55	6.61	8.88	3.41	1.13
		(5.19)	(6.57)	(5.49)	(6.89)				
SBAR_OATS_SBAR_SBAR_POTA__	POTA	33.71	32.69	34.04	32.99	3.08	3.13	0.97	0.91
WDWH_WBAR_OATS_SBAR_POTA__	POTA	33.97	32.90	34.26	33.13	3.22	3.34	0.85	0.72
WDWH_OATS_SBAR_SBAR_POTA__	POTA	33.80	32.68	34.04	33.00	3.35	3.08	0.71	0.97
SBAR_SBAR_SETA_SBAR_POTA__	POTA	33.27	32.89	33.61	33.13	1.16	1.43	1.00	0.73
WDWH_SBAR_SBAR_WBAR_POTA__	POTA	33.90	32.85	34.19	33.17	3.14	3.01	0.84	0.97
WDWH_SBAR_SBAR_SBAR_POTA__	POTA	33.77	32.67	34.01	32.98	3.32	3.06	0.70	0.96
WDWH_SBAR_PEAS_SBAR_POTA__	POTA	33.66	32.56	33.85	32.93	3.30	2.77	0.58	1.12
WDWH_WBAR_SETA_WBAR_SBAR_POTA_	POTA	31.48	30.88	31.85	31.16	1.92	2.20	1.18	0.90
			(33.13)		(31.96)				
WDWH_SBAR_PEAS_SBAR_SDPO__	PEAS	4.41	3.75	4.43	3.79	16.19	15.80	0.51	0.90
WDWH_SBAR_PEAS_SBAR_POTA__	PEAS	5.06	4.67	5.08	4.72	7.96	7.52	0.49	0.93
SBAR_SBAR_OATS____	OATS	4.00	4.32	4.55	4.67	-7.74	-2.43	12.99	7.70
SBAR_OATS_SBAR_SBAR_POTA__	OATS	3.54	5.13	4.43	5.59	-36.66	-23.09	22.27	8.46
WDWH_OATS_SBAR_SBAR_POTA__	OATS	4.96	5.85	5.69	6.16	-16.42	-7.95	13.67	5.19
SBAR_SBAR_RAPE_OATS___	OATS	3.88	5.06	4.85	5.65	-26.59	-15.19	22.32	10.88

OATS_WDWH_SBAR_SETA_WBAR_SDPO_	OATS	4.96	5.74	5.52	5.78	-14.68	-4.55	10.79	0.64
WBAR_OATS_SBAR_SBAR_SDPO__	OATS	3.21	4.69	4.32	5.61	-37.47	-25.97	29.46	17.83
WDWH_WBAR_OATS_SBAR_POTA__	OATS	4.61	5.14	5.11	5.64	-10.98	-9.94	10.31	9.27
WDWH_SBAR_SBAR_OATS_SDPO__	OATS	4.10	4.73	4.74	5.08	-14.22	-7.04	14.42	7.24
WDWH_SBAR_SBAR_CARR___	CARR	44.29	45.16	44.30	45.16	-1.95	-1.94	0.01	0.00

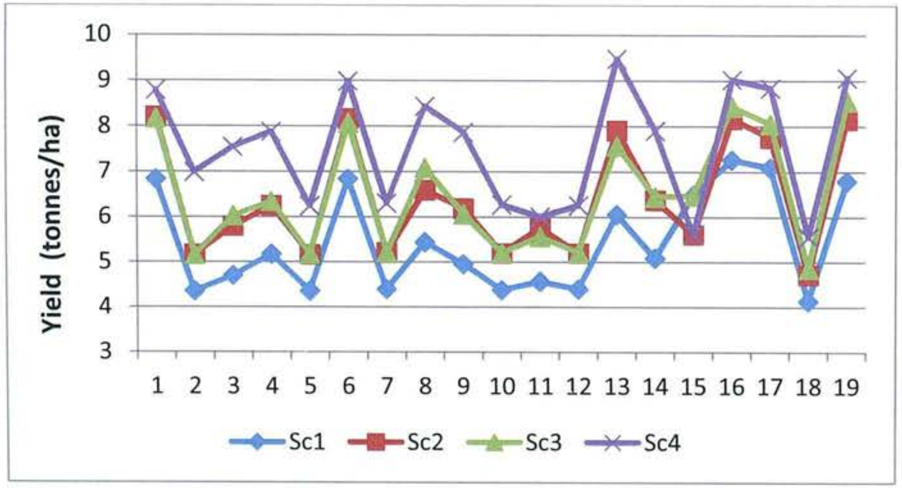
( ): corrected COUP values
RD: relative difference

Average annual nitrate leaching absolute (kg/ha) and relative (%) values

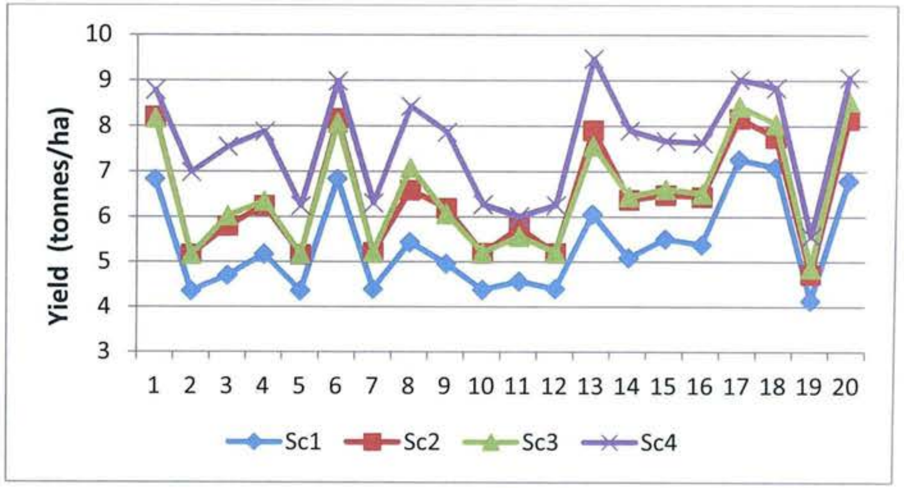
Rotation	Sc1	Sc2	Sc3	Sc4	RD Sc1-Sc2	RD Sc3-Sc4	RD Sc1-Sc3	RD Sc2-Sc4
WDWH_WBAR_RAPE____	33.41	53.93	39.45	59.04	-46.99	-39.78	16.59	9.06
WDWH_SBAR_RAPE____	64.89	64.67	50.37	77.19	0.35	-42.06	-25.21	17.66
WBAR_SBAR_SBAR_RAPE___	26.53	52.24	33.54	61.83	-65.28	-59.34	23.34	16.82
WDWH_WDWH_SBAR_RAPE___	34.49	60.44	42.69	71.27	-54.69	-50.15	21.26	16.44
SBAR_SBAR_OATS____	26.83	44.89	26.59	44.70	-50.34	-50.79	-0.90	-0.41
WDWH_SBAR_SETA____	92.28	130.21	106.17	146.00	-34.10	-31.59	14.00	11.43
WBAR_SBAR_SBAR_SETA___	68.25	105.22	74.96	118.08	-42.63	-44.68	9.38	11.52
SBAR_SBAR_SBAR_SETA___	69.15	107.45	73.37	117.86	-43.38	-46.53	5.92	9.24
SBAR_SBAR_RAPE_OATS___	31.99	54.27	37.87	62.06	-51.67	-48.42	16.84	13.40
WDWH_SBAR_WDWH_SBAR_SDPO__	35.48	60.25	37.80	61.33	-51.75	-47.47	6.33	1.78
SBAR_SBAR_SETA_SBAR_SDPO__	65.53	108.13	72.50	121.08	-49.06	-50.19	10.10	11.30
SBAR_SBAR_SETA_SBAR_POTA__	64.47	108.62	77.27	124.78	-51.01	-47.03	18.07	13.85
RAPE_WDWH_SETA_SBAR_SBAR_SDPO_	74.42	109.79	89.00	122.55	-38.39	-31.72	17.83	10.98
WDWH_SBAR_SBAR_WBAR_POTA__	29.92	56.25	36.90	64.22	-61.12	-54.04	20.90	13.24
OATS_WDWH_SBAR_SETA_WBAR_SDPO_	64.11	100.29	75.54	116.01	-44.02	-42.26	16.38	14.54
WDWH_WBAR_SETA_WBAR_SBAR_POTA_	81.97	116.66	98.15	108.37	-34.93	-9.90	17.97	-7.37
WDWH_WBAR_SBAR_WBAR_SBAR_SDPO_	31.95	55.86	33.51	56.30	-54.47	-50.76	4.76	0.78
SBAR_SBAR_SBAR_RAPE___	24.26	42.96	35.40	65.00	-55.62	-58.98	37.32	40.84

WDWH_SBAR_SBAR____	31.72	50.53	32.43	51.65	-45.74	-45.70	2.23	2.18
WDWH_SBAR_SBAR_SBAR_POTA__	30.08	57.01	36.18	63.76	-61.83	-55.19	18.42	11.19
WDWH_SBAR_SBAR_SBAR_SDPO__	32.63	58.13	34.50	59.19	-56.21	-52.72	5.58	1.81
WDWH_SBAR_PEAS_SBAR_POTA__	33.19	59.76	39.59	66.57	-57.16	-50.83	17.58	10.78
WDWH_SBAR_PEAS_SBAR_SDPO__	33.51	59.46	35.33	61.44	-55.83	-53.95	5.30	3.27
WDWH_SBAR_SBAR_OATS_SDPO__	29.46	53.95	30.41	55.21	-58.72	-57.92	3.17	2.30
WDWH_WBAR_OATS_SBAR_POTA__	34.56	60.50	40.92	66.66	-54.58	-47.85	16.86	9.69
WDWH_OATS_SBAR_SBAR_POTA__	29.95	55.35	36.02	61.45	-59.57	-52.17	18.41	10.43
WBAR_OATS_SBAR_SBAR_SDPO__	26.50	49.36	28.89	55.08	-60.29	-62.37	8.66	10.95
SBAR_OATS_SBAR_SBAR_POTA__	28.84	52.25	32.76	57.28	-57.73	-54.48	12.70	9.19
WDWH_SBAR_SBAR_CARR___	25.56	50.79	26.65	53.23	-66.09	-66.56	4.17	4.69
FALL	17.80	20.90	n/a	n/a	-16.02	n/a	n/a	n/a

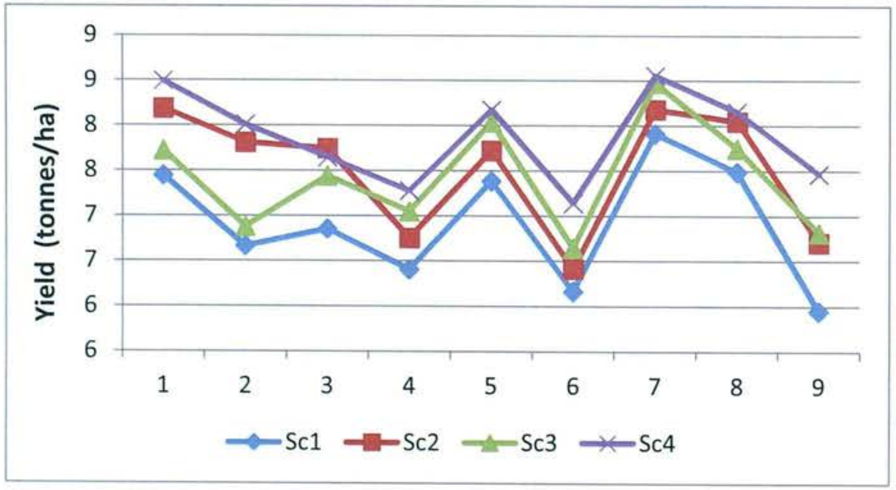
RD: relative difference



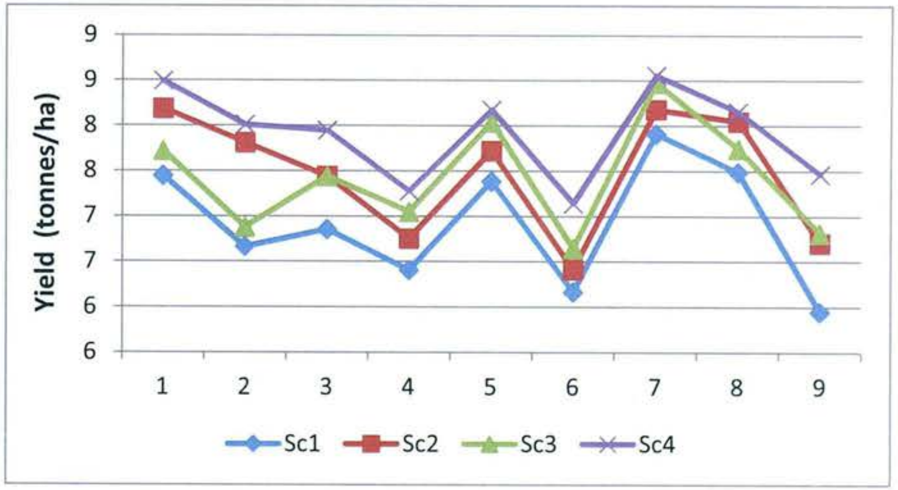
Original yield values - Winter wheat



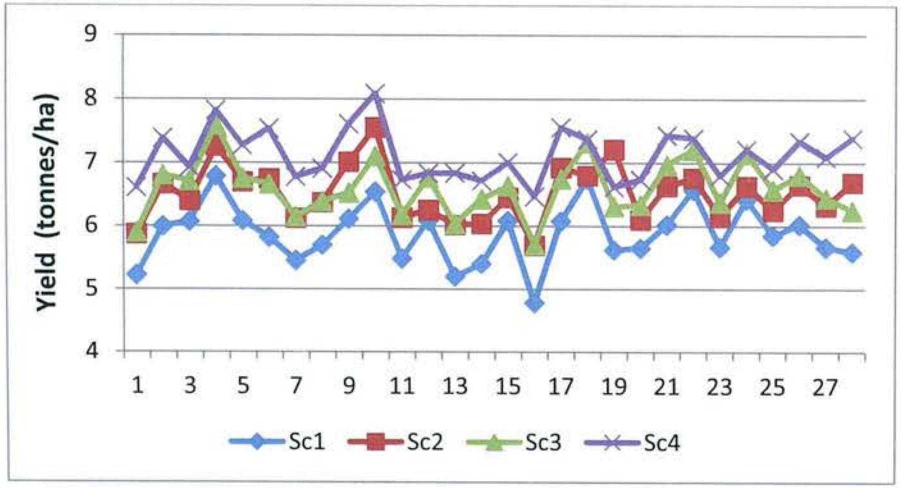
Corrected yield values - Winter wheat



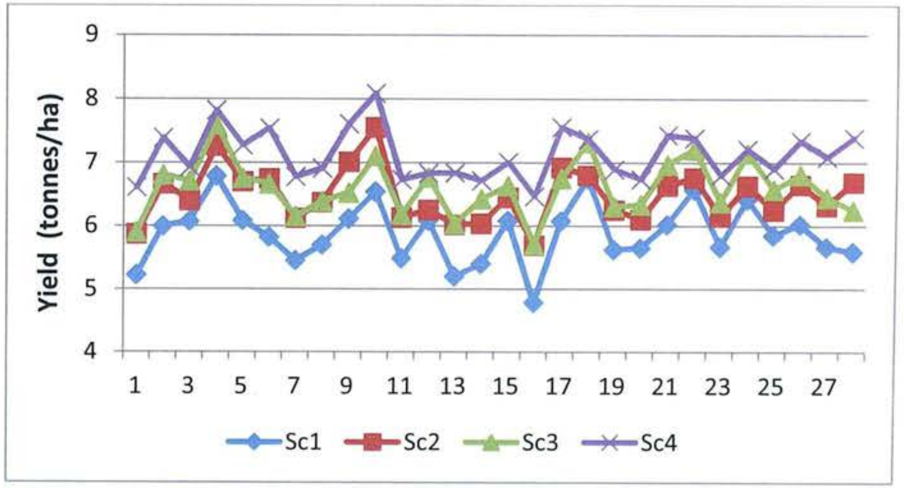
Original yield values – Winter barley



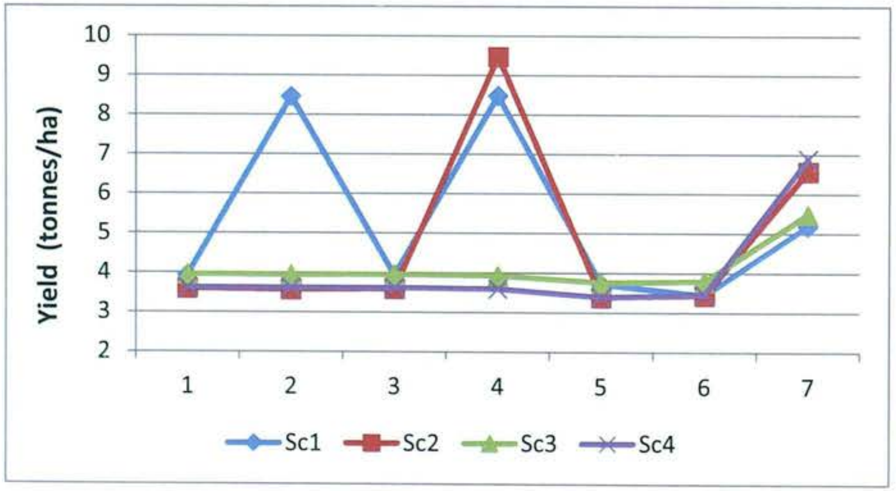
Corrected yield values – Winter barley



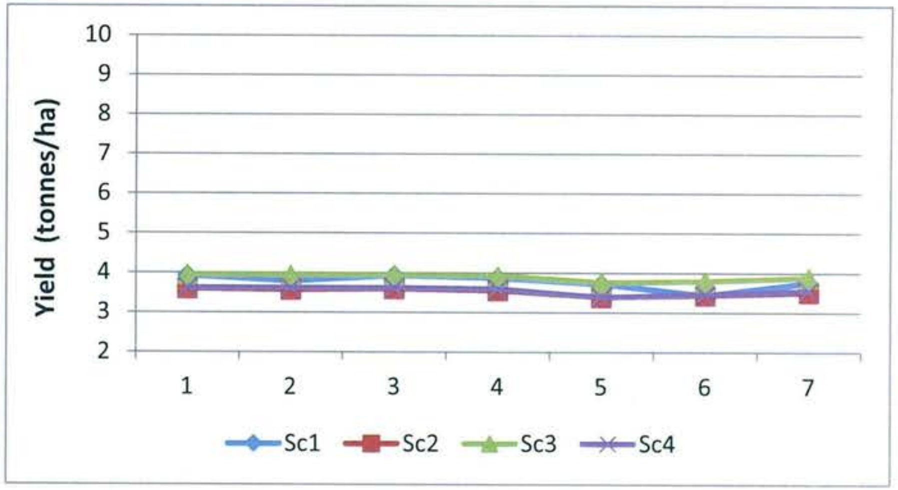
Original yield values - Spring barley



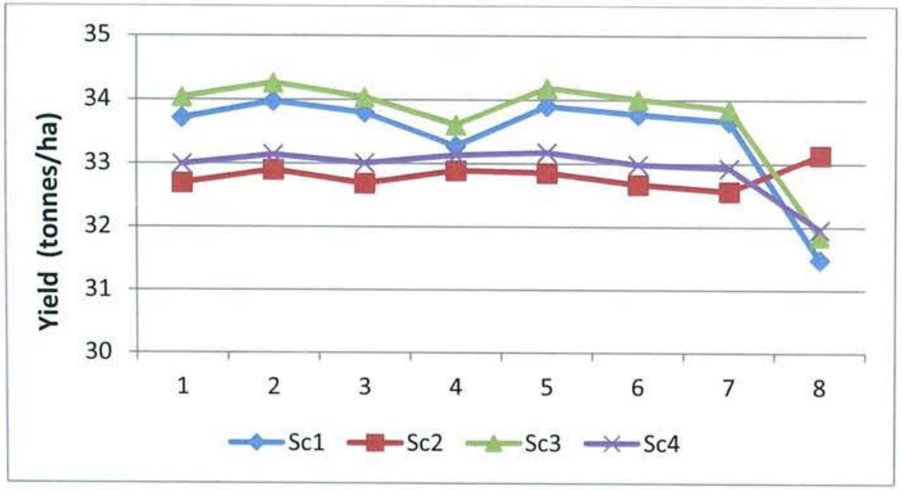
Corrected yield values - Spring barley



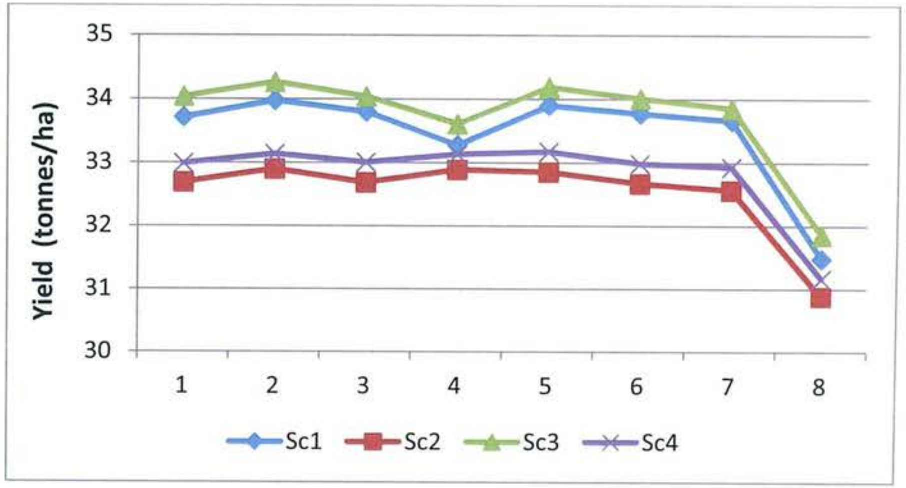
Original yield values - Winter oilseed rape



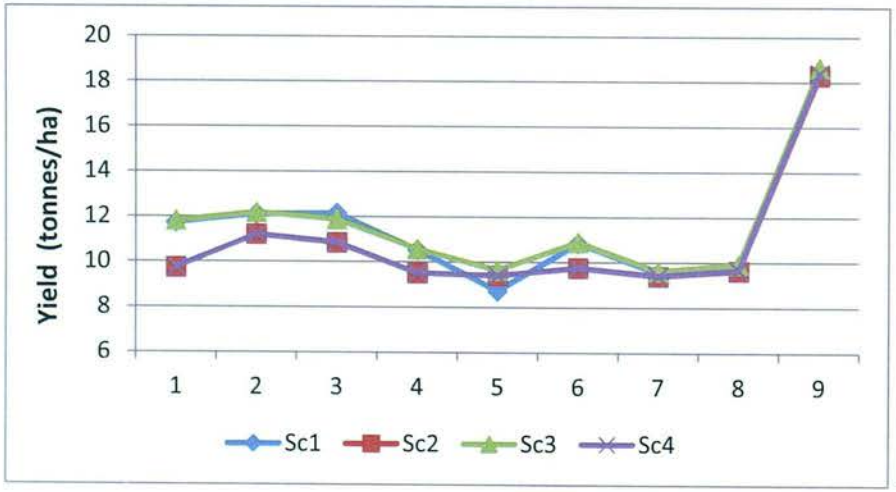
Corrected yield values - Winter oilseed rape



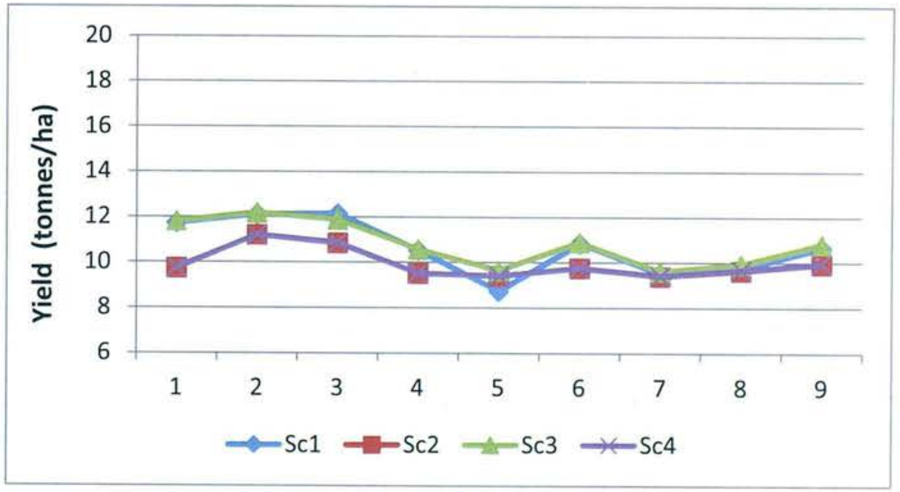
Original yield values - Maincrop potatoes



Corrected yield values - Maincrop potatoes



Original yield values - Seed potatoes



Corrected yield values - Seed potatoes

Average per crop absolute (tonnes/ha) and relative (%) yields used for correction procedure

Crop	Sc1	Sc2	Sc3	Sc4	RD Sc1-Sc2	RD Sc3-Sc4	RD Sc1-Sc3	RD Sc2-Sc4
WDWH	5.38	6.44	6.51	7.63	-17.94	-15.84	19.01	16.92
WBAR	6.92	7.48	7.42	7.91	-7.78	-6.39	6.97	5.59
SBAR	5.88	6.49	6.60	7.14	-9.86	-7.86	11.54	9.54
RAPE	3.75	3.51	3.88	3.55	6.61	8.88	3.41	1.13
POTA	33.44	32.75	33.73	33.05	2.08	2.04	0.86	0.91
SDPO	10.66	9.93	10.81	9.94	7.09	8.39	1.40	0.10

RD: relative difference

Additional yield related figures per crop and scenario

Crop	Scenario	Standard Deviation	Minimum (tonnes/ha)	Maximum (tonnes/ha)	Count
WDWH	Sc1	1.08	4.14	7.26	19
WDWH	Sc2	1.24	4.72	8.21	19
WDWH	Sc3	1.28	4.86	8.56	19
WDWH	Sc4	1.24	5.56	9.48	19
WBAR	Sc1	0.67	5.95	7.91	9
WBAR	Sc2	0.68	6.41	8.19	9
WBAR	Sc3	0.62	6.64	8.47	9
WBAR	Sc4	0.51	7.14	8.55	9
SBAR	Sc1	0.47	4.78	6.78	28
SBAR	Sc2	0.42	5.69	7.55	28
SBAR	Sc3	0.44	5.70	7.59	28
SBAR	Sc4	0.39	6.46	8.08	28
OATS	Sc1	0.64	3.21	4.96	8
OATS	Sc2	0.52	4.32	5.85	8
OATS	Sc3	0.50	4.32	5.69	8
OATS	Sc4	0.45	4.67	6.16	8
RAPE	Sc1	0.17	3.43	3.92	7
RAPE	Sc2	0.08	3.38	3.59	7
RAPE	Sc3	0.08	3.75	3.95	7
RAPE	Sc4	0.09	3.38	3.62	7
SDPO	Sc1	2.65	19.37	26.95	9
SDPO	Sc2	1.44	20.85	24.87	9
SDPO	Sc3	2.18	21.34	27.04	9
SDPO	Sc4	1.43	20.88	24.87	9
POTA	Sc1	1.23	47.22	50.96	8
POTA	Sc2	1.01	46.32	49.34	8
POTA	Sc3	1.18	47.78	51.39	8
POTA	Sc4	1.01	46.74	49.76	8
PEAS	Sc1	0.46	4.41	5.06	2

PEAS	Sc2	0.65	3.75	4.67	2
PEAS	Sc3	0.46	4.43	5.08	2
PEAS	Sc4	0.66	3.79	4.72	2
CARR	Sc1	n/a	44.29	44.29	1
CARR	Sc2	n/a	45.16	45.16	1
CARR	Sc3	n/a	44.30	44.30	1
CARR	Sc4	n/a	45.16	45.16	1
SETA	Sc1	0.00	0.00	0.00	8
SETA	Sc2	0.00	0.00	0.00	8
SETA	Sc3	0.00	0.00	0.00	8
SETA	Sc4	0.00	0.00	0.00	8
FALL	Sc3	n/a	0.00	0.00	1
FALL	Sc4	n/a	0.00	0.00	1

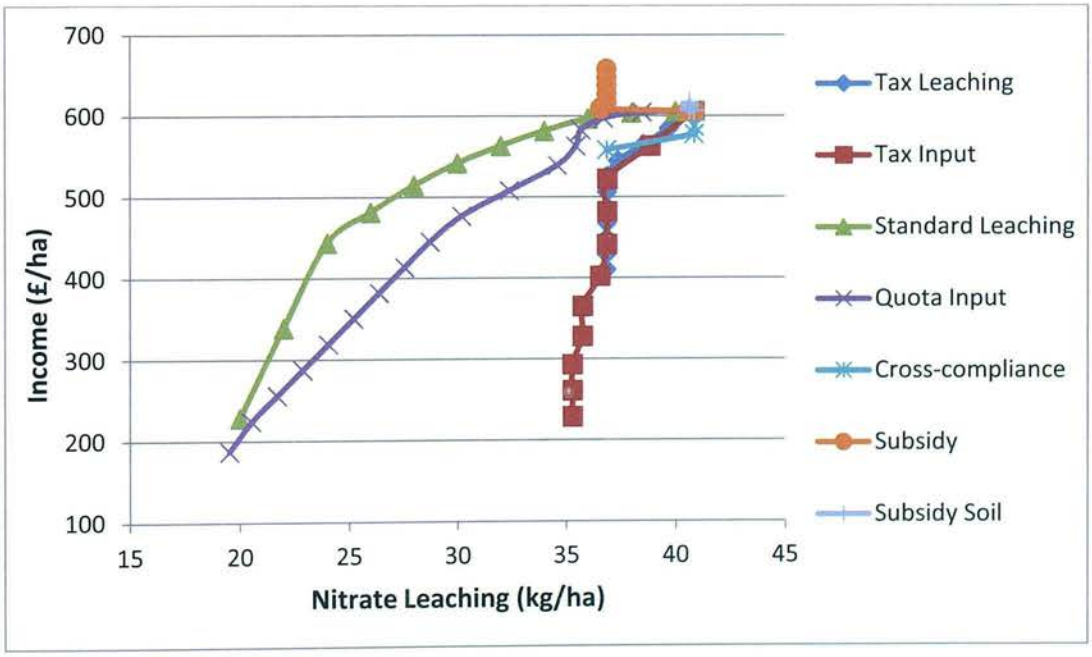
Annex XII - Additional FSSIM-REG Output

CAP Premiums per crop group, farm type, and scenario (£/ha)

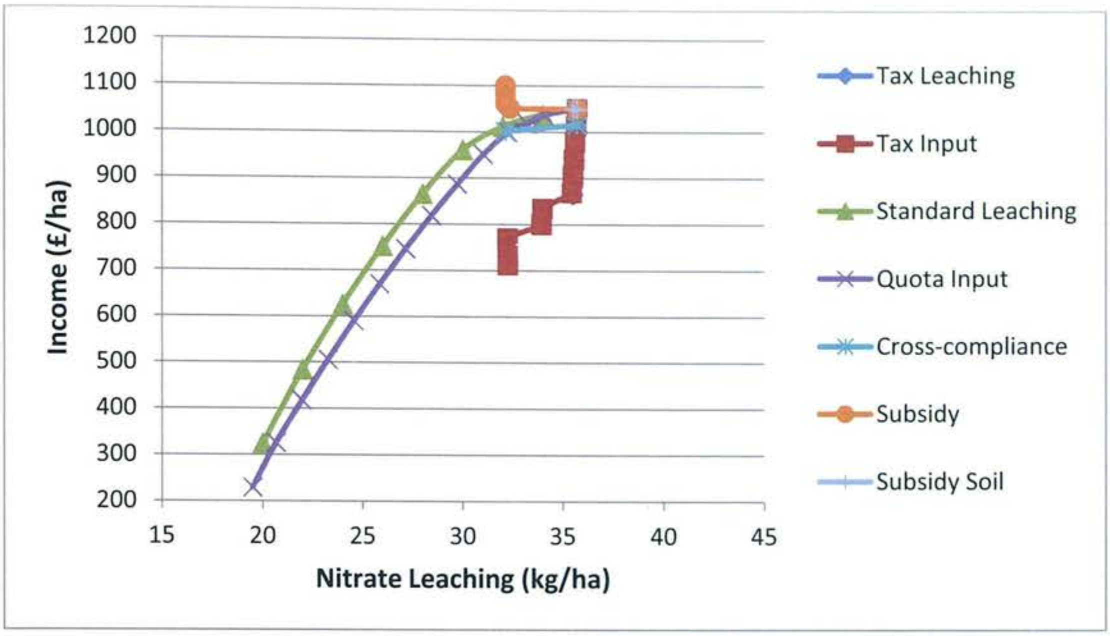
Crop Group	Agenda 2000	2003 CAP Reform				CAP Health Check			
	All	CC1	CC2	GC1	GC2	CC1	CC2	GC1	GC2
Cereals	226.2	242.1	234.2	185	199.5	242.1	235.2	194	204.3
Oilseeds	237.6	242.1	234.2	n/a	199.5	242.1	235.2	n/a	204.3
Proteins	260.8	n/a	n/a	185	199.5	n/a	n/a	194	204.3
Veget.	0	n/a	234.2	185	199.5	n/a	235.2	194	204.3
Set-aside	226.2	242.1	242.1	242.1	242.1	242.1	235.2	194	204.3

PMP estimated terms of the quadratic cost function

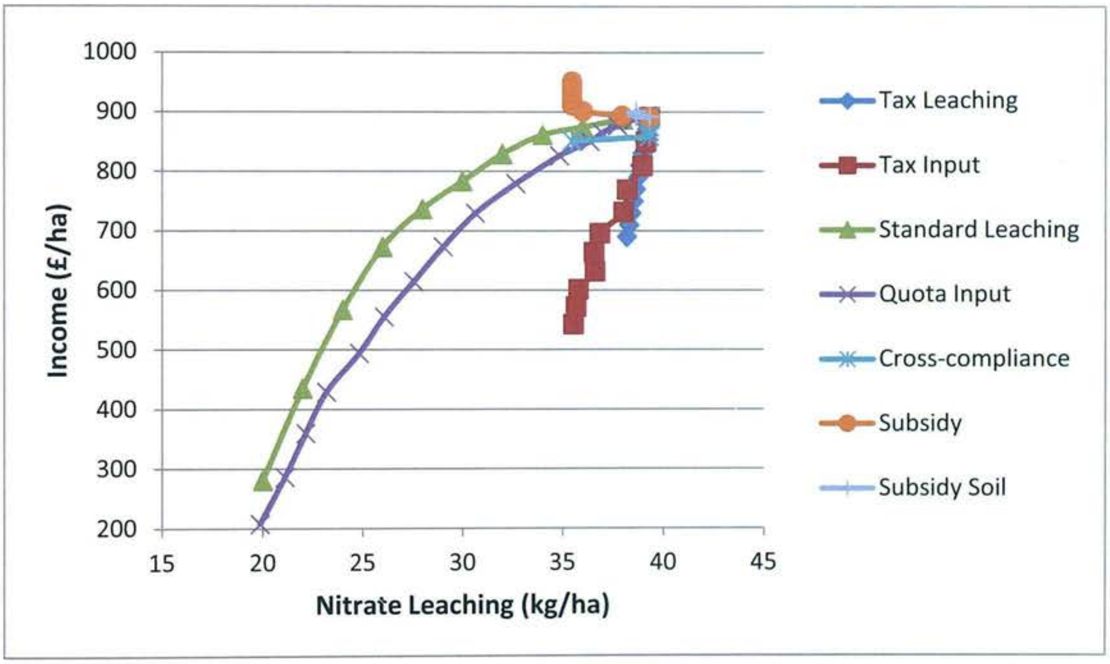
	Linear terms				Non linear terms			
	CC1	**CC2**	**GC1**	**GC2**	**CC1**	**CC2**	**GC1**	**GC2**
W. Wheat	9.1	-9.4	7.1	13.7	33.6	0.1	22.4	1.7
W. Barley	10.7	11.1	42.9	1.6	26.2	5.0	1132.4	0.4
S. Barley	n/e	0.4	-690.4	61.3	n/e	0.0	14.5	3.2
Oats	-328.9	n/a	-172.3	35.5	135.1	n/a	249.1	39.0
Rape	-254.3	-187.4	n/a	-1629.2	75.7	3.2	n/a	35.4
M. Potato	n/a	381.0	311.2	25.2	n/a	295.1	390.4	7.3
S. Potato	n/a	358.6	225.3	-81.7	n/a	1049.5	224.2	2.1
Peas	n/a	n/a	109.5	116.1	n/a	n/a	1599.4	160.1
Carrots	n/a	n/a	n/a	506.2	n/a	n/a	n/a	1437.6



Trade-off curve of nitrate leaching versus income for CC2 (a)



Trade-off curve of nitrate leaching versus income for GC1 (a)



Trade-off curve of nitrate leaching versus income for GC2 (a)

Main economic and environmental results for leaching taxes scenarios

		Baseline	TL-1	TL-2	TL-3	TL-4	TL-5	TL-6	TL-7	TL-8	TL-9	TL-10
CC1	**Farm income (£)**	8640	8336	8033	7729	7426	7125	6824	6524	6225	5926	5632
CC2	**Farm income (£)**	69226	66832	64507	62250	60052	57860	55669	53478	51287	49096	46906
GC1	**Farm income (£)**	18939	18604	18270	17936	17602	17268	16935	16601	16268	15935	15602
GC2	**Farm income (£)**	92283	90170	88063	85962	83867	81779	79696	77619	75548	73483	71425
CC1	**Income (£/ha)**	584	563	543	522	502	481	461	441	420	400	380
CC2	**Income (£/ha)**	606	585	564	545	525	506	487	468	449	430	410
GC1	**Income (£/ha)**	1051	1032	1014	995	977	958	940	921	903	884	866
GC2	**Income (£/ha)**	892	871	851	830	810	790	770	750	730	710	690
CC1	**N use (kg/ha)**	155.0	154.7	154.5	154.2	153.9	153.7	153.3	153.0	152.7	152.0	146.0
CC2	**N use (kg/ha)**	168.2	164.2	160.2	156.2	154.5	154.5	154.5	154.4	154.4	154.4	154.4
GC1	**N use (kg/ha)**	140.4	140.3	140.2	140.1	140.0	139.9	139.8	139.7	139.5	139.4	139.3
GC2	**N use (kg/ha)**	161.2	160.8	160.5	160.1	159.8	159.4	159.1	158.7	158.4	158.0	157.7
CC1	**Nitrate leaching (kg/ha)**	39.5	39.5	39.4	39.4	39.3	39.0	39.0	38.9	38.9	38.7	37.5
CC2	**Nitrate leaching (kg/ha)**	40.9	39.7	38.5	37.4	36.9	36.9	36.9	36.9	36.9	36.9	36.8
GC1	**Nitrate leaching (kg/ha)**	35.7	35.7	35.7	35.6	35.6	35.6	35.6	35.6	35.5	35.5	35.5
GC2	**Nitrate leaching (kg/ha)**	39.3	39.2	39.1	39.0	38.9	38.8	38.6	38.5	38.4	38.3	38.2
CC1	**Phosphorus use (kg/ha)**	54.9	54.8	54.8	54.7	54.6	54.6	54.5	54.4	54.3	54.2	53.6
CC2	**Phosphorus use (kg/ha)**	62.5	61.8	61.2	60.6	60.3	60.3	60.3	60.2	60.2	60.2	60.1
GC1	**Phosphorus use (kg/ha)**	78.8	78.8	78.8	78.8	78.8	78.8	78.7	78.7	78.7	78.7	78.7
GC2	**Phosphorus use (kg/ha)**	77.5	77.4	77.4	77.3	77.2	77.2	77.1	77.0	77.0	76.9	76.9
CC1	**Phosphorus losses (kg/ha)**	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
CC2	**Phosphorus losses (kg/ha)**	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
GC1	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
GC2	**Phosphorus losses (kg/ha)**	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Main economic and environmental results for input taxes scenarios

		TI-0.5	TI-1	TI-1.5	TI-2	TI-2.5	TI-3	TI-3.5	TI-4	TI-4.5	TI-5
CC1	Farm income (£)	8045	7454	6865	6285	5756	5255	4778	4305	3854	3405
CC2	Farm income (£)	64329	59638	55048	50459	45971	41719	37474	33504	29834	26164
GC1	Farm income (£)	18282	17628	16977	16328	15682	15043	14437	13884	13370	12859
GC2	Farm income (£)	87987	83772	79642	75722	72041	68707	65402	62275	59214	56166
CC1	Income (£/ha)	543	503	464	425	389	355	323	291	260	230
CC2	Income (£/ha)	563	522	482	441	402	365	328	293	261	229
GC1	Income (£/ha)	1014	978	942	906	870	835	801	770	742	713
GC2	Income (£/ha)	850	809	769	732	696	664	632	602	572	543
CC1	N use (kg/ha)	154.1	153.2	152.4	145.5	132.6	124.0	124.0	117.3	116.9	116.6
CC2	N use (kg/ha)	161.3	154.5	154.4	154.4	146.8	142.9	142.8	123.5	123.5	123.5
GC1	N use (kg/ha)	139.8	139.3	138.7	138.1	137.6	129.6	129.3	109.8	109.4	109.0
GC2	N use (kg/ha)	158.1	155.1	147.2	144.1	126.9	123.0	122.5	114.0	113.5	113.0
CC1	Nitrate leaching (kg/ha)	39.4	39.2	39.1	37.8	35.6	35.3	35.2	35.1	35.1	35.0
CC2	Nitrate leaching (kg/ha)	38.9	36.9	36.9	36.9	36.6	35.8	35.8	35.3	35.3	35.3
GC1	Nitrate leaching (kg/ha)	35.6	35.6	35.5	35.5	35.4	34.0	33.9	32.2	32.2	32.2
GC2	Nitrate leaching (kg/ha)	39.1	39.0	38.2	38.0	36.8	36.6	36.6	35.8	35.7	35.5
CC1	Phosphorus use (kg/ha)	54.7	54.5	54.3	53.5	52.4	52.2	52.1	52.0	51.9	51.8
CC2	Phosphorus use (kg/ha)	61.4	60.3	60.3	60.3	60.2	60.3	60.4	60.4	60.3	60.3
GC1	Phosphorus use (kg/ha)	78.8	78.8	78.8	78.7	78.7	78.7	78.7	78.8	78.8	78.8
GC2	Phosphorus use (kg/ha)	78.3	79.0	79.8	80.5	81.7	82.2	82.4	82.5	82.5	82.4
CC1	Phosphorus losses (kg/ha)	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
CC2	Phosphorus losses (kg/ha)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
GC1	Phosphorus losses (kg/ha)	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
GC2	Phosphorus losses (kg/ha)	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5

Main economic and environmental results for leaching standards scenarios

		S-40	S-38	S-36	S-34	S-32	S-30	S-28	S-26	S-24	S-22	S-20
CC1	**Farm income (£)**	8640	8557	8393	8173	7774	7328	6865	6387	5896	4793	3187
CC2	**Farm income (£)**	69207	69016	68194	66472	64378	61956	58820	55042	50743	38769	26128
GC1	**Farm income (£)**	18939	18939	18939	18717	18240	17325	15607	13569	11284	8733	5848
GC2	**Farm income (£)**	92283	91870	90564	89182	85848	81106	76291	69659	58735	45054	29057
CC1	**Income (£/ha)**	584	578	567	552	525	495	464	431	398	324	215
CC2	**Income (£/ha)**	605	604	597	582	563	542	515	482	444	339	229
GC1	**Income (£/ha)**	1051	1051	1051	1038	1012	961	866	753	626	484	324
GC2	**Income (£/ha)**	892	888	875	862	829	784	737	673	567	435	281
CC1	**N use (kg/ha)**	155.0	148.3	139.1	131.1	122.5	111.3	99.1	86.6	74.1	53.1	17.5
CC2	**N use (kg/ha)**	165.3	158.4	150.4	142.0	134.9	127.7	118.5	106.7	97.0	63.8	27.9
GC1	**N use (kg/ha)**	140.4	140.4	140.4	131.5	124.6	110.7	103.1	86.9	65.6	42.6	21.9
GC2	**N use (kg/ha)**	161.2	157.1	147.5	136.1	124.4	114.6	104.9	93.7	75.8	51.7	27.6
CC1	**Nitrate leaching (kg/ha)**	39.5	38.0	36.0	34.0	32.0	30.0	28.0	26.0	24.0	22.0	20.0
CC2	**Nitrate leaching (kg/ha)**	40.0	38.0	36.0	34.0	32.0	30.0	28.0	26.0	24.0	22.0	20.0
GC1	**Nitrate leaching (kg/ha)**	35.7	35.7	35.7	34.0	32.0	30.0	28.0	26.0	24.0	22.0	20.0
GC2	**Nitrate leaching (kg/ha)**	39.3	38.0	36.0	34.0	32.0	30.0	28.0	26.0	24.0	22.0	20.0
CC1	**Phosphorus use (kg/ha)**	54.9	53.8	52.7	51.5	49.1	45.0	40.6	36.0	31.4	23.1	7.6
CC2	**Phosphorus use (kg/ha)**	62.0	60.9	60.1	59.0	57.9	56.7	53.9	49.1	43.7	28.4	12.5
GC1	**Phosphorus use (kg/ha)**	78.8	78.8	78.8	78.6	77.4	73.6	64.1	52.9	40.7	28.8	15.7
GC2	**Phosphorus use (kg/ha)**	77.5	76.7	76.7	76.9	77.0	72.1	67.0	64.3	52.0	33.5	15.0
CC1	**Phosphorus losses (kg/ha)**	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.0
CC2	**Phosphorus losses (kg/ha)**	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.1
GC1	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.1
GC2	**Phosphorus losses (kg/ha)**	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.2	0.1

Main economic and environmental results for input quotas scenarios (part a)

		Q-160	Q-150	Q-140	Q-130	Q-120	Q-110	Q-100	Q-90
CC1	**Farm income (£)**	8640	8593	8437	8252	8000	7615	7189	6758
CC2	**Farm income (£)**	69080	68217	66553	64318	61619	58047	54472	50881
GC1	**Farm income (£)**	18939	18939	18938	18699	18361	18008	17153	15990
GC2	**Farm income (£)**	92277	91752	90745	89519	88003	85515	80654	75492
CC1	**Income (£/ha)**	584	580	570	557	540	514	486	456
CC2	**Income (£/ha)**	604	597	582	563	539	508	477	445
GC1	**Income (£/ha)**	1051	1051	1051	1037	1019	999	952	887
GC2	**Income (£/ha)**	891	886	877	865	850	826	779	729
CC1	**N use (kg/ha)**	155.0	150.0	140.0	130.0	120.0	110.0	100.0	90.0
CC2	**N use (kg/ha)**	160.0	150.0	140.0	130.0	120.0	110.0	100.0	90.0
GC1	**N use (kg/ha)**	140.4	140.4	140.0	130.0	120.0	110.0	100.0	90.0
GC2	**N use (kg/ha)**	160.0	150.0	140.0	130.0	120.0	110.0	100.0	90.0
CC1	**Nitrate leaching (kg/ha)**	39.5	38.7	36.7	35.4	35.1	33.8	31.9	29.8
CC2	**Nitrate leaching (kg/ha)**	38.5	36.7	35.7	35.4	34.6	32.4	30.2	28.7
GC1	**Nitrate leaching (kg/ha)**	35.7	35.7	35.7	34.1	33.2	32.3	31.0	29.7
GC2	**Nitrate leaching (kg/ha)**	39.2	38.5	37.7	37.0	36.4	34.8	32.7	30.7
CC1	**Phosphorus use (kg/ha)**	54.9	54.0	52.9	52.2	52.0	49.1	45.1	41.0
CC2	**Phosphorus use (kg/ha)**	61.2	60.2	60.4	60.4	58.8	54.6	50.4	45.8
GC1	**Phosphorus use (kg/ha)**	78.8	78.8	78.8	78.7	78.8	78.8	75.2	67.8
GC2	**Phosphorus use (kg/ha)**	77.8	79.7	80.9	81.1	82.4	81.9	77.7	73.7
CC1	**Phosphorus losses (kg/ha)**	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2
CC2	**Phosphorus losses (kg/ha)**	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
GC1	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
GC2	**Phosphorus losses (kg/ha)**	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4

Main economic and environmental results for input quotas scenarios (part b)

		Q-80	Q-70	Q-60	Q-50	Q-40	Q-30	Q-20	Q-10
CC1	**Farm income (£)**	6319	5875	5426	4970	4508	4035	3545	2990
CC2	**Farm income (£)**	47281	43678	40073	36465	32854	29240	25623	21415
GC1	**Farm income (£)**	14757	13453	12079	10634	9119	7533	5877	4134
GC2	**Farm income (£)**	69636	63623	57474	51137	44396	37223	29610	21496
CC1	**Income (£/ha)**	427	397	366	336	304	273	239	202
CC2	**Income (£/ha)**	414	382	351	319	287	256	224	187
GC1	**Income (£/ha)**	819	746	670	590	506	418	326	229
GC2	**Income (£/ha)**	673	615	555	494	429	360	286	208
CC1	**N use (kg/ha)**	80.0	70.0	60.0	50.0	40.0	30.0	20.0	10.0
CC2	**N use (kg/ha)**	80.0	70.0	60.0	50.0	40.0	30.0	20.0	10.0
GC1	**N use (kg/ha)**	80.0	70.0	60.0	50.0	40.0	30.0	20.0	10.0
GC2	**N use (kg/ha)**	80.0	70.0	60.0	50.0	40.0	30.0	20.0	10.0
CC1	**Nitrate leaching (kg/ha)**	27.9	25.7	24.0	23.1	22.4	21.8	21.0	20.0
CC2	**Nitrate leaching (kg/ha)**	27.6	26.4	25.2	24.0	22.9	21.7	20.5	19.5
GC1	**Nitrate leaching (kg/ha)**	28.4	27.2	25.9	24.6	23.3	22.0	20.7	19.5
GC2	**Nitrate leaching (kg/ha)**	29.0	27.6	26.1	24.8	23.2	22.2	21.1	19.9
CC1	**Phosphorus use (kg/ha)**	36.7	32.7	28.5	23.9	19.3	14.8	10.1	5.1
CC2	**Phosphorus use (kg/ha)**	41.0	36.2	31.4	26.7	21.9	17.1	12.3	6.3
GC1	**Phosphorus use (kg/ha)**	60.4	53.0	45.6	38.2	30.8	23.3	15.9	8.9
GC2	**Phosphorus use (kg/ha)**	66.5	58.8	51.2	43.0	34.8	26.2	17.7	8.9
CC1	**Phosphorus losses (kg/ha)**	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0
CC2	**Phosphorus losses (kg/ha)**	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.0
GC1	**Phosphorus losses (kg/ha)**	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1
GC2	**Phosphorus losses (kg/ha)**	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.1

Main economic and environmental results for cross-compliance and subsidy scenarios

		CC-10	CC-15	CC-20	CC-25	Su-10, 20,30	Su-40	Su-50	Su-60	Su-70	Su-80	Su-90	Su-100
CC1	**Farm income (£)**	8329	8173	7993	7993	8640	8649	8734	8881	9029	9177	9325	9473
CC2	**Farm income (£)**	67079	66005	63790	63790	69226	69252	69642	70648	71791	72934	74077	75220
GC1	**Farm income (£)**	18634	18482	18330	18054	18939	18939	18960	19135	19315	19496	19676	19856
GC2	**Farm income (£)**	90587	89740	88892	88094	92283	92519	93296	94305	95340	96376	97411	98446
CC1	**Income (£/ha)**	563	552	540	540	584	584	590	600	610	620	630	640
CC2	**Income (£/ha)**	587	577	558	558	606	606	609	618	628	638	648	658
GC1	**Income (£/ha)**	1034	1025	1017	1002	1051	1051	1052	1062	1072	1082	1092	1102
GC2	**Income (£/ha)**	875	867	859	851	892	894	901	911	921	931	941	951
CC1	**N use (kg/ha)**	155.0	155.0	123.1	123.1	155.0	142.5	128.6	123.1	123.1	123.1	123.1	123.1
CC2	**N use (kg/ha)**	168.2	168.2	140.0	140.0	168.2	160.7	142.2	140.0	140.0	140.0	140.0	140.0
GC1	**N use (kg/ha)**	140.4	140.4	140.4	112.7	140.4	140.4	113.9	112.7	112.7	112.7	112.7	112.7
GC2	**N use (kg/ha)**	161.2	161.2	161.2	127.2	161.2	144.3	130.8	127.2	127.2	127.2	127.2	127.2
CC1	**Nitrate leaching (kg/ha)**	39.5	39.5	35.9	35.9	39.5	39.1	36.0	35.9	35.9	35.9	35.9	35.9
CC2	**Nitrate leaching (kg/ha)**	40.9	40.9	36.9	36.9	40.9	40.6	36.6	36.9	36.9	36.9	36.9	36.9
GC1	**Nitrate leaching (kg/ha)**	35.7	35.7	35.7	32.1	35.7	35.7	32.4	32.1	32.1	32.1	32.1	32.1
GC2	**Nitrate leaching (kg/ha)**	39.3	39.3	39.3	35.5	39.3	38.0	36.0	35.5	35.5	35.5	35.5	35.5
CC1	**Phosphorus use (kg/ha)**	54.9	54.9	54.3	54.3	54.9	54.8	54.3	54.3	54.3	54.3	54.3	54.3
CC2	**Phosphorus use (kg/ha)**	62.5	62.5	63.7	63.7	62.5	62.5	62.7	63.7	63.7	63.7	63.7	63.7
GC1	**Phosphorus use (kg/ha)**	78.8	78.8	78.8	79.0	78.8	78.8	78.8	79.0	79.0	79.0	79.0	79.0
GC2	**Phosphorus use (kg/ha)**	77.5	77.5	77.5	78.7	77.5	78.1	78.7	78.7	78.7	78.7	78.7	78.7
CC1	**Phosphorus losses (kg/ha)**	0.4	0.4	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
CC2	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
GC1	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
GC2	**Phosphorus losses (kg/ha)**	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Main economic and environmental results for soil subsidy scenarios

		SuS-10, 20, 30	SuS-40	SuS-50	SuS-60	SuS-70	SuS-80	SuS-90	SuS-100
CC1	**Farm income (£)**	8640	8649	8709	8769	8828	8888	8948	9007
CC2	**Farm income (£)**	69226	69230	69451	69672	69894	70115	70337	70558
GC1	**Farm income (£)**	18939	18939	18941	18948	18954	18961	18967	18973
GC2	**Farm income (£)**	92283	92374	92525	92677	92828	92979	93130	93281
CC1	**Income (£/ha)**	584	584	588	592	596	600	604	608
CC2	**Income (£/ha)**	606	606	608	610	612	613	615	617
GC1	**Income (£/ha)**	1051	1051	1051	1051	1052	1052	1052	1053
GC2	**Income (£/ha)**	892	892	894	895	897	898	900	901
CC1	**N use (kg/ha)**	155.0	142.5	142.5	142.5	142.5	142.5	142.5	142.5
CC2	**N use (kg/ha)**	168.2	161.7	161.7	161.7	161.7	161.7	161.7	161.7
GC1	**N use (kg/ha)**	140.4	140.4	139.3	139.3	139.3	139.3	139.3	139.3
GC2	**N use (kg/ha)**	161.2	155.4	155.4	155.4	155.4	155.4	155.4	155.4
CC1	**Nitrate leaching (kg/ha)**	39.5	39.1	39.1	39.1	39.1	39.1	39.1	39.1
CC2	**Nitrate leaching (kg/ha)**	40.9	40.6	40.6	40.6	40.6	40.6	40.6	40.6
GC1	**Nitrate leaching (kg/ha)**	35.7	35.7	35.5	35.5	35.5	35.5	35.5	35.5
GC2	**Nitrate leaching (kg/ha)**	39.3	38.6	38.6	38.6	38.6	38.6	38.6	38.6
CC1	**Phosphorus use (kg/ha)**	54.9	54.8	54.8	54.8	54.8	54.8	54.8	54.8
CC2	**Phosphorus use (kg/ha)**	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
GC1	**Phosphorus use (kg/ha)**	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8
GC2	**Phosphorus use (kg/ha)**	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
CC1	**Phosphorus losses (kg/ha)**	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
CC2	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
GC1	**Phosphorus losses (kg/ha)**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
GC2	**Phosphorus losses (kg/ha)**	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Cost-effectiveness ratios for cereal farms

CC1				CC2			
Scenario	**Cost/10 (£/ha)**	**Leaching Abatement (kg/ha)**	**Abatement Cost/10 (£/kg)**	**Scenario**	**Cost/10 (£/ha)**	**Leaching Abatement (kg/ha)**	**Abatement Cost/10 (£/kg)**
SuS-100	2.5	-0.45	-5.6	**SuS-100**	1.2	-0.22	-5.4
SuS-90	2.1	-0.45	-4.7	**SuS-90**	1.0	-0.22	-4.5
SuS-80	1.7	-0.45	-3.7	**SuS-80**	0.8	-0.22	-3.6
SuS-70	1.3	-0.45	-2.8	**SuS-70**	0.6	-0.22	-2.7
SuS-60	0.9	-0.45	-1.9	**SuS-60**	0.4	-0.22	-1.8
Su-100	5.6	-3.55	-1.6	**Su-100**	5.2	-4.00	-1.3
Su-90	4.6	-3.55	-1.3	**Su-90**	4.2	-4.00	-1.1
SuS-50	0.5	-0.45	-1.0	**SuS-50**	0.2	-0.22	-0.9
Su-80	3.6	-3.55	-1.0	**Su-80**	3.2	-4.00	-0.8
Su-70	2.6	-3.55	-0.7	**Su-70**	2.2	-4.00	-0.6
Su-60	1.6	-3.55	-0.5	**Su-60**	1.2	-4.00	-0.3
Su-50	0.6	-3.55	-0.2	**Su-50**	0.4	-4.30	-0.1
Su-40	0.1	-0.45	-0.1	**Su-40**	0.0	-0.29	-0.1
SuS-40	0.1	-0.45	-0.1	**SuS-40**	0.0	-0.22	0.0
S-38	-0.6	-1.50	0.4	**Q-160**	-0.1	-2.38	0.1
Q-150	-0.3	-0.84	0.4	**S-38**	-0.2	-2.86	0.1
S-36	-1.7	-3.50	0.5	**S-36**	-0.9	-4.86	0.2
Q-140	-1.4	-2.82	0.5	**Q-150**	-0.9	-4.14	0.2
S-34	-3.2	-5.50	0.6	**S-34**	-2.4	-6.86	0.4
Q-130	-2.6	-4.09	0.6	**Q-140**	-2.3	-5.17	0.5
S-32	-5.9	-7.50	0.8	**S-32**	-4.2	-8.86	0.5
S-30	-8.9	-9.50	0.9	**S-30**	-6.4	-10.86	0.6
Q-120	-4.3	-4.43	1.0	**S-28**	-9.1	-12.86	0.7
S-28	-12.0	-11.50	1.0	**Q-130**	-4.3	-5.41	0.8
S-26	-15.2	-13.50	1.1	**S-26**	-12.4	-14.86	0.8
S-24	-18.5	-15.50	1.2	**S-24**	-16.2	-16.86	1.0
Q-110	-6.9	-5.69	1.2	**Q-120**	-6.7	-6.27	1.1
CC-20	-4.4	-3.55	1.2	**Q-110**	-9.8	-8.47	1.2
CC-25	-4.4	-3.55	1.2	**CC-25**	-4.8	-4.00	1.2
Q-100	-9.8	-7.64	1.3	**CC-20**	-4.8	-4.00	1.2
Q-90	-12.7	-9.67	1.3	**Q-100**	-12.9	-10.66	1.2
Q-80	-15.7	-11.59	1.4	**Q-90**	-16.1	-12.13	1.3
Q-70	-18.7	-13.76	1.4	**S-22**	-26.6	-18.86	1.4
Q-60	-21.7	-15.45	1.4	**Q-80**	-19.2	-13.30	1.4
S-22	-26.0	-17.50	1.5	**Q-70**	-22.4	-14.47	1.5
Q-50	-24.8	-16.36	1.5	**Q-60**	-25.5	-15.64	1.6
Q-40	-27.9	-17.13	1.6	**Q-50**	-28.7	-16.81	1.7
Q-30	-31.1	-17.74	1.8	**TL-3**	-6.1	-3.48	1.8
Q-20	-34.4	-18.49	1.9	**Q-40**	-31.8	-17.98	1.8
S-20	-36.8	-19.50	1.9	**TL-2**	-4.1	-2.32	1.8

Q-10	-38.2	-19.47	2.0	**TL-1**	-2.1	-1.16	1.8
TI-0.7	-19.5	-3.88	5.0	**S-20**	-37.7	-20.86	1.8
TI-3	-22.9	-4.24	5.4	**Q-30**	-35.0	-19.15	1.8
TI-0.8	-26.1	-4.27	6.1	**Q-20**	-38.1	-20.33	1.9
TI-4	-29.3	-4.40	6.7	**Q-10**	-41.8	-21.34	2.0
TI-0.9	-32.3	-4.43	7.3	**TL-4**	-8.0	-3.98	2.0
TI-5	-35.4	-4.45	7.9	**TI-1**	-8.4	-3.97	2.1
TI-2	-15.9	-1.74	9.1	**TI-0.5**	-4.3	-2.00	2.1
TL-10	-20.3	-1.96	10.4	**TL-5**	-9.9	-3.98	2.5
TL-5	-10.2	-0.46	22.4	**TL-6**	-11.9	-3.99	3.0
TL-6	-12.3	-0.51	23.8	**TI-1.5**	-12.4	-3.98	3.1
TL-9	-18.3	-0.76	24.0	**TL-7**	-13.8	-4.00	3.4
TL-7	-14.3	-0.57	25.0	**TL-8**	-15.7	-4.00	3.9
TL-8	-16.3	-0.63	26.0	**TI-2**	-16.4	-3.99	4.1
TI-0.6	-12.0	-0.40	30.1	**TL-9**	-17.6	-4.01	4.4
TI-1	-8.0	-0.27	30.2	**TI-3**	-24.1	-5.10	4.7
TI-0.5	-4.0	-0.13	30.3	**TI-2.5**	-20.3	-4.29	4.7
TL-4	-8.2	-0.17	49.3	**TL-10**	-19.5	-4.01	4.9
TL-3	-6.2	-0.12	49.3	**TI-3.5**	-27.8	-5.10	5.4
TL-2	-4.1	-0.08	49.4	**TI-4**	-31.3	-5.57	5.6
TL-1	-2.1	-0.04	49.4	**TI-4.5**	-34.5	-5.56	6.2
				TI-5	-37.7	-5.56	6.8

Cost-effectiveness ratios for general cropping farms

GC1				GC2			
Scenario	**Cost/10 (£/ha)**	**Leaching Abatement (kg/ha)**	**Abatement Cost/10 (£/kg)**	**Scenario**	**Cost/10 (£/ha)**	**Leaching Abatement (kg/ha)**	**Abatement Cost/10 (£/kg)**
Su-100	5.1	-3.55	-1.4	**Su-100**	6.0	-3.84	-1.5
Su-90	4.1	-3.55	-1.2	**SuS-100**	1.0	-0.67	-1.4
SuS-100	0.2	-0.18	-1.1	**Su-90**	5.0	-3.84	-1.3
SuS-90	0.2	-0.18	-0.9	**SuS-90**	0.8	-0.67	-1.2
Su-80	3.1	-3.55	-0.9	**Su-80**	4.0	-3.84	-1.0
SuS-80	0.1	-0.18	-0.7	**SuS-80**	0.7	-0.67	-1.0
Su-70	2.1	-3.55	-0.6	**SuS-70**	0.5	-0.67	-0.8
SuS-70	0.1	-0.18	-0.5	**Su-70**	3.0	-3.84	-0.8
Su-60	1.1	-3.55	-0.3	**SuS-60**	0.4	-0.67	-0.6
SuS-60	0.0	-0.18	-0.3	**Su-60**	2.0	-3.84	-0.5
SuS-50	0.0	-0.18	-0.1	**SuS-50**	0.2	-0.67	-0.4
Su-50	0.1	-3.33	0.0	**Su-50**	1.0	-3.31	-0.3
S-36	0.0	0.00	0.0	**Su-40**	0.2	-1.36	-0.2
Su-40	0.0	0.00	0.0	**SuS-40**	0.1	-0.67	-0.1
S-38	0.0	0.00	0.0	**Q-160**	0.0	-0.07	0.1
Q-150	0.0	0.00	0.0	**S-38**	-0.4	-1.31	0.3
Q-140	0.0	-0.04	0.1	**S-36**	-1.7	-3.31	0.5

S-34	-1.2	-1.69	0.7	**S-34**	-3.0	-5.31	0.6
Q-130	-1.3	-1.64	0.8	**Q-150**	-0.5	-0.77	0.7
S-32	-3.9	-3.69	1.0	**S-32**	-6.2	-7.31	0.9
Q-120	-3.2	-2.46	1.3	**Q-140**	-1.5	-1.58	0.9
CC-25	-4.9	-3.55	1.4	**CC-25**	-4.0	-3.84	1.1
Q-110	-5.2	-3.44	1.5	**Q-130**	-2.7	-2.35	1.1
S-30	-9.0	-5.69	1.6	**S-30**	-10.8	-9.31	1.2
Q-100	-9.9	-4.66	2.1	**S-28**	-15.4	-11.31	1.4
S-28	-18.5	-7.69	2.4	**Q-120**	-4.1	-2.96	1.4
Q-90	-16.4	-5.95	2.7	**Q-110**	-6.5	-4.46	1.5
S-26	-29.8	-9.69	3.1	**S-26**	-21.9	-13.31	1.6
Q-80	-23.2	-7.25	3.2	**Q-100**	-11.2	-6.64	1.7
Q-70	-30.4	-8.54	3.6	**Q-90**	-16.2	-8.65	1.9
S-24	-42.5	-11.69	3.6	**S-24**	-32.4	-15.31	2.1
Q-60	-38.1	-9.83	3.9	**Q-80**	-21.9	-10.27	2.1
S-22	-56.6	-13.69	4.1	**Q-70**	-27.7	-11.75	2.4
Q-50	-46.1	-11.13	4.1	**Q-60**	-33.6	-13.23	2.5
Q-40	-54.5	-12.42	4.4	**S-22**	-45.6	-17.31	2.6
Q-30	-63.3	-13.72	4.6	**Q-50**	-39.7	-14.47	2.7
S-20	-72.6	-15.69	4.6	**Q-40**	-46.3	-16.12	2.9
Q-20	-72.5	-15.01	4.8	**Q-30**	-53.2	-17.16	3.1
Q-10	-82.1	-16.18	5.1	**S-20**	-61.1	-19.31	3.2
TI-4	-28.0	-3.46	8.1	**Q-20**	-60.5	-18.19	3.3
TI-4.5	-30.9	-3.45	8.9	**Q-10**	-68.4	-19.43	3.5
TI-5	-33.7	-3.44	9.8	**TI-2.5**	-19.6	-2.47	7.9
TI-3	-21.6	-1.72	12.6	**TI-4**	-29.0	-3.53	8.2
TI-3.5	-25.0	-1.77	14.1	**TI-3**	-22.8	-2.76	8.3
TI-2.5	-18.1	-0.27	68.1	**TI-4.5**	-31.9	-3.65	8.7
TI-2	-14.5	-0.21	68.2	**TI-5**	-34.9	-3.78	9.2
TI-1.5	-10.9	-0.16	68.4	**TI-3.5**	-26.0	-2.72	9.6
TI-1	-7.3	-0.11	68.5	**TI-1.5**	-12.2	-1.12	10.9
TI-0.5	-3.6	-0.05	68.6	**TI-2**	-16.0	-1.29	12.4
TL-10	-18.5	-0.19	97.7	**TL-10**	-20.2	-1.12	18.0
TL-9	-16.7	-0.17	97.8	**TL-9**	-18.2	-1.01	18.0
TL-8	-14.8	-0.15	97.8	**TL-8**	-16.2	-0.89	18.1
TL-7	-13.0	-0.13	97.8	**TL-7**	-14.2	-0.78	18.1
TL-6	-11.1	-0.11	97.8	**TL-6**	-12.2	-0.67	18.1
TL-5	-9.3	-0.09	97.9	**TL-5**	-10.1	-0.56	18.1
TL-4	-7.4	-0.08	97.9	**TL-4**	-8.1	-0.45	18.2
TL-3	-5.6	-0.06	97.9	**TL-3**	-6.1	-0.34	18.2
TL-2	-3.7	-0.04	97.9	**TL-2**	-4.1	-0.22	18.2
TL-1	-1.9	-0.02	98.0	**TL-1**	-2.0	-0.11	18.2
				TI-1	-8.2	-0.35	23.5
				TI-0.5	-4.2	-0.17	23.7