CANTOGETHER

Crops and ANimals TOGETHER

Grant agreement no. : FP7-289328

Collaborative project

Seventh framework programme

Towards land management of tomorrow - Innovative forms of mixed farming for optimized use of energy and nutrients

Deliverable D3.5: Impact of MFS in regional trends in soil organic matter contents and nutrient losses

Due date: M36

Actual submission date: Jan 2016

Project start date: January 1st, 2012 **Duration:** 48 months

Workpackage concerned: WP3

Concerned workpackage leader: H. Korevaar

Names of the responsible authors & organizations : M.C. Hanegraaf (NMI), R. Kaczynski (IUNG), F. Vertès (INRA), G. Siebielec (IUNG), G.J. Doppenberg (NMI) and H. Korevaar (PRI).

Dissemination level: PU

Contents

Inhoud

Acknowledgements

This work was carried out as part of the EU project CANTOGETHER (FP7-KBBE-20115, grant no. 289328). For the Netherlands, co-funding was obtained from the District Water Board 'Rijn en IJssel'.
The cooperation of farmers and other stakeholders in the three case study areas during the realisation of this work is greatly appreciated.

Abstract

Over the past decade, Mixed Farming Systems (MFS) have gained renewed interest in the farming, research and political community. The concept has been framed as a means for improving sustainability, in terms of energy, nutrient efficiencies and ecosystem services. Within the EU, various policies call for accelerated implementation of integral farming systems and related technologies. Research has shown that opportunities exist for crop-animal systems in both low and high input systems. A major challenge is to identify successful MFS and to assess the prerequisites for extrapolating these systems to areas with different agro-ecological features. In the context of mixed farming systems within the EU-project CANTOGETHER, land sharing refers to cooperation between productive and ecological areas, and/or between livestock farms and arable farms.

Land sharing may have an impact on soil and water quality, landscape and biodiversity. Changes in soil organic carbon (SOC) is a major indicator by which these impacts may be assessed. However, not much is known about possible effects on SOC due to land sharing at the farm or regional level. Therefore, a farming system approach was used to evaluate the impact of land sharing on SOC at mixed farms, as compared to SOC at specialised arable or livestock farms. The three case studies included in the assessment were: (1) Arable farms at mineral soils of low SOC, aiming at intensification (Dolnoslaskie region, Poland); (2) Dairy farms at mineral soils with high SOC and high milk production, aiming to increase biodiversity and to reduce mineral losses (Winterswijk region, Netherlands); (3) Dairy farms at mineral soils with moderate milk production, aiming to reduce nitrogen losses (Lieue de Grève region, France). For each region, specialised and mixed farming systems were defined using regional farm typologies using data on crop rotation, use of dairy manure, nitrogen balance, and/or milk production. Modelling of SOC was done using the Roth-C model for the Dolnoslaskie and Winterswijk regions, using agronomic data from the national database and empirical farm data, respectively, and a time frame up to the year 2050. For both case studies, the model was validated with regional SOC data. For the Lieue de Grève region, changes in SOC were assessed from modelled nitrogen fluxes with CASIMOD'N, and use of empirical farm data.

Results indicate that in intensive arable systems on soils low in SOC, the amount of C-input from crop residues and/or manure is the driving force for increasing SOC rather than the specialist (cereal-based) or mixed character of the farming system. However, the Roth-C model calculations also showed that this contribution may be higher in mixed arable systems than in specialised arable systems. At soils high in SOC, specialised (potato-based) arable systems lead to significant carbon loss over time. In contrast, the specialised dairy farms as well as the mixed dairy farms increased SOC. Concerning the latter, mixed systems with cereal cultivation to stimulate biodiversity provided more carbon than mixed systems with measures to reduce mineral losses to ground- and surface waters. However, results of the calculations for the Lieue de Grève farms show that highest gain in carbon was obtained by the specialist (grass-based) dairy system at moderate production level. Thus in intensive dairy farming systems similar in SOC, C-input was proportional to grassland age which, at the high production farms, was related to the grass-maize rotation management strategies. Overall, the findings in the three case studies suggest that mixed farming systems could make a modest contribution to the "4 ‰ initiative". Major factors that determine the outcome of land sharing on SOC-contents are 1) agro-ecological conditions; and 2) production goal. For land sharing to have potential as a blueprint for sustainable intensification, specific regional incentives may be needed to arrive at the optimal combination of these driving forces.

1. Introduction

1.1 Land sharing as a feature of mixed farming systems

Over the past decade, Mixed Farming Systems (MFS) have gained renewed interest in the farming, research and political community. The concept has been framed as a means for improving sustainability, in terms of energy and nutrient efficiencies while delivering ecosystem services. Recently, conservation of landscape and soil quality at the regional level have been added to its virtues. Within the EU, policies such as the CAP, Water Frame Directive and European Climate Change Programme call for accelerated implementation of integral farming systems and related technologies. Previous world-wide research has shown that opportunities exist for crop-animal systems in both low and high input systems (Van Keulen and Schiere, 2004). A major challenge is to identify successful MFS and to assess the prerequisites for extrapolating these systems to areas of different socio-economic and agro-ecological features.

Definitions of mixed farming systems may differ with respect to system boundaries, i.e. farm or regional level. On-farm MFS are characterised by the presence of two (or more) agricultural sectors at a farm, e.g. animal husbandry and arable farming. To count as MFS, the management of the productions should be partially or fully integrated. Between-farm MFS concerns cooperation and/or shared land use by two or more specialised farms. Each farm makes a sector-specific contribution. An example of cooperation is the exchange of manure and straw. The distinction in on-farm and between-farm MFS offers the possibility to assess the impact of the MFS on the regional environmental quality (Figure 1.1). Elements of such an analysis could be the regional distribution of nutrients, availability of organic matter, or improvement of water quality.

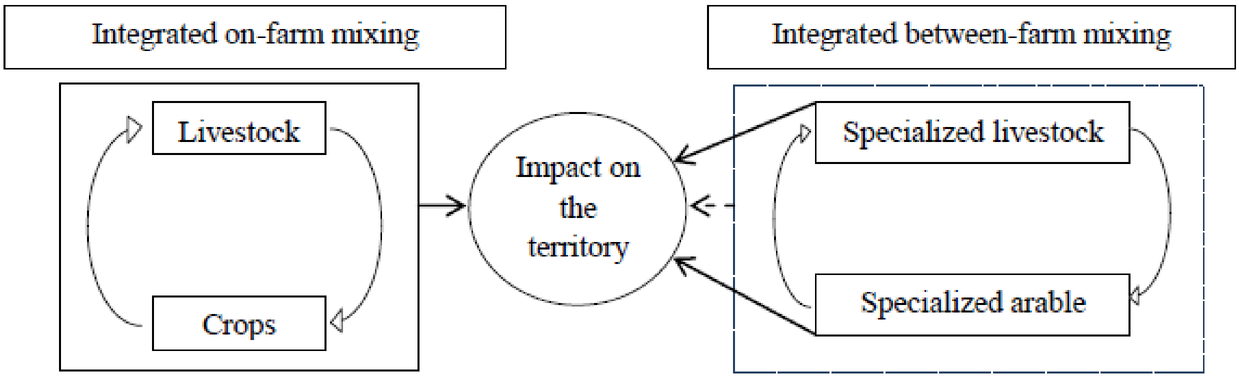

Figure 1.1. Land sharing as possible key feature of mixed farming systems (Donzallaz, 2012).

Between-farm mixing may include for instance the sharing of land between individual farmers and/or third party land-owners. Examples are the exchange of manure from a dairy farm for maize from an arable farmer, and the use of grassland in nature conservation areas by a dairy farmer. At field level, a positive impact is known from the grassland – potato cooperation, as the potato benefits from the nitrogen mineralisation after ploughing the grassland, thereby reducing nitrate leaching as compared to other crops (e.g. new grassland, maize). However, not much is known about the impact of the sharing of land on regional landscape and water quality as compared to specialised farming. It has been suggested that the character of a cooperation between stakeholders may be regarded as the driving force for reaching impact, which in the case of land sharing may be identified as ‘territorial synergy’ (Moraine, 2014).

Internationally, the debate on land sharing relates to quite a different goal, i.e. meeting demands for world food production. The question of how to meet rising food demand at the least cost to biodiversity requires the evaluation of two contrasting alternatives: land sharing, which integrates both objectives on the same land; and land sparing, in which high-yield farming is combined with protecting natural habitats from conversion to agriculture (Phalan et al., 2011). The complexity of the landscape is one of the key factors in determining species richness. Thus Egan & Mortensen (2012) found that in more complex landscapes land sharing would provide greater gains than land sparing. The explanation of this would be that the majority of plant species in agroecosystems are found in small fragments of non-crop habitat so that, in landscapes with little non-crop habitat, richness can be more readily conserved through land-sparing approaches. Herzog & Schüepp (2013) pose the question whether the discussion on land sharing versus land sparing is also relevant for Europe, where agriculture is withdrawing from marginal regions whilst farming of fertile lands continues to be intensified. They argue that intensive agriculture and biodiversity must and should be intertwined, e.g. on productive farmland, semi-natural habitats are required to yield ecosystem services relevant for agriculture.

In the context of mixed farming systems within CANTOGETHER, land sharing refers to cooperation between productive and ecological areas, and/or between livestock farms and arable farms (Description of Work, 2011). In this study the focus is on the perspectives of land sharing, as part of MFS, to contribute to the regional balance in soil organic matter. The evolution of SOC in both grasslands and arable fields may be affected by management, e.g. tillage, fertilization and crop rotation (Figure 1.2). Low C-stock and/or a negative C-balance are indicators for the risk of yield decline. As assessed by the EU-project Smartsoil, at a European level major risks are found in the southern, Mediterranean part (Merante et al., 2015). In addition to a potential yield decline, a low SOC is in general considered as negative for soil biodiversity, also determining ecosystem functions such as nitrate leaching and carbon sequestration (Rutgers et al., 2012). With the nutrients N and P of major importance for crop growth, as well as for pollution of ground- and surface waters, the relationship between SOM and N needs special attention. A decline in SOM may lead to an increase in nitrate losses and in particular leaching. Furthermore, a reduction in SOM is all the more important since a reduction to the minimum contents for crop production may be irreversible. It has not been studied, so far, to what extent land sharing and land use change have an impact on regional soil and water quality. The working hypothesis of the present study is that MFS, in particular involving land sharing are beneficial for regional ecological intensification. The rational behind this is that when agriculture and nature share the environment, agriculture is the responsible actor for maintaining/improving the environment, in terms of e.g. biodiversity and water quality. The agricultural measures involved in the sharing of land are partly connected to conservation of biodiversity, partly to improving water quality of ground- and surface waters.

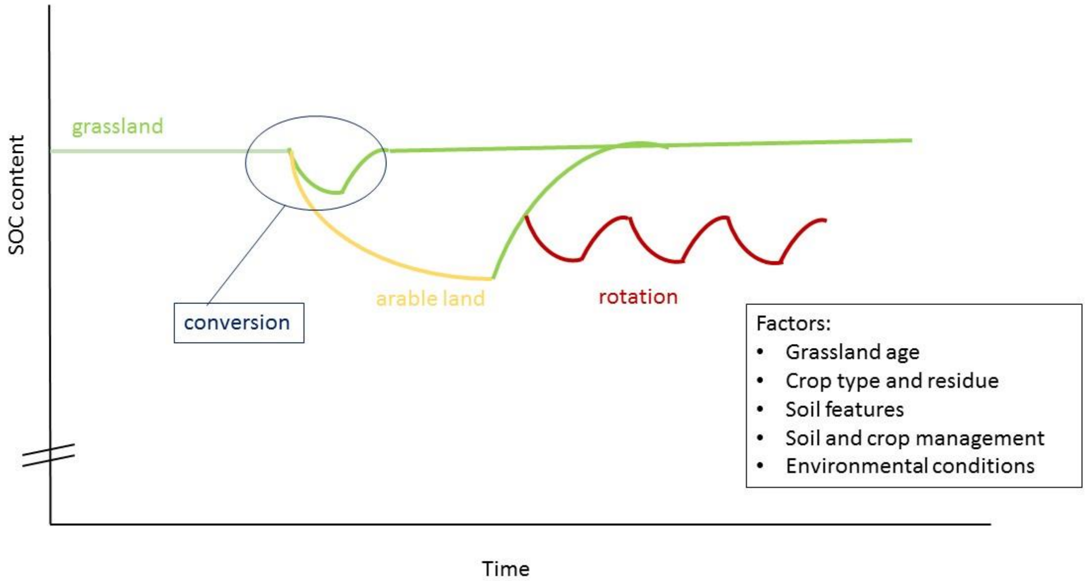

Figure 1.2. Evolution of SOC as affected by land use and management (after Conijn et al. 2002, Arrouays et al. 2002).

1.2 Objectives

With the above in mind, the EU-project CANTOGETHER (Crops and ANimal TOGETHER) aims to contribute to the knowledge base for MFS in the EU, researching innovations in the sustainability of MFS at both the farm and district level (www.CANTOGETHER.eu). The research includes a wide range of topics concerning, e.g. socio-economy, energy production, GHG-emissions, and nutrient management. The present study is directed at two agro-ecological aspects i.e. soil organic matter (SOM) and nutrients (N, P).

The objectives of the study were to analyse the impact of MFS on regional trends in soil organic matter contents and (potential) nutrient losses in view of promoting land sharing for regional development. Three mixed farming systems were assessed using empirical farm data from district level case studies in the temperate climate zone in Europe. The strategies assessed were: (1) Reduction of N-leaching in dairy farming; (2) Regional digesters of manure to provide organic matter in arable farming systems; (3) Land sharing between dairy and arable farms, and between dairy farms and nature areas.

The divers character of the three case studies in terms of regional objectives, farming systems design, stakeholder cooperation, and data heterogeneity do not allow the use of a complete harmonised methodology. Instead, in each case study the best regional method was used to assess the impact of MFS on regional trends in soil organic matter contents and nutrient losses. For each of the three case studies the current situation (regional baseline) was examined and the impact of Innovations assessed. Selected innovations offer perspective at the regional level and include some form of land sharing as discussed above. This allows a synthesis and interpretation of the results in view of generalization of the research findings for the EU.

2 Materials and methods

2.1 General approach

A farming systems approach was employed in the selected case study districts to compare specialised and mixed farms. The specialised farms studied consisted of crop and livestock farms that employed one of four district level crop-livestock integration strategies already defined within the project, i.e. (1) use of animal manure/digestate in arable region; (2) implementation of 'arable' measures to reduce nitrate losses in dairy region, (3) implementation of biodiversity measures to improve the landscape in dairy region, (4) land sharing between dairy and arable farms. By describing and analysing the participating farms and areas in terms of farm characteristics, soil quality, manure and nutrient management, biodiversity practices, etc., we were able to characterise how the studied innovative crop-livestock integration strategies work and are effective at district scale.

The general approach applied across the diverse case studies was to compare baseline(s) with innovations. The baseline addressed specialised farms, the innovations considered the inclusion of arable or biodiversity measures.

2.2 Methodology

This section describes the general methodology of the overall work in terms of selected indicators, upscaling, and modelling. Details per case study are given in the respective chapters.

Soil organic carbon as indicator

The monitoring of soil organic matter is important from both agricultural and environmental viewpoints. The early studies on environmental performance of farming systems did not include the C-status of the soil. The development of climate smart agriculture changed that. At present, several indicators exist for the monitoring of soil organic matter and nutrient losses, e.g. soil organic matter balance, soil organic C-status (SOC), N-surplus, nitrate concentration in groundwater, etc. With regard to soil organic matter, it is questionable whether the focus should be on the content or on the change in content. The term 'indicator' has been defined as: 'a variable which supplies information on other variables which are difficult to access and which can be used as benchmark to take a decision' (Gras et al., 1989, in Van der Werf and Petit, 2002). Indicators linked to environmental objectives with a local or regional geographical target should be area-based, while indicators with a global focus should be product-based (Van der Werf and Petit 2002; Halberg et al., 2005). Thus for C, the focus is on SOC when regional quality is concerned, and on CO_2/l milk when climate change is addressed. Also, indicators based on environmental effects of farmer practices are preferable to indicators based on the practises themselves, as the link with the objective is direct and the choice of means is left to the responsibility of the farmer.

Upscaling in time and space

Aim of this study was to assess the change in C-contents of soils over time for selected types of agricultural land-use. Changes in SOC were assessed at field (crop) level as the net result of input and mineralisation of organic matter per year. For this purpose, the carbon model Roth-C and the nitrogen model CASIMOD'N are used (see next section). Validation was carried out, in so far as possible, with data from monitoring SOC in the field, before upscaling results in time and space. Results were subsequently extrapolated over time to the year 2050 (Dolnoslaskie and Winterswijk) and aggregated to the regional level (Winterswijk and Lieue de Grève).

2.3 Modelling

2.3.1 Rothamsted Carbon Model (Roth-C)

The Rothamsted Carbon model (Roth-C) is a model that allows for modelling the effects of soil type, temperature, moisture content and plant cover on the turnover process (Coleman & Jenkinson, 1999). It is used in the case studies Dolnoslaskie and Winterswijk.

Roth-C was originally developed and parameterized to model the turnover of organic C in arable top soils from the Rothamsted Long Term Field Experiment. The model has performed well in predicting SOC changes by agricultural management in long-term experiments in neighboring countries using independent crop input data. In fact, it is a one of a very few models currently used world-wide to study global C dynamics and to report in national inventories of C stocks for the United Nations Framework Convention on Climate Change (Grace, 2005). Dynamics of the model has been extensively tested using long term SOC data from a wide range of soil types, land uses and environments and the model needs relatively few inputs (Skjemstad et al., 2004; Smith et al., 2005; Barancikova G., 2007).

In the model, soil organic carbon is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). Each compartment decomposes by a first-order process with its own characteristic rate. The IOM compartment is resistant to decomposition. The structure of the decomposition process as included in the model is shown in Figure 2.1 (Coleman & Jenkinson, 1999).

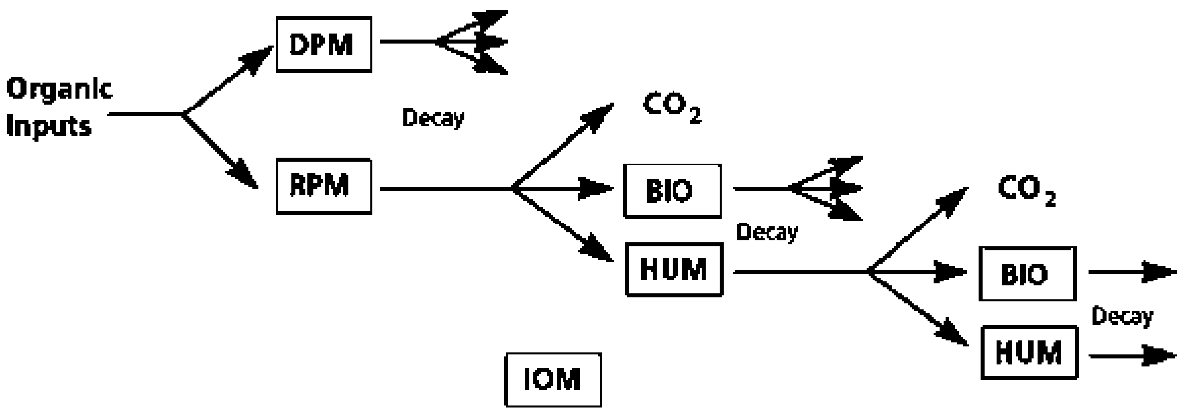

Figure 2.1. Schematic representation of the decomposition process in the Roth-C model.

To run the model, first an initialization step is required. With this step the model is parameterized to local conditions by running it with local data until equilibrium in SOC- contents is reached. This may involve a period of 10.000 – 50.000 years. Subsequently, scenario analyses may be performed, using detailed monthly information on input of organic matter from crop and manure. As the model does not include a submodel for plant production, it needs few inputs, which are easily obtainable (Table 2.1).

Table 2.1. Input data for the Roth-C model.

Input category	Data required
Weather	• Monthly rainfall (mm) • Monthly potential evapotranspiration (mm) • Average monthly mean air temperature (°C)
Soil	• Clay content of the soil (%) • Depth of soil layer sampled (cm) • Soil cover (yes / no)
Crop residues	• Monthly input of plant residues (C t .ha^{-1}) • An estimate of the decomposability of the incoming plant material, the DPM/RPM ratio
Farmyard manure	• Monthly input of farmyard manure (FYM) (C t .ha^{-1})

It is necessary to indicate whether or not the soil is vegetated because decomposition has been found to be faster in fallow soil than in cropped soil, even when the cropped soil is not allowed to dry out. The plant residue input is the amount of C that is put into the soil per month (t C ha^{-1}), including C released from roots during crop growth. The amount of FYM (t C ha^{-1}) put on the soil, if any, is inputted separately, because FYM is treated slightly differently from inputs of fresh plant residues.

The decomposability of crop residues and input from farmyard manure is characterized by the DPM/RPM ratio of the materials. In general, a value of 1.44 to the DPM/RPM ratio of crop residues may be used (Coleman & Jenkinson, 1999). However, when it is necessary to distinguish between crop residues, specific values are needed. These crop specific values may be obtained from a linear relationship between the humification coefficient and the DPM/RPM-ratio (Anonymus, 2008):

DPM/RPM = -2,174 h_c + 2,020 (for $h_c < 0,92$; for $h_c > 0,92$ DPM/RPM = 0)

2.3.2 The Casimod'N model

The integrative model CASIMOD'N (Catchment and Agricultural Systems Integrated MODel for Nitrogen) assesses the effects of farming systems on nitrogen (N) dynamics at the catchment level (Moreau et al., 2013). It was used in the case-study Lieue de Grève.

An important feature of the model is the consideration of the level of the farming system through production strategies, farmer decisions and the expression of decisions as management practices, along with the link between these farming systems, their practices and water pollution. CASIMOD'N integrates farming systems at the farm level and N transfers and transformations at the field, farm and catchment levels. It results from adapting and combining 3 models: the agro-hydrological model TNT2, which simulates all N fluxes at the catchment scale (Beaujouan et al., 2002), and two decision-making models that simulate farming system management at the farm scale, TOURNESOL (Garcia et al, 2005) and FUMIGENE (Chardon et al., 2008). TNT2 is process-based and spatially distributed to account for potential spatial interactions such as nitrate leached upslope and its effect on lowland uptake or bottomland denitrification (Oehler et al., 2009). It represents crop growth and nitrogen transformation based on the plant-soil model STICS. In TNT2, field management practices are input data.

TOURNESOL and FUMIGENE introduce the farming system level into CASIMOD'N. They have already been applied independently to two farms with a detailed dataset (Chardon et al., 2008) and to one experimental farm with a detailed dataset (Garcia et al, 2005), respectively. Both models are planning models by optimisation and determine once a year, the management practices to apply to each field in the coming year. TOURNESOL produces crop allocation plan and FUMIGENE a manure allocation plan to fulfill the objectives of each farming system, given farmer constraints. The intrinsic logic behind farming system design and function was represented by ensuring agreement between animal feeding and manure-management strategies under specific farm constraints (land fragmentation, distance between fields and farmyards) and agronomic rules. The model is thus able to simulate management practices (crop, manure and mineral fertiliser allocation) and test the generated farming systems from scenarios (Figure 2.2, (Moreau et al., 2013)).

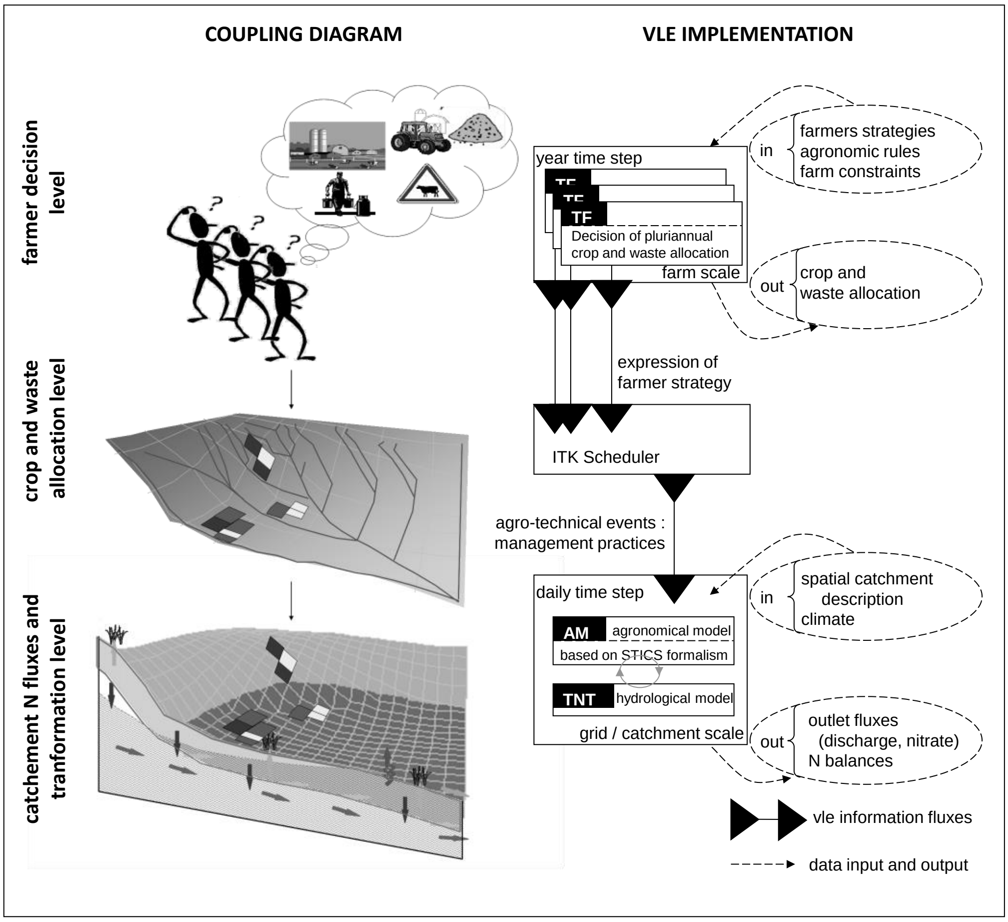

Figure 2.2. Schematic representation of the CASIMOD'N model.

The model requires data as listed in Table 2.2.

Table 2.2. Input data for the CASIMOD'N model.

Input category	Data required
General strategy	• type(s) of animal production (dairy, suckler, pig, poultry) • herd characteristics (size, breed, productivity, animals per age class) • animal requirements for silage maize • animal requirements for silage and grazed grass • animal requirements for straw • cash crops (types, production)
Manure	• type (cattle manure, cattle slurry, pig slurry, poultry manure) • nitrogen content • prohibition on spreading periods • prohibition on spreading locations • maximum number of applications per crop • prioritisation of crop-manure pairs • minimum and maximum manure rates by application
Crop	• crop type • potential yield • minimum and maximum durations in years for perennial crops • minimum return period
Field	• spatial distribution • area • farmstead location • accessibility for dairy cows • maximum distance for manure spreading • soil agronomic potential

3 Assessment of Dolnoslaskie (PL)

3.1 The Challenge

In the Dolnoslaskie region, agriculture has become very intensive, characterized by a large use of inputs and by a very low livestock density. Attempt was made to estimate the impact of present and future specialized and mixed farming systems on SOC, using data from a long period (1960 – 2010). The process-based SOC dynamic model Roth-C was applied to evaluate changes in SOC, using initial SOC content, data of agricultural management and estimated carbon input from crops and manure as input data to the model. The recorded changes of SOC contents in soil profiles were used for model validation. Finally, comparison is made of the change in C-stock between specialized farms and MFS.

3.2 Description of the area

The case study area comprises 1,800 km^2 in the south-east part of the Dolnoslaskie province (979,000 ha), covering a homogeneous region in terms of soil and climatic conditions (Figure 3.1a). The farms are relatively large, comparing to national Polish average (11 ha), with a mean area of the farm of about 16 ha (taking into account only farms > 1 ha UAA). The area of CS has very favorable agro-climatic conditions for cropping, especially for wheat, barley, corn, rape, sugar beet, therefore these crops now dominate in the crop rotation. Prevailing soil types are: cambisols and luvisols and the textures are silt and silty loam. The soil organic matter content is low and oscillates around 2% (Figure 3.1b). Soil water budget is typically precipitation depending. The climate is a typical land climate with mean annual precipitation of 628 mm and mean annual temperature of 8.9 °C.

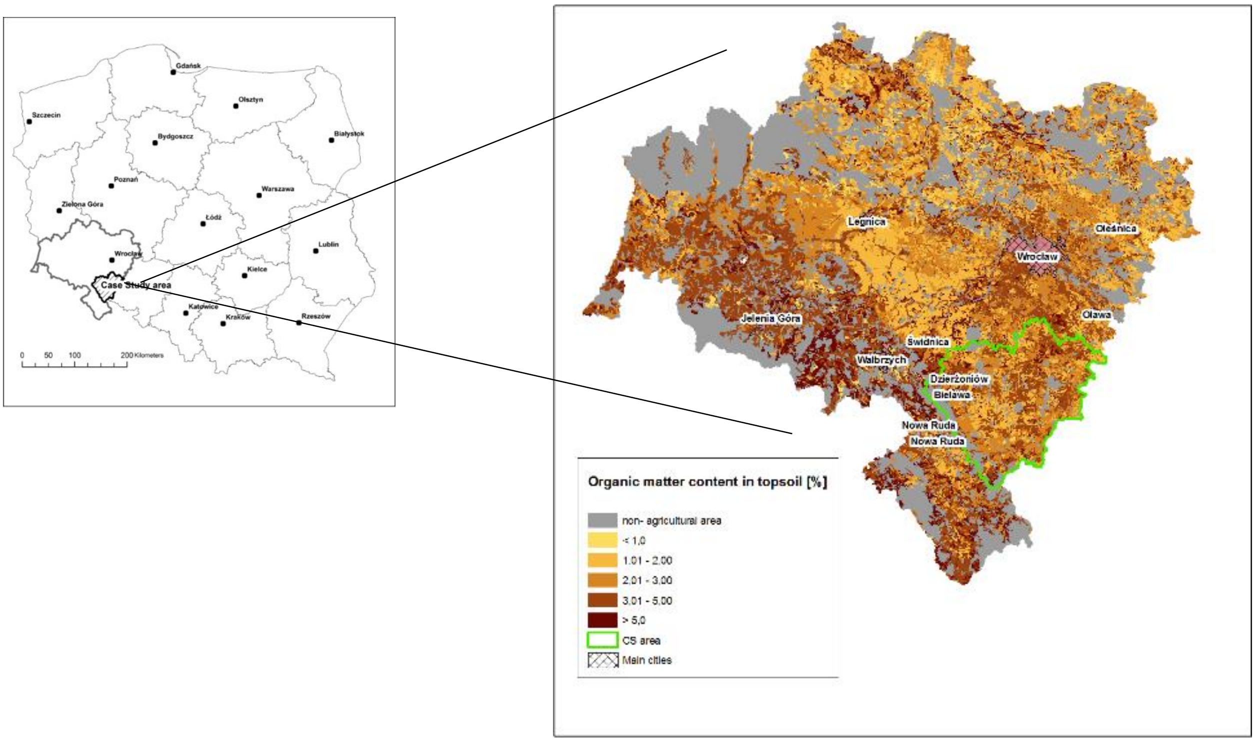

Figure 3.1. Case study area; a) location in the Dolnoslaskie province in Poland; b) Map of SOC-contents.

Over the last 50 years, significant changes in agriculture have occurred, e.g. simplification of crop rotation, decrease of forage crops area and livestock density. The production direction has changed considerably over the period 1969 – 2010, from the mixed cropping-animal farming to highly specialized crop production without livestock (Figure 3.2).

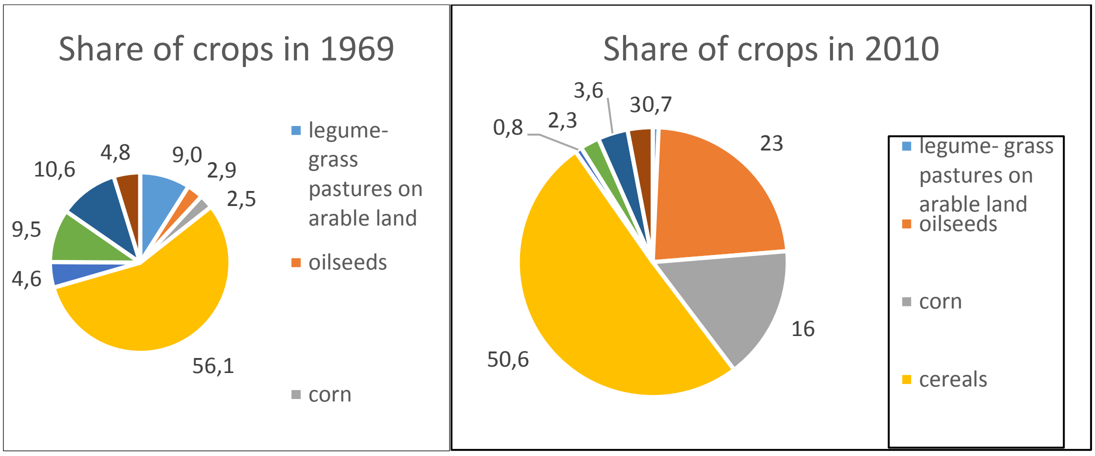

Figure 3.2. Crop structure of CS Dolnoslaskie in 1969 and 2010.

Also the acreage of the main crops, e.g. potatoes, cereals, grass, has changed considerably over time. In 1969, MFS were the predominant type of farming, with every farm having both livestock and arable crops. Permanent grassland was c. 13% of total UAA (Table 3.1). Substantial doses of manure were applied to the soil, following high livestock density (c. 80 LU / 100 ha UAA). In contrast, by 2010 most farms had become highly specialized arable farms, without livestock (LU c. 14 / 100 ha UAA). At this time, most agricultural land is occupied by arable land, i.e. the cropping area occupies 93% of UAA whereas permanent grassland only 5,5%. Over time the areas in fodder and legumes/grasses diminished accordingly.

Table 3.1. Changes of agricultural lands in the Dolnoslaskie region.

Year	1969	2010
Land Use	Area size (ha)	
Permanent grassland	216,539	144,955
Arable land		
cereals	581,926	516,931
corn	7,039	71,042
oilseed	10,986	128,721
potatoe	130,163	23,410
sugarbeet	46,945	19,370
pulses	41,846	6,680
grassclover leys	54,479	9,451
Other	114,133	58,735
Total area	1,204,056	979,295

Current options to improve SOC include a wider introduction of catch crops, introduction of straw as a fertilizer (instead of use as a fuel in the boilers), and introduction of exogenous organic matter such as digestates etc. as fertilizer. The role of biogas plant is visibly increasing in Dolnoslaskie region. In the area, some groups of stakeholders are active to promote biogas production, e.g. arable farmers, companies for manure digestion, and researchers. Efforts to improve the area are being carried out by the regional government, who stimulates manure digestion as a means of higher input of organic matter to the agricultural soils. Meanwhile, soil quality is being monitored on a systematic base. Other regional programs in 2001-2010 decade involved co-financing of soil liming as a mean to sustain soil quality and productivity potential.

3.3 Methodology

3.3.1 Outline

This case study aimed to evaluate changes in SOC stocks due to transformation from mixed farming systems to specialized farming systems, in agricultural soils of the Dolnoslaskie province over the period 1960–2013, and, after validation, to give a forecast of the SOC responses to agricultural management in 2050. In addition, maps were drawn to indicate any regional variation in the modelled C-change.

3.3.2 Selection of baseline and time scenarios

The starting point for the scenario analysis was the situation in 1960 with mixed production system, low intensity with animal production and diverse crop rotation (Table 3.2). The first baseline “as was” (S1) reflects the low transition into specialized and more intensive production with simplification of crop rotation and progressive decline in livestock density, as registered in the sensus data. In addition, a second baseline (S2) constituted the (hypothetical) continuation of the sustainable starting situation. For this scenario, constant areas of particular crops over the whole 1960-2010 period were assumed, but with increase in yields, reflecting the statistics. Livestock density remained constant from the point when it reached its maximum in 1988.

Table 3.2. Typology of baseline and innovations for C12 Dolnoslaskie.

Typology	Farm types
S1-Baseline: “As was” scenario of transition from mixed to specialized agriculture	Increasing number of specialised farms
S2-Baseline: Mixed agriculture	Continuation of sustainable practices present in 1960

Both baselines scenarios have been extrapolated over time, i.e. the period 2010-2050. As for the specialised scenario, continuation of intensive farming (“as was”) was assumed, with limited animal production and reduced perennial/forage crops potentially strongly influencing C-change. For the second scenario, a return to sustainable farming system was assumed, i.e. integrating crops and livestock and having a diversified crop rotation.

3.3.3 Modelling

Roth-C was applied to evaluate changes in SOC, using initial SOC content, data of agricultural management and estimated carbon input from crops and manure as input data to the model. The recorded changes of SOC contents in soil profiles were used for model validation. The selection of the Roth-C-26.3 model was based on its good performance in long-term experiments in neighbor countries using independent crop input data (Ludwig et al., 2007; Barancikova et al., 2010a, b). Furthermore, the input data required for running the Roth-C model correspond to what can be realistically collected at the LAU-2 level in Poland for the period 1960 - 2014.

Initialisation

First of all, the initial SOC content was used for running the Roth-C model to equilibrium under constant environmental conditions. The constant climatic conditions were taken as the average of the climatic data from 1960–1990. For each locality, firstly the model was run to equilibrium (10.000 years), iteratively fitting carbon inputs to match the initial SOC stock and thus the distribution in fractions (DPM, RPM, BIO, HUM) with different decomposition rates. The data of carbon and radiocarbon ages in all these compartments received in equilibrium mode (initial soil state, initial radiocarbon ages) were used to run the model in short term mode (for the modelling of SOC in the time period from 1960–2014).

Scenario analyses

A step approach of cohorts of 10 years was applied for short term modelling (period 1960-2014), corresponding to the availability of data from official agricultural statistics. The result of each step was used as input data to the subsequent step. This method allows to illustrate trends in changes in organic carbon content in relation to changing agronomic factors (and in consequence C-input from crop residues and manure) and changes in soil organic carbon stock.

For the second analysis, i.e. the extrapolation of both scenarios over the time period 2010 - 2050, current levels (2010) of carbon input from crops and livestock were taken into account.

Validation

The model outputs were validated using laboratory SOC measurements in soil samples collected in two periods 1960-1970 and 2004-2013. For establishing initial SOC contents we used the database of reference soil profiles, utilized in 1960-1970 in production of the analogue soil agricultural map of Poland. The database contains approximately 10,000 georeferenced soil profiles across Poland, described and analysed for basic soil parameters. In this database, 600 points represent the Dolnoslaskie region, and 94 profiles are located within the study area. A set of information describing the profiles contains: land use, location of the profile within the landscape and slope, soil/land suitability class, soil type, texture, SOC content, pH, available nutrients. The database was developed at IUNG, Pulawy. Roth-C modelling was performed for each sampling location separately (94 soil profiles). A number of 94 separate forecasts was obtained of SOC content (%) and SOC stock (t ha-1) for 2014 as response to SOC initial content, pedo-climatic conditions and transformations in agriculture. A number of 34 out of the 94 soil profiles located in the study area were re-sampled and analysed for SOC in 2010-2014 period. SOC levels measured in 2010-2014 were then used for validation of the model projections.

3.3.4 Data collection

The following information fed the Roth-C-26.3 model used in the study:

Agronomic factors
Indicators potentially explaining impact of agricultural management on SOC content and trends were extracted from National Agricultural Census of Poland (Central Statistical Office of Poland, 2015) for the following years: 1960, 1969, 1979, 1988, 1996, 2002 and 2010 with relatively high spatial resolution (data for LAU-2). The database contains information on area of individual crops, their yields, livestock density and mineral or organic fertilizer rates. These data were used to estimate annual carbon input from crops and manure. The average carbon input was calculated every 10 years (according to the times when editions of the agricultural censuses were carried out) to be used in Roth-C (Table 3.3).

Table 3.3 Yield and C input changes within 1960-2010 period for CS Dolnoslaskie.

Year	Yield cereal[1]	Plant input	Manure input
	FM $t.ha^{-1}$	C $t.ha^{-1}$	
1960	2.154	0.71	0.34
1969	2.839	0.81	0.44
1979	4.031	0.81	0.55
1989	4.080	0.95	0.36
1996	3.966	1.28	0.19
2002	4.296	1.56	0.12
2010	5.155	1.78	0.07

[1] average grain yield of wheat, rye, barley and oat

For croplands, the weighted carbon input from residues was calculated based on the area of the crop reported in the agricultural census and the values for individual crops. The current crop C input values were adjusted over time to represent the trends in crop yield during whole decades by means of converting historic crop yield data into carbon input. A linear relationship between crop yield and carbon input was used (Franko, 1997), with coefficients of C accumulation by Franko (1997) as a base. Two alterations were deemed necessary. Firstly, original calculations (Franko, 1997) did not include the input of root carbon. Therefore, the root C-input for non-cereal crops was obtained by multiplication of their above-ground inputs by 1.15, and cereal and oilseeds above-ground inputs were multiplied by 1.25. Most authors use multiplier 1.5 (Van Wesemael, 2010) for cereals, but that value led to considerable overestimation of model results in our modelling process (rapid increase of accumulated C in all soils within short time). Secondly, the relationship between crop residues and grain yield is not linear when considerable changes occur in, e.g., selection and performance of crop cultivars, harvesting methods and/or straw management strategies. These types of changes had been occurring in the period 1960-2000. In order to better reflect the trend of these changes for cereals, oilseeds and maize, a direct method was used for calculating the amount of crop residues and organic carbon, in accordance with the methodology of Johnson et al. (2006).

The estimate of the decomposability of the plant material was set as default value in the model. The information on the length of period when soil is covered by plants was equal to the length of vegetation period in the area.

Carbon input from manure was derived from the livestock numbers in each category (livestock unit per 1 ha arable land) multiplied by their average manure production and the time spent in the stables. Based on statistical data and literature we also took into account the method of holding animals (shallow or deep litter), which affects the consumption of straw and manure production. Because no information is available about the ratio manure /slurry (especially in the past), therefore, it was assumed that the whole organic fertilizers was farm yard manure with 25% of dry matter and organic C content was 35% of the dry matter.

Climatic data
Climatic data were obtained from the Model of Agroclimate of Poland (MAP) in the GRID format (Górski & Zaliwski (2002). This model is based on the meteorological station network belonging to the Institute of Meteorology and Water Management and some mathematical algorithms (taking into account e.g. elevation). The mean annual precipitation in the study area is 643 mm and mean annual temperature is 8.9 °C. Potential evaporation was calculated from potential evapotranspiration (MAP) by dividing it by 0.75 as suggested by Coleman and Jenkinson (1999).

Soil data
The initial organic carbon stock in the IUNG database was calculated using bulk density assessed with a pedotransfer function (PTF). Depth of top soil layer was calculated taking the changes of tillage depth over time into account. The historical SOC data represent the 60's and 70's of the last century when the depth of soil conversion was smaller than presently. Deeper tillage resulting from more intensive mechanization and modern machinery had an effect in dilution of SOC in topsoil (Van Meirvenne et al., 1996). The change concerned the 25-30 cm layer. It was assumed in our study, based on the databases of historical soil profiles, that prior to mixing 0 – 25 cm and 25 – 30 cm layers, organic matter content in the layer of 25-30 cm was half of its content in the soil top layer (Stuczynski et al., 2007). The initial SOC content was corrected for change in ploughing depth (see Appendix A).

Roth-C modelling was performed for each sampling location separately (94 soil profiles). Therefore we obtained 94 separate forecasts of SOC content (%) and SOC stock (t ha^{-1}) for 2014 as response to SOC initial content, pedo-climatic conditions and transformations in agriculture.

3.4 Results

3.4.1 Baseline modelling

The modelling processed for scenario S1 revealed that, on average, SOC stocks, after decreasing in 70's and 80's, started to raise from the beginning of 21th century as response to intensification of crop farming (Figure 4.4). This constant increase has been observed until final year of the forecast. It must be noted that in 1960-2010 period rapid increase in yields was observed, resulting in higher amounts of plant residues (Table 3.3). This effect was also related to progress in plant breeding effectiveness, affecting crop yields, crop resistance to diseases and changing grain/straw ratio. The second baseline scenario assumed that from the end of the 80's, mixed farming system was kept (Figure 3.4, blue line). This scenario shows an almost constant SOC, with minor changes only visible at narrow scale. Even so, the change starts as sharply around 1999, as for the trend lines at medium and high SOC (orange and brown lines, respectively). The trend line at low SOC (yellow line) shows a sharp change at around the year 1989. These sharp changes cannot be fully explained by changes from the 10-year census.

3.4.3 Validation

The initial contents of SOC in sampling locations (n=34) included in the comparative soil analyses were in the range 0.5 – 1.7 % with the highest concentration around 0.8 – 0.9 %. The SOC measurements performed in the same profiles in 2010-2013 revealed SOC accumulation in most of sampling locations. However, the relationship between SOC initial content and the size of SOC change was weak and statistically insignificant.
Results of the repeated SOC measurements correspond to SOC increase observed in the modelling process for the S1 "as was" scenario under which in most soil profiles the lower or greater increase in SOM content was found after 40-50 years. The Roth-C model explained 56% of variability of the measured SOC stock which can be treated rather as a good prediction, especially taking the resolution of the agricultural data included in the model into account. Therefore, the use of the regressions derived with the Roth-C model and the available census data were considered appropriate for extrapolation over the longer time period up to 2050.

3.4.1 Extrapolation over time

The forecast of potential future SOC changes was performed for the S1-specialization and S2-Return to MFS scenarios. As input data the results from the S1 Baseline modelling were used. For the S1-specialisation scenario, currently 90% of the land use consists of cereals (mainly wheat and barley), rape and corn. A first assumption was constant C input from crops and manure between 2015 and 2050. Farming in this region is already highly specialized, and a further increase in specialization is not likely. Also, implementation of new practices under the European "greening" policy will not affect C input in the region. The obligation for farmers to maintain 5% of arable land as Ecological Focus Area will be likely fulfilled by cover crops. This may include cultivation of green manures, but in a small amount that will not significantly replace manure. A second assumption was that all straw from corn and rape remains on the fields and is ploughed into the soil. Hence even in the S1-Specialisation scenario the Roth-C model calculated an increase in C over time, i.e. from 49,500 kg.ha^{-1} in 2014 to 52,000 kg.ha^{-1} in 2050.

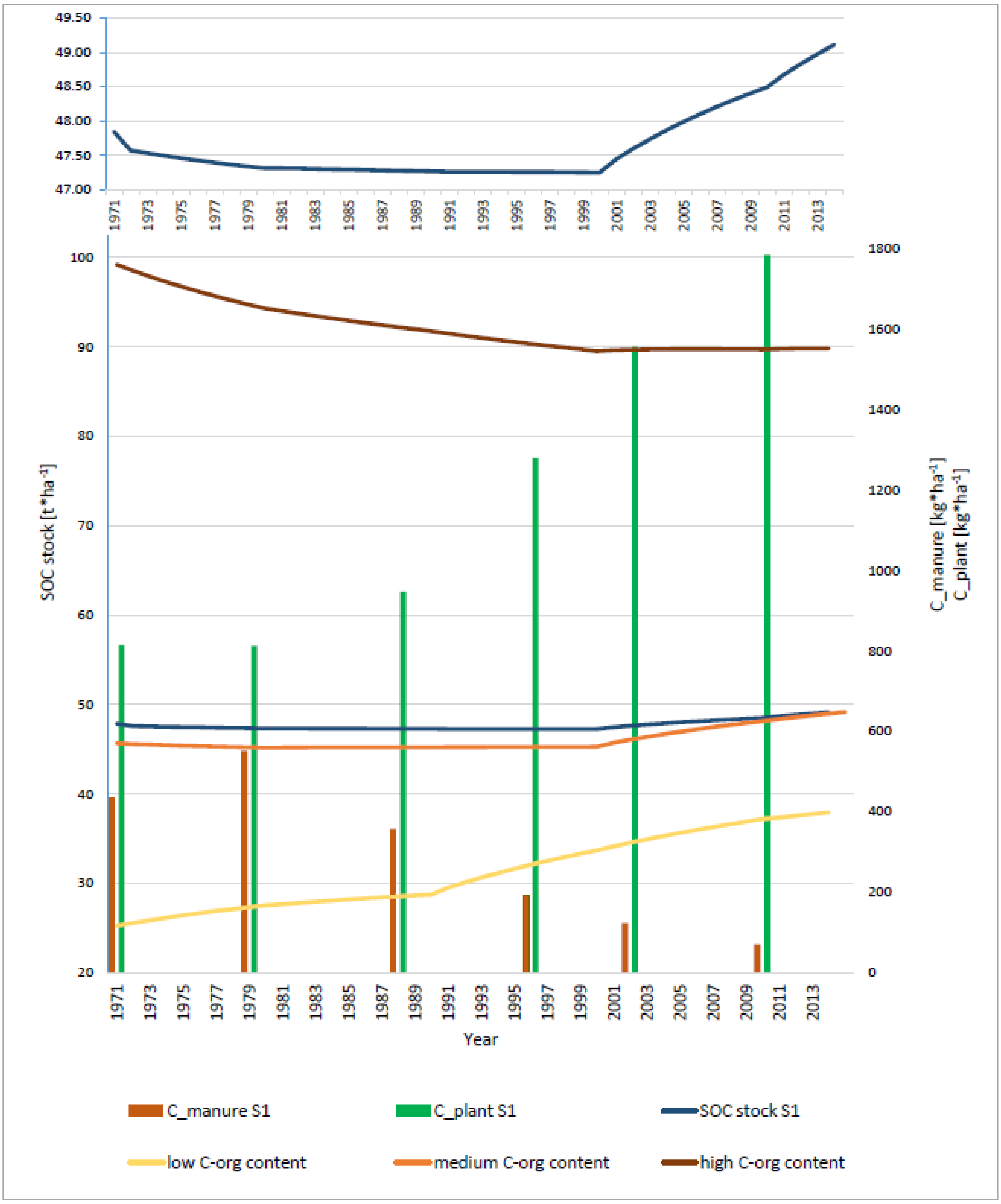

Figure 3.4 Average trend of modelled SOC stock changes in scenario S-1 and example trends for individual soils with the highest, lowest and median initial SOC content. Bars mean average manure and plant inputs of C in years of national agricultural census. Upper plot presents SOC stock changes in S-1 scenario in narrow scale in order to better show SOC fluctuations with time.

For the S2-Return to MFS scenario, it was assumed that some farms return to a form of mixed farming system, which, in the conditions offered by the area (fertile soil, lack of pasture) and with the current economic determinants, most probably involves dairy cattle production. Occurrence of some large dairy farms was assumed (1-2 per LAU-2 area), which would be based on feed produced within their own farm or gained by exchange with neighboring farms. This might involve exchange between arable and livestock systems, e.g. corn silage for manure. There may also be exchange of land for fertilization by organic fertilizer, so that manure production would be "dissolved" over each LAU-2 area. Estimating the amount of C input from crops and manure, appropriate crop rotations were assumed to provide a source of feed. Accordingly to the size of the livestock production, we introduced the cultivation of grass mixtures with legume and maize for silage. These two crops are currently the primary source of feed for cattle kept in a closed system. The assumed livestock production level was not very high (35-45 LSU/100 ha UAA) because at such favorable agro-climatic conditions and farm structure (majority of large farms), most of the farmers would be still more interested in intensive crop production.

In this S2-scenario also an increase in C takes place, at a rate of 54,000 – 49,800 = 4,200 $kg.ha^{-1}$. The carbon accumulation is more pronounced than in the S1-Specialisation scenario. It can therefore be concluded that the introduction of a mixed farming system even in a part of farms and the return of some livestock production may give measurable benefits in the form of C-sequestration in soils of the region.

All calculations show that the positive trend in C-change extents to 2050 (Table 3.4). By then, C-change per ha per year in MFS amounts to 120 $kg.ha^{-1}.yr^{-1}$, or 150% from the baseline of permanent MFS. Over time, the difference between specialized arable systems and MFS will diminish substantially. Still, comparison of the baselines and extrapolations shows a clear benefit from MFS (arable + livestock) over specialized arable systems with an increased C input from high yielding crops.

Table 3.4. Changes in carbon stocks with time for different farming systems.

Farming system	Year	1971	2011	C-Change per ha	C-Change per year
		C-stock $kg.ha^{-1}$		$kg.ha^{-1}.yr^{-1}$	
S1- Transition of low intensity MFS into specialisation		47,800	48,500	700	18
S2-Permanent MFS		47,800	51,000	3,200	80
	Year	2015	2050	C-Change per ha	C-Change per year
		C-stock $kg.ha^{-1}$		$kg.ha^{-1}.yr^{-1}$	
S1-Specialisation		49,500	52,000	2,500	71
S2-Return to MFS		49,800	54,000	4,200	120

3.4.2 Upscaling to the regional level

No accurate data are available regarding the current areas under specialized and mixed farming systems for the study area. Therefore, the current carbon balance at regional level cannot be fully and precisely assessed. This would also require estimating SOC change in land under permanent grassland. So far there is no indication that the SOC change in permanent grasslands would be negative.

Geo-referencing all individual locations enabled spatial expression of modelled C stock changes. A C-stock change map was produced in Arc-GIS 9.2 software based on the digital soil-agricultural map of Poland in scale 1:25,000. The data of soil profiles for which the individual modelling was performed were linked to the map polygons. The soil map polygons represent soil texture, soil type and soil/land suitability class. The relationship between chemical characteristics of soil profiles and soil polygons enabled extrapolation of such soil data as initial SOC stock and SOC stock change within 1971-2050 period.

The algorithm used for the extrapolation assumed assigning the map polygons to soil profile data based on similarity of soil texture. In addition, the algorithm involved compatibility of soil/land suitability classes and physiographic regions, according to Kondracki (2002). Another important condition for linking the given polygon with the given soil profile of similar characteristics is the closest distance from the centroid of polygons to the soil profile. The proximity of locations of soil profiles and polygons is very important because the statistical data describing agronomic factors (crop structure, yield, fertilization, etc.) are collected at LAU-2 administrative level, independent from the soil spatial diversity.

Figure 3.5 *left* shows the change in SOC for S1-Specialisation in 2050, with a large area having an intermediate SOC (50-60 kt.ha^{-1}). When this area would be converted to MFS, the resultant would be a decline in SOC (Figure 3.5 *right*). This is supposedly due to the occurrence of cash cropping as part of the MFS. However, in a larger part of the area the difference between S2-Return to MFS and S1-Specilisation is positive (green). This is of particular importance given the low SOC prevailing in this area under the S1-Specialisation system.

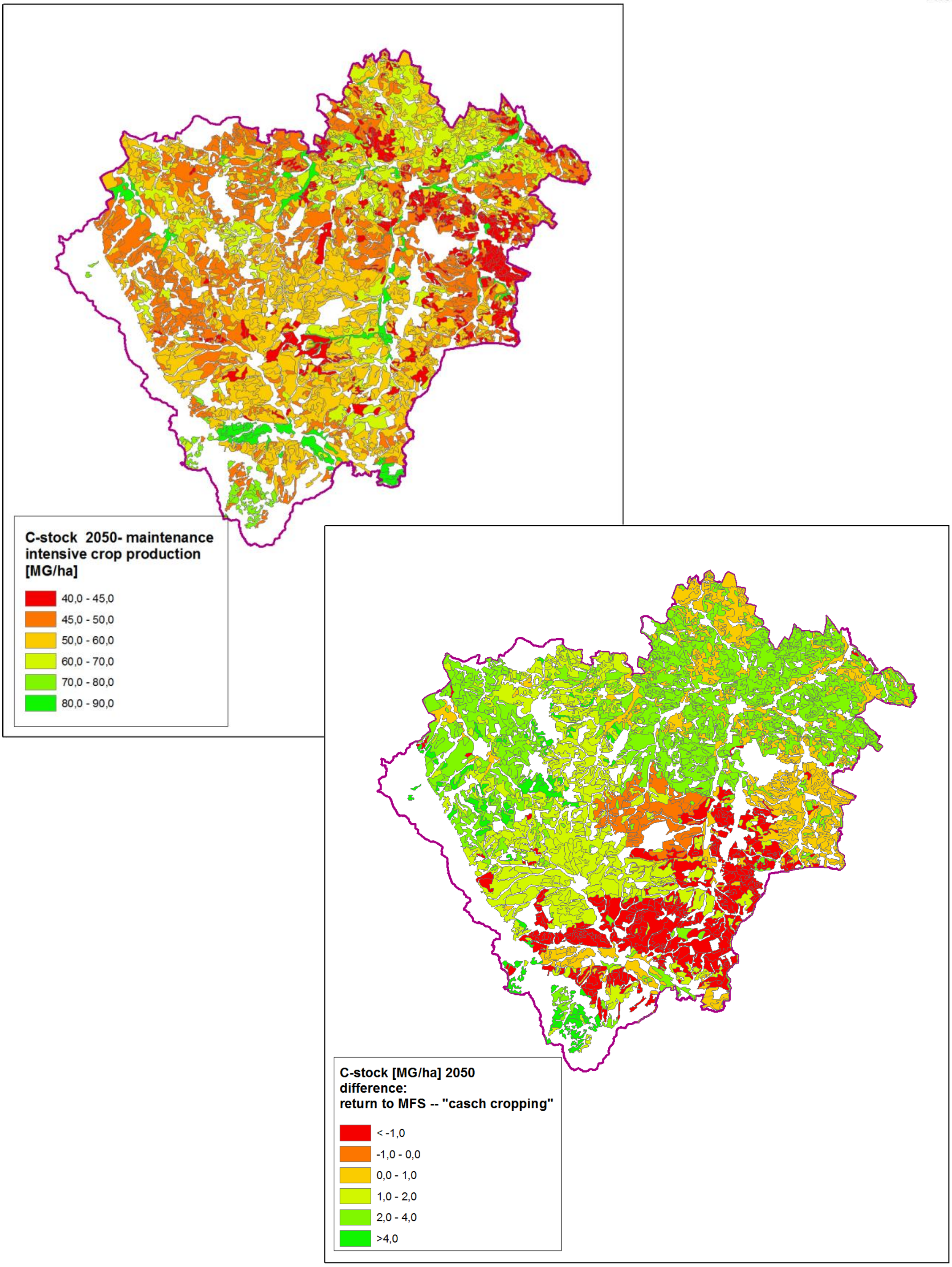

Figure 3.5. *Upper:* Forecast of SOC stock in arable land of CS Dolnoslaskie in 2050 in S1-Specialisation; *Lower:* difference in C stock between S2-Return to MFS and S1-Specialisation.

3.5 Discussion

In this study both crop-specialized and MFS scenarios projected accumulation of SOC. Carbon sequestration in the scenario representing transition from MFS to specialized crop production was confirmed by SOC measurements in samples collected from the same soil profiles taken in 1960-1970 vs 2010-2014

The SOC contents in the Dolnoslaskie area are low comparing to European data, collected within LUCAS project (Toth et al., 2013). Average SOC content in the climate zone containing Poland (sub-oceanic to sub-continental) in LUCAS programme was 1.5%, whereas in Atlantic and Suboceanic zones they were 2.0 and 1.9%, respectively. Given the very low SOC contents the case study area, it is not surprising that any input of crop residues would make a positive contribution to SOC.

SOC stock in agricultural land is ultimately determined by an equilibrium between the annual input of crop residues and other organic inputs, and the annual rates of decomposition. This theory of the steady SOC state is well supported by long term experiments (Sleuter et al., 2006). In addition, the equilibrium has a strong pedo-climatic dependence, as both the parent material and temperature and moisture are driving forces of mineralization process. The influence of agricultural management is by the addition of organic matter (amount and quality), soil tillage, i.e. ploughing, and fertilization.

Numerous regional studies showed declining SOC stocks in intensively managed croplands in Europe during last few decades (Sleutel et al., 2003; Belamy et al., 2005; Saby et al., 2008). In contrast, other studies have reported increases in the topsoil SOC stock under intensive arable land use (Van Meirvenne et al., 1996; Nieder and Richter, 2000, Barancikova et al. (2010)). In many of these latter cases, SOC gain was accompanied by deepening ploughing depth and substantial surge of mineral or animal fertilizer rates over a period of several decades (Sleuter et al., 2006). In Dolnoslaskie slow SOC decline between 70' and end of 90's corresponded to livestock decline, accompanied with changes in crop structure, as in similar situation described by Goidts and van Wesemael (2007). Such transitions in agriculture were associated with higher yields due to cultivar breeding, but also higher harvest indexes, increased share of root crops in the rotation and reduced area of legumes.

In the case of Dolnoslaskie the probable reason for the observed SOC accumulation is the high input of plant residues, especially straw of cereals, rape and corn grown for grain. After the economic transformation in Poland in 1990, most of arable land passed into private hands. These farms shifted production into crop production, therefore corn and rape reached a large share in the crop structure. Under favorable pedo-climatic conditions in this area they achieved high yields, therefore substantial amounts of straw remained in the field and was ploughed. Moreover, with very low livestock density, the straw is nowadays almost fully left in the field. Highly developed, intensive agriculture provides optimal nitrogen fertilization, which enables high yields and have a positive effect on the process of plant residue humification (Goidts et al., 2007).

The estimation of the SOC changes was very much dependent on the key figures for carbon input from crop residues and manure. Over the study period, crop production has increased due to increased use of fertilizers. This will have led to higher input from crop residues than in the early stages. The modelling took this into account only by increasing C-input at decanal scale, no distinction was made in DPM/RPM ratios of specific agricultural crops.

In considering implementation of MFS at a wider scale and/or extrapolating to other areas, two points of special interest are the level of intensity (proportion of cereal and grass-clover leys vs. root crops) and the availability of manure. Further model explorations may indicate to what extent the system may be further optimised. However, it must be pointed out that one of reasons for the modelled and observed SOC accumulation trends was the low initial SOC content in most of soils in the study area. Similar SOC sequestration under crop specialization could not be expected for soils initially rich in organic matter.

3.6 Conclusions

The research proposed the approach for combining spatial soil and climatic data with statistical information on agriculture and confirmed its utility for modelling SOC stock changes using Roth-C model. The method has certain limitations and weaknesses, e.g. resolution of statistical data on agriculture, however provides reliable projections of SOC stock trends, validated by comparative soil analysis in the same georeferenced locations.

At the regional level it was assessed that both specialised and mixed farming systems may increase SOC levels, with highest contribution offered by MFS including dairy farming. However, currently there are no effective policy instruments and strategies stimulating development of animal production sector in the region.

Scenario analysis revealed that potentially Dolnoslaskie has high capacity for increasing SOC levels in agricultural soils by a return to mixed farming systems. Mean contribution by MFS was assessed at 120 $kg.ha^{-1}.yr^{-1}$ in the period until 2050, which may be considered significant in the framework of climate change.

4. Assessment of Winterswijk (NL)

4.1 The Challenge

The region of Winterswijk is known for its small-scale 'coulissen' landscape with high nature and landscape values. The larger part is used for agriculture and the remainder is forest and nature areas. Land use is dominated by grassland (65%) and maize silage (24%). Mixed farms were dominant in the landscape for centuries up to the midst of the 20th century. After the introduction of maize silage and the EU-milk quota system, specialisation took place in dairy husbandry systems. A major environmental concern in the area is the water quality, of which the nitrate and phosphorous content in major rivers are too high. Though most farms are under pressure of high natural constrains, agriculture is considered the base for landscape preservation. Farmers and other stakeholders in the region are involved in projects testing innovative practises, e.g. to reduce mineral losses and increase biodiversity. So far, the impact of such measures on soil organic carbon has not been taken into account. The present case study aims to assess the effects of specialised and mixed farming systems on the regional soil carbon balance.

4.2 Description

Agricultural area

The municipality of Winterswijk is part of the Achterhoek district, a region of the province Gelderland, located in the eastern part of the Netherlands along the border with Germany (Figure 4.1). The area (c. 20,000 ha) is known for its small-scale 'coulissen' landscape with high nature and landscape values, consisting of a mosaic of grasslands, arable fields, hedgerows, woodlots and small brooks with high water quality. The larger part is used for agriculture (c. 15,000 ha) and the remainder is forest and nature areas. Land use in Winterswijk is dominated by grassland (65%) and maize silage (24%). Other crops are cereals (4%) and potatoes (6%). Only 1% is used for horticulture, tree nurseries and fruit production.

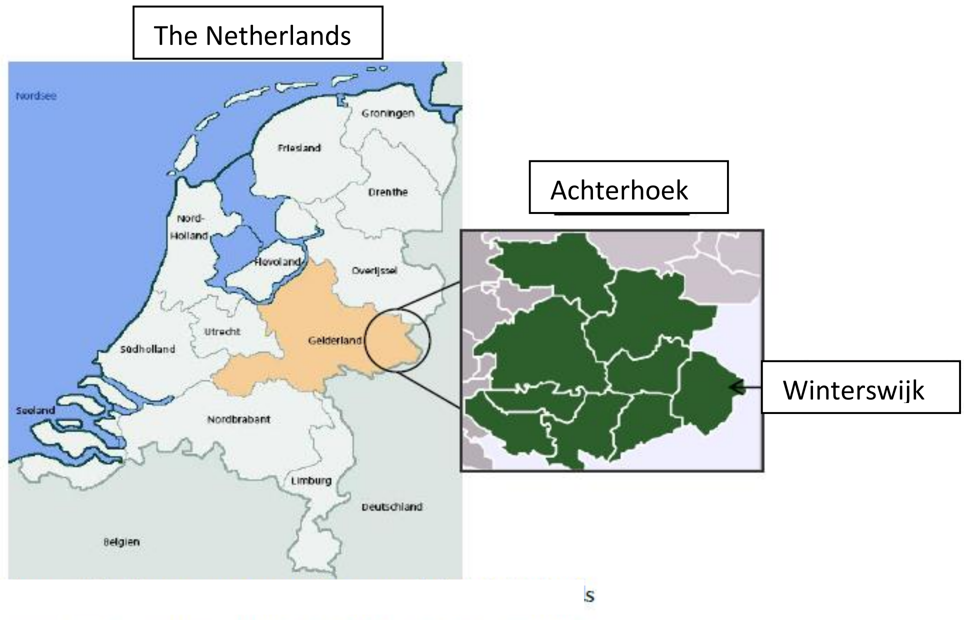

Figure 4.1. Location of the CS Winterswijk region in the Netherlands.

Dairy farming is the dominant agricultural activity (~157 specialised dairy farms). Other farm types include arable (~57 farms), pig (~40 farms) and poultry farming (~10 farms), respectively. The total number of farms in the region decreased from 487 to 331 (-33%) in the period 2000 to 2012. Main dairy factories and supply companies are outside the area. The small number of arable farms in this region as compared to dairy farms is explained by climate, landscape and soil conditions, which are not suitable for producing cash crops but are good for fodder production.

Tourism and recreation are major activities in the region next to agriculture, especially hiking and cycling. Some farmers are offering camping places and B&B facilities on the farm. Of the working population, c. 5% is working in agriculture and 6% in recreation and tourism. For the next decade, a slight reduction of the population is expected (-2% to 2030). Due to the beautiful landscape Winterswijk became in 1993 a so-called Valuable Man-made Landscape with extra funding for a great diversity of projects to stimulate agricultural development, nature and landscape conservation and investments in the infrastructure for recreation. The region was designated in 2005 as one of the Dutch National Landscapes.

Environmental problem

A major environmental concern in the area is the water quality, of which the nitrate and phosphorous content are too high. The high fertilisation rates in the past and present have led to high levels of N and P in the watershed of the Slinge river. The water quality in the area is also partly determined by the inflow of water with high levels of, e.g., N and P from the Bovenslinge in Germany (Feldwisch, 2013). The implementation of the Nitrates Directive in the Netherlands enables dairy farmers to apply for a derogation from the EU-standard of 170 N kg-ha^{-1} (Van den Ham & Luessink, 2012). Specific conditions apply, e.g. at least 70% of their UAA must be in grassland (as from 1 January 2014 it was 80%). When derogation is granted, an amount of 250 N kg.ha^{-1} (230 N kg.ha^{-1} as from 2015) from manure may be applied on grassland. All maize cultivation has to be combined with the cultivation of a green manure, sown either during the growing season or after the maize harvest. In addition, dairy farms with overproduction of manure are obliged to dispose of it. The amount of manure exported from a dairy farm is an important economic parameter since all export is charged to farmers. In the province of Gelderland, c. 50% of the specialised dairy farms have manure overproduction while very few mixed dairy farms have manure surpluses. In general, the overproduction of manure is sold to a manure collector company for transportation to arable farms in other provinces. Some farms have engaged on manure processing, e.g. though splitting in thick and thin fractions, and export of the former. Current agricultural policy for dairy farms in the Netherlands requires that dairy farmers have to register and submit each year details concerning the manure production at their farms. The combined outcome of the choices on derogation, manure processing and manure distribution determine to a large extent whether input of N or P is the major restricting nutrient at the farm.

Stakeholder Process Design

In the Winterswijk region, many environmental regulations come together to protect nature and water quality (e.g., four Natura2000 reserves, Nitrates Directive, Water Framework Directive, CAP, etc.). The main objective for the region is to maintain the so-called small scaled landscape which is also attractive for tourists and to promote a sustainable and profitable agricultural development.. A driving force behind regional development in this area is the foundation 'Waardevol Cultuurlandschap Winterswijk' (valuable cultural landscape, WCL Winterswijk), a platform in which municipality, farmer's organization, owners of small estates, local nature and environmental groups, recreation and tourism sector, local industries and citizens groups of the different villages cooperate. WCL Winterswijk (www.wclwinterswijk.nl) aims to maintain the beautiful small scale landscape, develop the agricultural infrastructure and improve the ecological values of the region. Since its foundation in 1994, WCL has been active in many projects in the region, including the development of multifunctional and sustainable agriculture. Since farmers play an important role in the maintenance of the landscape, continuation of farming is considered essential for landscape conservation. Farmers from their part are willing to protect nature, landscape and environment but need to be rewarded for their efforts. Facilitated by WCL, stakeholders in the region are working together to sustainably strengthen the region (Figure 4.2).

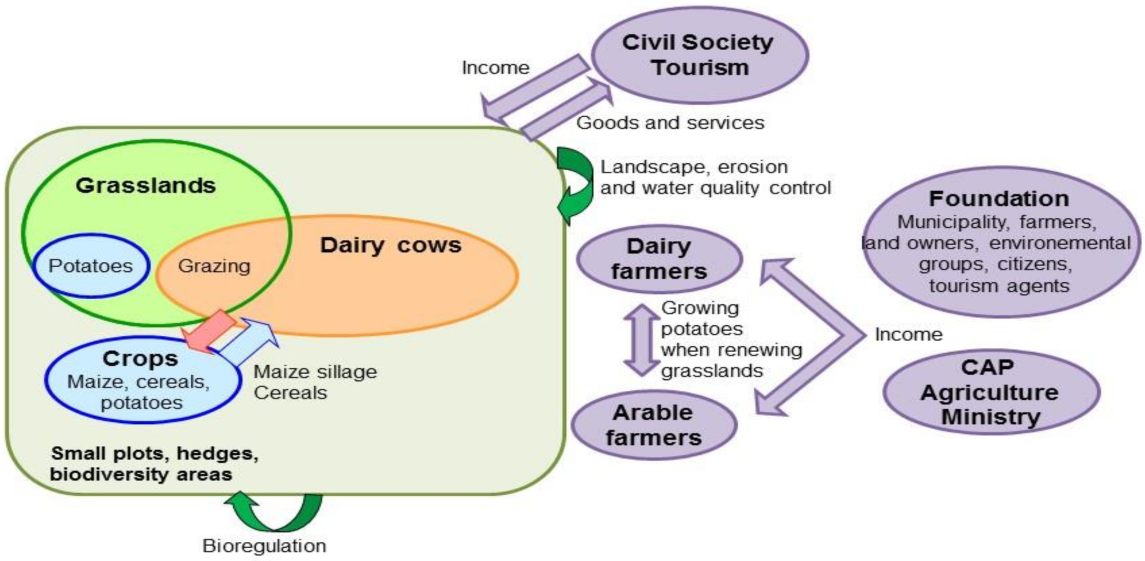

Figure 4.2. Stakeholder model of the mixed farming systems in the CS Winterswijk.

Within the framework of CANTOGETHER, the type of integration in CS Winterswijk was identified as 'territorial synergy' (Moraine et al., 2014). Important projects in the stakeholder process so far were the development (and failure) of a rewarding scheme for farmers that deliver ecological services for society, and the testing of innovative agricultural practices aimed at improving biodiversity and water quality. In the coming decade, WCL will continue its work to maintain a viable and ecologically sound agriculture (WCL Vision 2015-2025).

Mixed farming systems

In the region, mixed farms with combinations of arable, pig and dairy production were dominant in the landscape for centuries up to the midst of the 20th century. After the introduction of maize silage in the 60's, most arable fields have been turned into fields with silage maize, often in rotation with grassland. After the arrival of the milk quotas in the 80's, further specialisation took place in dairy husbandry systems, which is the dominant agricultural activity up to this day (~157 specialised dairy farms). As from this period, the milk production per cow increased substantially. Following the implementation of the Nitrates Directive, most dairy farms have opted for derogation (which up to 2014 was based on 70% grass and 30% maize per farm), that gives them higher manure-application limits.

Land sharing as part of a mixed farming system refers to the territorial synergy of the stakeholder process. To a certain extent land sharing is linked to governance aspects, e.g. ownership of agricultural lands by third parties and short-term lease to farmers. Examples of land sharing are the cultivation of crops (cereals, potato) on grasslands in-between their renewal, various agricultural measures to improve water quality and biodiversity, and the management of so-called natural grasslands. Farmers in the region have been involved in projects testing innovative practises aiming at sustainable agriculture. This included measures directed at diversification of crops to stimulate biodiversity (Korevaar and Geerts, 2012; Korevaar et al, 2014) and reduction of N- and P-losses to ground and surface waters (Den Boer and De Haas, 2013). The testing of the measures to reduce N- and P losses included both the effect on N and P as well as on yield, costs and practical applicability. Measures to improve and stimulate biodiversity may be applicable to agricultural fields (e.g. cultivation of cereals as dairy concentrates) and/or the natural boundaries (i.e. hedgerows) surrounding them (Appendix B, Table B.1). Application of the measures to reduce potential mineral losses (e.g. refrain from applying manure, raise pH) to all suitable fields in a subregion of 5000 ha would lead to a reduction of 123 t N and 72 t P_2O_5, amounting to 8-9% of the N applied in the area as manure and chemical fertilisers and 19-20% of the P_2O_5 applied.

4.3 Methodology

4.3.1 Outline

A scenario analysis was performed for a farm typology of baselines and innovations to assess change in SOC from measures that had been selected for their capacity to improve biodiversity and/or reduce mineral losses. The results were used for upscaling to the regional level. To this end, calculations were performed at increasing level of spatial scale:

Step 1: at field level, per cultivation, using Roth-C;

Step 2: at farm level, per farm type, from a summation of the results per cultivation, of SOC-changes at field level (times, area, size);

Step 3: at regional level, from a summation of the results per cultivation, of SOC-changes at field level (times, area, size in the region).

The time-scale of the scenario analysis was twofold, i.e. a 20 year period was kept as a period over which an individual farmer might influence SOC in his land, and a 35 year period was kept in order to assess SOC changes in the year 2050.

4.3.2 Selection of baseline and innovations

Since dairy farming is the dominant farming system in the CS Winterswijk, the focus of this study was on assessing SOC change for mixed dairy farming systems, in particular with respect to land sharing. Innovations were selected from the earlier work from Korevaar & Geerts (2012) and Den Boer & De Haas (2013), including those measures that may have an impact on soil organic matter (Appendix B, Tables B.1 and B.2). These innovative measures were grouped as follows:

Dairy farming with extra crop:

- cereals for dairy concentrates;
- potato cultivation; and
- grass clover.

Dairy with ecosystem service:

- no farm yard manure;
- raise pH to 5.5; and
- full catch crop in maize.

Thus two types of mixed dairy farming systems were considered. For the purpose of comparison, specialised arable and specialised dairy farm were included as baselines (Table 4.1).

Table 4.1. Typology of baseline and innovations in CS Winterswijk.

Typology	Farm types
S0-Baseline 1: Specialised arable farming	Arable farms with potato / cereals / sugar beet rotation
S0-Baseline 2: Specialised dairy farming	Dairy farms with grass/maize rotation, using their manure on their own land and buying concentrates
S1-Innovation: Mixed dairy farming with crops	Dairy farms that cultivate potato for cash income, or grow cereals and grass-clover leys as cattle feed.
S2-Innovation: Mixed dairy farmers with services	Dairy farms that take measures for biodiversity and/or improvement of water quality

The notation ‘specialised’ in this case study does not relate to intensity in terms of production per ha or input per production-unit. It indicates only that a single agricultural sector is being practised at the farm. A specialised dairy farm could be both an extensive dairy farm producing all grass and roughage, using all produced manure, as well as an intensive farm that imports concentrates and exports manure. Thus the specialised farms do not necessarily share a similar ‘environmental profile’ in terms of external inputs, losses and/or footprint.

4.3.3 Data collection

Farm type

Farm data conforming the typology of baselines and innovations was collected via an inventory in the region with respect to a single calendar year (2012) via farmer face-to-face interviews and follow-up contact. Farmers were approached from the network of farmers that had resulted from previous projects. In addition to general features, the interviews focussed on aspects relevant for nutrient management, e.g. farm local context, integration practices, farming practices, input use, feeding strategies, fertilising strategies, land use, nutrient recycling, and agronomic and economic performance. Afterwards, all farms were assigned to one of the four distinguished typology groups (Table 4.2).

Table 4.2. Characteristics of typical farms groups in CS Winterswijk.

Parameter	Specialised Arable	Specialised Dairy	Mixed Dairy (crops)	Mixed Dairy (services)
Number of farms	4	2	4	3
Utilised agricultural area (ha)	169 ± 78	101 ± 3	55 ± 8	64 ± 6
Milk production (ton)	not relevant	1187 ± 224	650 ± 97	641 ± 163
Permanent grassland (%)	0	69 ± 2	58 ± 13	70 ± 11
Temporary grassland (%)	11 ± 11	0	11 ± 10	4 ± 4
Grass-clover (perm. or temp.) (%)	0	0	10 ± 6	33 ± 33
Silage Maize (%)	15 ± 7	31 ± 2	18 ± 5	14 ± 5
Potatoes (%)	56 ± 19	0	4 ± 4	0
Cereals (%)	15 ± 14	0	7 ± 5	12 ± 10
Stocking rate (LSU ha^{-1})	not relevant	1.97 ± 0.23	1,83 ± 0,23	2.04 ± 0,37
NUE (%)	113 ± 19	25 ± 1	27 ± 2	39 ± 4
PUE (%)	142 ± 29	45 ± 3	57 ± 6	108 ± 4
N surplus ($kg.ha^{-1}$)[1]	1 ± 16	216 ± 37	215 ± 29	93 ± 22
P surplus ($kg.ha^{-1}$)[1]	4 ± -4	16 ± 1	12 ± 3	-1 ± 1
Other crops (%)	3 ± 3	0	1 ± 2	0

[1] NP surplus is calculated on the bases of ha in use by the farmer, irrespective of ownership of the land.

Land use

Derogation requires a proportion of lands cropped with grass and maize/other crops (70-30%, as from 2014 80-20%). From a farming systems perspective, the area of a specific crop at a farm has more informative value than the actual proportion since farm management of the fields is partly influenced by the area a farmer has to manage. This may be even more so in a small-scale landscape with hedgerows and with respect to extra crops and/or ecosystem services. Based on the empirical data from the inventory, four standard configurations of farming systems were formulated, assigning key figures for the area sizes per crop in AA (Table 4.3).

Table 4.3. Land use at model farm types in CS Winterswijk.

Farming system	Grass*	Potatoes	Maize	Cereals	Total
			ha		
Arable, specialised		120	40	10	170
Dairy, specialised	70		30		100
Dairy, mixed with arable crops	30	5	10	5	50
Dairy, mixed with services	50		10	5	65

* mixed systems: grass-clover

4.3.4 Modelling

To assess the validity of the Roth-C model in the region of Winterswijk, the model was run with data from two fields of the experimental farm 'De Marke' and validated by comparison with SOC-measurements. For this purpose, data were used from Verloop (2013), concerning soil characteristics, C-input, and weather (mean monthly temperature and rainfall over the period 1993-2005).

Initialisation of Roth-C

For the initialisation procedure, data were used for two sandy soils with a maize-grass rotation at De Marke, differing in SOM content, i.e. 4.1 and 6.2%, corresponding to 2.4 and 3.6% C. The fraction IOM was assessed using the formula of Falloon et al. (in Coleman & Jenkinson, 1999). Initial values of the fractions DPM, RPM, BIO and HUM were assessed by running the model towards equilibrium for 10.000 years with assumed constant climatic conditions of the region Winterswijk.

Scenario analyses

Following the initialisation of the Roth-C model, calculations were made for the change in SOC over a period of 20 and 35 years. The modelling has been carried out using initialisation data from the De Marke field with low SOC content as starting point, for which 5 scenarios (measures) were modelled (Figure 4.3).

Figure 4.3. Scenarios analysis with the Roth-C model.

1) Cultivation of cereals or potato as compared to maize.

2) Cultivation of grass-clover swards instead of grass; since data on the C-input for a grass clover sward were not available, we used data for grass and clover cultivation, taking into account an intercropping effect of 75%.

3) Cultivation of a successful catch crop in maize as compared to a poor catch crop; in many cases the crop does not yield much in terms of dry matter production. Calculations were done for a catch crop of winter rye, using high and low levels of C-input.

4) No manure when soil-P is high, in all cultivations.

5) Raise soil pH in maize land to current recommendation levels; the measure applies to all fields with pH < 5.5. For our calculations, it was assumed that liming was done in January and thus the pH-effect would be potentially effective all year.

Input data and coefficients

Standard data were used for the C-input and humification coefficients of the various crop residues (Appendix B, Table B.3). For each of the cultivations, typical fertilizations with dairy manure in terms of month of application and amount (Appendix B, Table B.4). C-content of the manure was assumed to be 33 kg per tonne. Since the analysis involves land use with a selection of crops, the standard DPM/RPM-ratio for agricultural crops in Roth-C does not suffice and crop specific values for the DPM/RPM-ratio are needed. For this purpose, the linear relationship between the humification coefficient (h.c.) and the DPM/RPM-ratio was used (section 2.3.1). It was assumed that during the 20-year period, C-input from crop residues and manure would not change. A catch crop was included in all scenarios with maize land, as it is compulsory in the Netherlands from 2006.

Since the Roth-C model itself is not formally parameterised for pH, an appropriate coefficient was derived from data found in the literature. Leifeld et al. (2008) adjusted the Roth-C model rate constant for plant litter decomposition by pH response functions and obtained a good fit over the pH-range 2 - 8. Although this results may need validation at a wider scale, we assumed it would be useful for our analysis to indicate the perspectives of the agricultural practice.

4.3.5 Scaling up results

In the second step, results of SOC-change per cultivation at field level are used to assess SOC-change at farm level, using the proportion of each cultivation within the standardised specialised and mixed farming systems as defined for the model farms (Table 4.3).

Finally in the third step, calculation is made of the change in SOC at the regional level. For this purpose, data on the potential areas for each of the proposed measures in the region of Winterswijk are used, as provided by Korevaar and Geerts (2012) and Den Boer and De Haas (2013). Given the different geographical boundaries of their particular studies, the areas are neither similar nor additive. Based on the relative percentages of the various land-uses, an assessment was made of the potential of these land-uses for the entire agricultural area of Winterswijk (c. 15,000 ha). According to Den Boer & de Haas (2013), and Korevaar & Geerts (2012) the applicability of the measures may be assessed as follows:

- Introduction of cereals or potatoes: the total area researched by Korevaar & Geerts (2012) was 945 ha; cereals were introduced at c. 31,4% of the land, which amounts to 359 ha. Den Boer & de Haas (2013) used a different approach and calculated the availability of land for an extra crop, within the existent specialised dairy systems at two levels of self-sufficiency in roughage. Extrapolating their results to the greater Winterswijk area shows that 399 ha would be available for cultivation of cereals and/or potato.

- Introduction of grass-clover; the total area researched by Korevaar & Geerts (2012) was 945 ha; grass-clover was introduced at c. 36,4% of the land. We assume that grass-clover may be introduced in all dairy based mixed farming systems.

- Cultivation of a successful catch crop; since 2006 it is compulsory, in the Netherlands, to have a catch crop during or after maize. In many cases the crop does not yield much in terms of dry matter production. However, by choosing a cereal crop with relative high dry matter production, and improved cultivation techniques, the measure offers potential for all maize fields.

- No manure when P is high; the area within 10 m from surface waters was established, per crop, from land-use maps. The area with fields having a P-PAE ≤ 7 was also assessed per crop, from the BLGG database of routine soil samples. The majority of grasslands is outside this area while halve of the maize, potatoe and beet fields are within this area. Thus 15% of the grasslands and 50% of other fields fall within this category.

- Raise pH to 5.5; the respective areas (<4.5, 4.5 – 5.0, and 5.0 – 5.5) have been assessed from the BLGG database of routine soil samples. It was found that 87% of all maize fields fall within this category.

4.4 Results

4.4.1 Modelling results of Roth-C at field level

For the two maize fields of the De Marke, it was calculated that, after 20 years, initial SOC contents of 64.7 and 97.6 t $C.ha^{-1}$ would have reduced to 64.7 and 87.4 t $C.ha^{-1}$, thus a change of 0 and -10.2 t $C.ha^{-1}$ respectively. For comparison with measured SOM data, model results have been converted to SOM assuming C% of 58% (Figure 4.4). For the time points in 2006 and 2008 the measured values appear to have gone down and up, which is not reflected in the modelled results. The measured values are probably due to sampling and/or measurement errors. Overall, the declined SOC from modelling matches the measured amounts of SOC reasonable well at both the lower and higher SOC contents. Therefore, the use of the Roth-C model, calibrated for "De Marke" was considered appropriate for the scenario analyses of baseline and innovations.

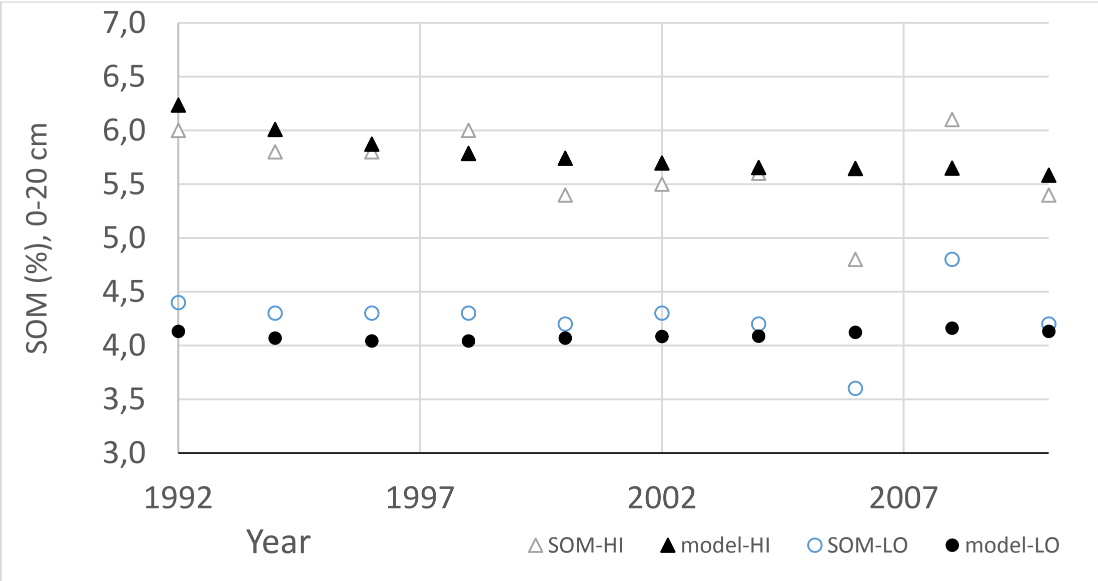

Figure 4.4. Validation Roth-C with measured data from experimental farm De Marke.

With the low SOC maize field of De Marke as starting point, the changes in SOC-content were assessed for each of the innovations (Figure 4.5). Innovation-1 concerns the cultivation of the arable crops cereals or potato at a dairy farm, instead of maize, and the cultivation of grass-clover instead of grass. After 20 years, SOC change in cereal fields is positive (+18.2 t $C.ha^{-1}$) and negative in potato fields (-2. t $C.ha^{-1}$) as compared to maize. Thus the cultivation of a cereal crop instead of maize would turn out positively in terms of SOC. For the interpretation of the change in the cultivation of potato, it has to be taken into account that potatoes are grown in rotation, e.g. 1:4 years. Therefore, the calculated losses over 20 years do not reflect the actual situation. They do show, however, that cultivation of potato instead of maize is worse in terms of C-loss. Comparing the cultivation of grass-clover with pure grassland shows that grass-clover leads to a decrease (-2.7 t $C.ha^{-1}$) in SOC-contents. The difference is due to the lower input of fresh organic matter by clover than by grass, and the lower additions of manure.

Innovation-2 concerns the inclusion, within the dairy farming system, of services that improve the quality of ground- and surface waters in terms of N and P. These are the inclusion of a full grown catch crop in maize, withholding manure where soil-P is high, and raising pH to recommendation levels. The inclusion of a full grown catch crop in maize would add more carbon to the soil as compared to the current practice of poor-to-moderate catch crops. Over 20 years, an extra SOC-content of 1.6 t $C.ha^{-1}$ may be achieved. The practice of withholding manure would increase carbon losses. In maize land this would be -4.6 t $C.ha^{-1}$; for grassland -8.9 t $C.ha^{-1}$. Finally, the effect of liming of maize soils from pH 4.5 to 5.5 was assessed by calculating the difference in SOC contents in soils with pH 4.5 and 5.5, respectively. As acid conditions reduce mineralisation, SOC content was calculated to be higher than when liming was applied. The total change by liming amounts to -9.7 $C.ha^{-1}$.

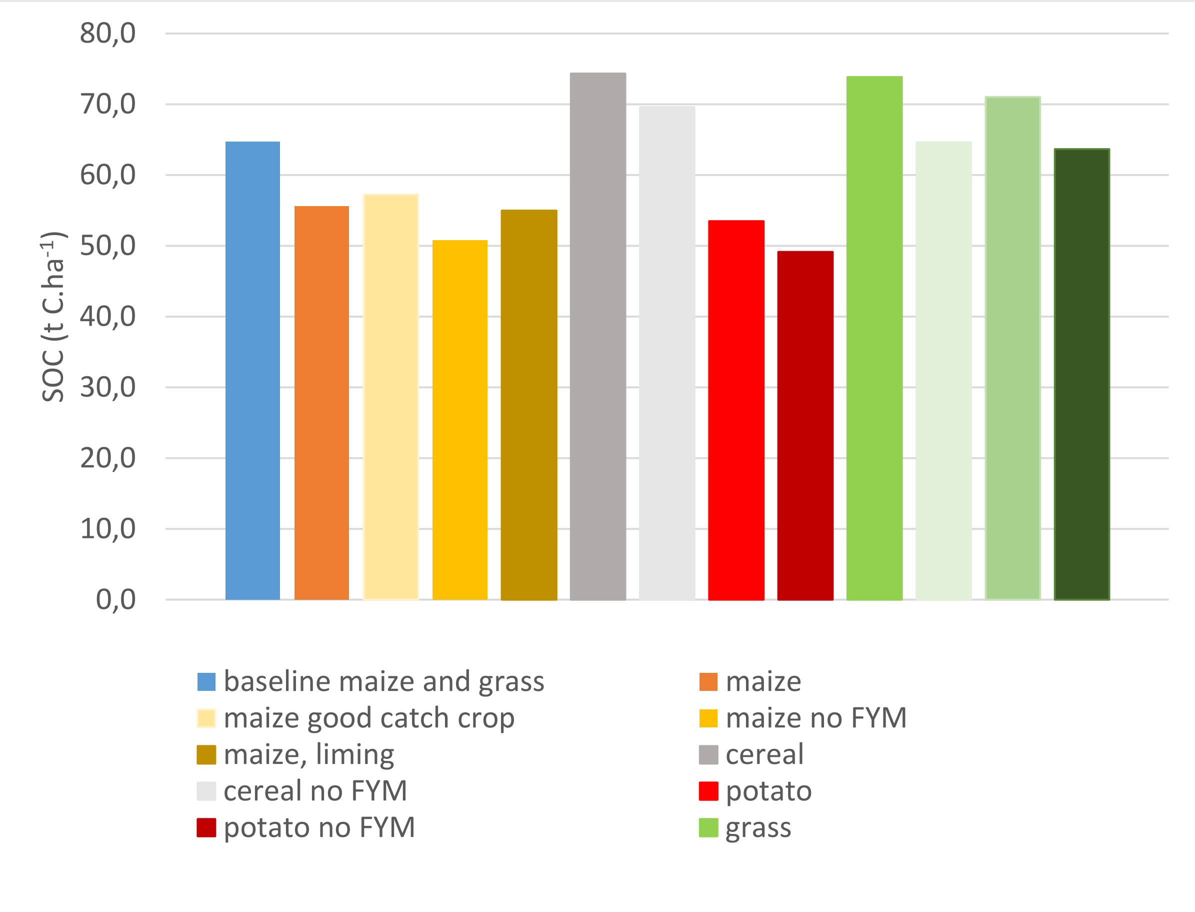

Figure 4.5. Modeled effects of agricultural measures on SOC content at field level (legend reads from left to right).

Not surprisingly, Figure 4.5 shows as best options for maintaining SOC level, the cultivation of cereals and permanent grassland including grass-clover. Maize fields with too low pH also maintain carbon; liming to reduce mineral losses in margins close to surface water increases C-loss. In general the arable crops maize and potato show loss of C, only marginally affected by the measure 'no FYM'. It should be kept in mind that the measures had been selected because no empirical evidence was found of negative agronomic effects.

Most measures with a capacity to reduce N- and P- losses to surface waters, showed to be also beneficial in terms of conservation of soil carbon. With one exception, i.e. the raising of soil pH within close distance to surface water.

4.4.2 Scenario analyses at farm level

Using the results of the individual measures on SOC, the scenario analyses have been performed for the standardised specialised and mixed farming systems with cropping areas representative for the area of Winterswijk (Table 4.4). Regarding the services 'No manure where P is high' and 'Raise pH to 5.5', it was assumed that their applicability at farm level was proportional to the area sizes found at regional level in the BLGG database.

Table 4.4. Change in SOC (0-20 cm) following scenario analyses in CS Winterswijk.

Farming system	Farm size	Farm C-stock (original)	Change in farm C-stock	Change 20 yrs		Change per ha per yr
	ha	t C	t C	%	t C .ha^{-1}	kg C .ha^{-1} .yr^{-1}
Specialised						
arable	170	10,999	-1,611	-15	-9	-474
dairy	100	6,470	371	6	4	186
Mixed						
Dairy mixed with crops						
dairy + potato	50	3,235	73	2	1	73
dairy + cereal	50	3,235	282	9	6	282
dairy + grass-clover	50	3,235	94	3	2	94
Dairy mixed with environmental services						
dairy + 'no FYM' (GC/M/C)*	65	4,206	186	4	3	143
dairy + 'pH to 5,5' (M)*	65	4,206	296	7	5	228
dairy + 'catch crops' (M)	65	4,206	294	7	5	226

The calculation procedure allowed to assess the impact of the farming system on soil carbon stock irrespective of the actual rotation at arable or dairy farms. However, sometimes a rotation is supplemented by extra additions of organic matter, e.g. compost. Such additions are not included in the above calculations. Furthermore, in practice multiple measures may be implemented simultaneously at farm level, even within a particular cultivation, e.g. maize cultivation without FYM and with a successful catch crop.

SEVENTH FRAMEWORK PROGRAMME

4.4.3 Regional carbon balance

Assuming all measures would be implemented in all the fields where applicable reveals the gain or loss in carbon at the regional level (Table 4.5). With business as usual, C-change over 20 years amounts to -42 t C. Mixed farming measures add an extra 36 t C to this, so that total C-loss would be 78 kt C for the greater area of Winterwijk (20,817 ha). The extra loss (85%) takes places on approx. 50% of the agricultural fields, i.e. 10,000 ha.

The loss is largely due to the per hectare losses of the measure 'raise pH to 5.5 along water borders'. Other large losses may be mostly attributed to the measure 'no manure where P is high,' in various crops. The extra loss occurs despite some accumulation of C from permanent grasslands, the cultivation of a successful catch crop and the cultivation of cereals.

Grassland may be affected by two, and maize land by three measures. However, it was not possible to calculate the total area affected by individual measures. In addition, they may be intertwined. For instance, for the implementation of the measure 'successful catch crop', it may be needed to first raise the pH by liming.

Table 4.5. Effect of MFS on the regional carbon balance in CS Winterswijk.

Land-use	Total	Total		New practise	Total improved area	
	%	ha	t C		ha	t C
Grassland	52.1	10,802	98,866	Introduction of cereals	200	1,932
				Cultivation of potato	200	-2,236
				No manure where P is high	1,479	-1,492
				Introduction of grass-clover	416	2,648
				grassland BAU	8,507	77,856
Maizeland	14.7	3,048	-27,771	No manure where P is high	1,629	-22,616
				Improved catch crop	3,048	-22,736
				Raise pH to 5.5	2,579	-22,028
				maizeland BAU	0	0
Cereals	2.6	539	5,208	No manure where P is high	250	1,225
				cereals BAU	289	2,789
Potato	2	415	-4,637	No manure where P is high	193	-2,993
				potato BAU	222	-2,483
Sugarbeet	0.4	83	-927	No manure where P is high	39	-599
				sugarbeet BAU	44	-497
Total area (ha)		14,887				
Total C (t C)		963,190	70,739			8,771
Total C-change (%)			7.3			0.91

SEVENTH FRAMEWORK PROGRAMME

4.5 Discussion

1. Comparing measures

Agriculture in the region of Winterswijk has gone through a process in which dairy mixed farming systems have become specialised in the '80s, and is now making another transition in which some aspects of mixed farming come back. Land sharing, seen as a specific feature of mixed farming, is involved in efforts to improve biodiversity, e.g. the cultivation of crops (cereals, potato) on grasslands in-between their renewal, and various agricultural measures to improve water quality.

The modelling of such measures as part of specialised and mixed farms has shown a positive change in SOC (in descending order):

Cereal > Grass > Grassclover > Cereal no FYM

A negative change in SOC was calculated for the other measures (in increasing order):

Grass no FYM > Grassclover no FYM > Maize good catch crop > Liming acid maize soils > Potato > Maize no FYM > Potato no FYM

Introduction of cereals or potatoes

The inclusion of an extra crop in the common dairy grass-maize rotation in the region shows the two extremes to which this may lead. The cultivation of cereals as dairy concentrates showed the highest increase in SOC, whereas the cultivation of potato (no FYM) showed the largest loss of SOC. Cereals in the rotation would deliver several benefits, e.g. for biodiversity (birds, landscape), the nitrogen balance (less input from concentrates), and built-up of soil organic matter. However, the economics of cereal cultivation in the region are less favourable, all the more so when compared to, e.g. the cultivation of potato. Over the past years, dairy farmers have experimented with the cultivation of cereals to technically increase crop yield and as a part of a paid ecosystem service scheme. These activities took place within the framework of an EU CAP-pilot and showed promising results (Korevaar et al., 2014). However, cereal cultivation has not become part of the measures stimulated by greening the CAP. In addition, new derogation requirements include 80% grassland, reducing the maximum maize acreage to 20%, which on many dairy farms is minimally needed to maintain production. It is expected that, despite the afore mentioned benefits, the cultivation of cereals in the region will be discontinued due the implementation of new EU-regulations.

Introduction of grass-clover

Evaluation of the measure 'introduction of grass-clover' involves not only the comparison with grass, but also its function within the rotation of the farming system. In terms of net gain in carbon, it was shown that grass-clover contributes less carbon to the soil than grass. Knowing that grass-clover contributes more nitrogen than grass, the question than arises if the carbon loss would negatively affect soil quality. In permanent grasslands, the overall effect of grass-clover on soil quality would probably be a loss in SOC and a gain in N content until a new equilibrium will have set in. In a grass – maize rotation, the substitution of grass-clover for grass may improve the soil in terms of both C and N.

Cultivation of catch crop in maize

The measure ‘catch crop in maize’ is not really an innovative measure, since it is compulsory as from 2006. However, in most maize fields the catch crop yields a poor result. The catch crop is meant to take up residual nitrogen in soil. However, the soil may be depleted for N after the maize harvest. No figures are available as to the number of maize fields in which this would apply. Another reason for poor yields may be inadequate technical management of the catch crop, in particular when undersowing is practiced. Or the maize is harvested too late for a catch crop to establish itself before winter. The modelling results refer to a successful catch crop (adding 1.5 t C .ha^{-1}) and show that this would reduce carbon losses in maize fields, but not compensate them fully. The data on carbon content of the catch crop refer to varieties of the past. We suggest that evaluation of this measure requires actualisation, involving monitoring data on the N residue in the soil and the carbon content of current catch crops.

No manure where P is high (< 10 m. from surface waters)

Obviously, the measure ‘No FYM’ leads to a decrease in SOC but it need not affect soil quality equally in all cultivations. Grasslands with a continuous supply of fresh organic matter of roots could probably bare a small decrease in SOC without losing productivity. In crops with a negative carbon balance (potato, maize), the deterioration of soil quality may be enhanced by not applying manure. However, very often soil quality alongside brooks and rivers is rather poor for other reasons (poor drainage, shade from trees). Crops may not be able to fully benefit from the nutrients added with manure, whereas crops in other parts of the field may make better use of extra manure. It is suggested to assign such borders for biodiversity.

Raise pH in acid maize soils

It was calculated that raising the pH would lead to very large carbon losses. It is well known that liming increase breakdown of SOM. However, the vicinity of the fields in question to surface waters may prevent, to some extent, for the mineralisation to happen. The effect of pH on mineralisation may be diverse. Without a validated algorithm for the effect of pH on C-mineralisation, models such as Roth-C cannot predict this accurately. Further research is required to assess the effect of pH on mineralisation of soil C, in particular in relation to soil moisture level.

2. Comparing farming systems

The results of the model for the specialised arable (SpA) and dairy (SpD) systems and the mixed dairy (MD) farming systems, ranged from C-loss of almost 500 $kg.ha^{-1}.yr^{-1}$ (SpA) to C-gain of almost 300 $kg.ha^{-1}.yr^{-1}$ (MD+cereal).

On the base of the farm mean change in C per ha, the systems may be ranked as follows (in decreasing order):

MD+cereal > MD+liming, MD+catch crop > MD+NoFYM, SpD > MD+potato, MD+grassclover > SpA

Dairy farms mixed with cereal and/or ecosystem services maintain more C per ha at farm level than the specialised dairy and arable system. In general, calculated differences between mixed dairy systems are moderate, indicating flexibility for selecting measures that fit best considering other farm features.

Contrary to expectations, the inclusion of grass-clover in the rotation does lead to similar results as the introduction of potato at the level of farm mean C per ha. Obviously, in terms of nutrient use efficiency, results will be different with grass-clover leading to low surplus at the nitrogen balance and potato to a high N-surplus. In combination, this suggests that expressing change in C as a mean per ha at farm level, may not always be the best way to differentiate between farming systems.

SOC at specialised arable farms is seriously at risk both from the 'stock' as from the 'change' point of view. However, potato cultivation is dominant in making farm decisions because potato cultivation is the economically preferred crop in the rotation. The inclusion of crops that do contribute to SOC, e.g. cereals and catch crops, are less attractive due to low revenues and/or difficulties in the cultivation.

3. Regional carbon balance

In the Winterswijk area, implementation of the measures where applicable would improve, in terms of biodiversity and reduction in N- and P-losses, about 40% of all agricultural land in the region. The net soil carbon balance in the area would be almost zero. Measures may be grouped into packages to realise specific goals in terms of C, N, and P. Some distinct differences are shown with respect to carbon gain or loss. Three observations are made:

- Cultivation of cereals contributes to C-storage, whereas cultivation of potato reduces it. This is relevant for dairy farms at sandy soils low in C (soil type 'veldpodzol'). In addition, biodiversity (birds) is stimulated by the cultivation of cereals. However, new legislation (CAP, derogation) may diminish the cultivation of cereals at dairy farms. It may be worthwhile for the region to experiment further with the cultivation of cereals as a greening measure within the CAP.
- From an agricultural point of view, the small reduction in C of grass-clover as compared to grass is considered less important than the accompanying increase in N, whereas the small increase in C by the catch crop in maize may be more important than the N it catches. With respect to the quality of surface waters, both systems may require more intensive monitoring as to nitrate levels in soil and leaching patterns.
- Ecosystem services ('liming', 'no FYM') alongside brooks and surface waters may have effects on biodiversity and/or production at field level which remain to be quantified. It may be recommendable to assign specific values to the preservation of such borders in the small-scale landscape of Winterswijk. In this respect the measure 'no FYM' is to be preferred to 'liming acid maize soils'.

4.6 Conclusions

Land sharing may be seen as a specific feature of mixed farming, directed at efforts to improve biodiversity and/or improve water quality. Current specialised dairy systems in the region of Winterswijk have developed from mixed farming systems. Adjusting the management of these specialised intensive dairy farms to maintain nature values and abiotic ecosystem boundaries of the regional landscape resulted in a wide range of practices. Since not all of these practices are economically viable, payments for specific ecosystem services could stimulate farmers to implement these practices. For further development of the mixed farming systems involved, ecological intensification applied at the regional level is advocated. For this, networks for knowledge exchange and collective design and trials of innovative practices should be organized to move towards more integrated systems.

5. Assessment of Lieue de Grève (F)

5.1 The Challenge

The Lieue de Grève catchment, 65% of which is AA, comprises 170 farmers, mostly dairy and/or beef producers (some specialized) who aim to reduce nitrate leaching drastically by implementing at the regional and, as far as possible, farm level, a set of co-built systemic indicators of N inputs and stocking rates per ha of grassland. The aim is to guide production systems towards better agro-ecological performance. A working group of stakeholders (i) worked with eight pilot dairy farms that modified their practices or production systems to implement the indicators, and (ii) extrapolated the changes to all farms in the catchment with the CASIMOD'N model, which included farmers' main decision rules concerning land use and manure management (Moreau *et al.*, 2013). Results are used to infer possible impact on soil organic matter.

5.2 Description of the area

Agriculture

The Lieue de Grève (Lieue de Grève) catchment is located in northern Brittany, France. The climate is humid temperate with a mean annual temperature of 11.7 ◦C and a mean annual rainfall of 950 mm. It covers 12 000 ha, of which approximately 67% is usable agricultural area (UAA), 24% is woodlands, and 8% is urban (Figure 5.1, France (from Avadi et al., submitted). Agricultural soil type is Cambisol of silty loam texture (USDA). Organic matter contents range from 3.0 – 6.5% (0-30 depth). The Lieue de Grève catchment is divided into five sub-catchments, all flowing into the same bay (Gascuel et al., 2015).

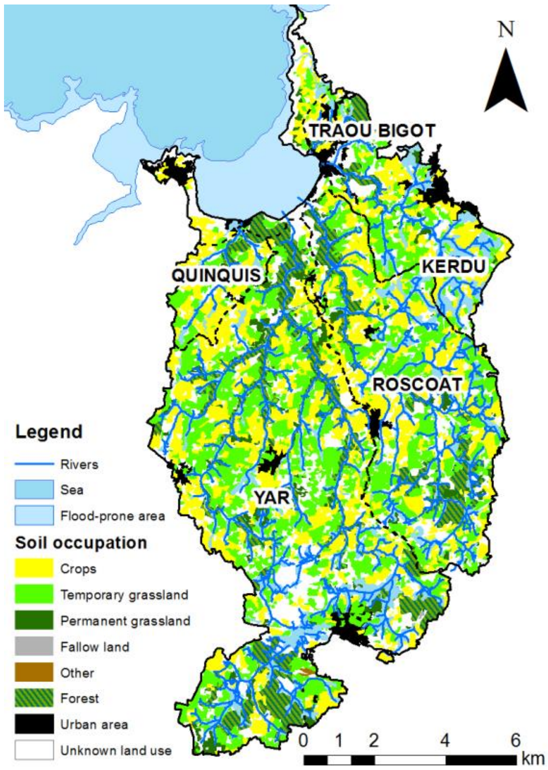

Figure 5.1. Location of the Lieue de Grève catchment.

The main economic activity of the Lieue de Grève catchment is farming, with 162 conventional and 8 organic farms. Agricultural production includes production of cow milk (39.7 million t/year, using up to 85% of the UAA), suckler-beef cattle, combined milk and suckler-beef cattle, and swine. Most farms grow forage and cash crops, the former generally for self-consumption. Nearly all cattle farms, most of which are dairy farms, have a fodder system based on grassland and maize silage. There are a few dairy farms with confined animal production such as swine or poultry (<5% by number), as well as a few beef-swine farms (<1%), crop-only farms (<3%), and sheep farms (<2%) (Table 5.1). The small number of crop-only farms in this region is explained by climate and soil conditions, which are not suitable for producing cash crops but are good for fodder production, and by the generally moderate size of farms (mean = 72 ha). Grass yields are high, thus supporting over nine months of cattle grazing per year. According to survey data, Lieue de Grève cattle production (≈12 500 heads) accounts for 3% of milk and 8% of beef production of the surrounding Côtes-d'Armor department annually, which contains roughly 182 500 head of cattle (AGRESTE, 2011).

On average, about 50% of cattle-farm UAA is devoted to grasslands, either grazed by cattle or cut for hay, haylage or silage, while 20% is used for maize silage. Livestock feed is based mainly on grazing/grass silage and maize silage, supplemented by regionally produced or imported concentrated feed. Farmers include maize silage in dairy cattle feed, however, because it (1) has higher and more consistent yields than grasslands and (2) is easier to manage than grasslands. Produced manure/slurry is use to fertilise their crops, some farmer import pig slurry or poultry manure from neighbours. Some dairy farmers import fodder and straw as well from other farms in the region with a surplus (e.g. crop and swine farms, or cattle farms with higher grassland productivity, better management, or lower stocking rates), during difficult years in most cases but systematically for some farms. In terms of N, most cattle farms import 50-100 kg N/ha UAA in concentrated feed and mineral fertilisers, while ≈8% of them import >100 kg N/ha UAA.

Table 5.1. Total land use by farm type in the Lieue de Grève district (Corson et al., 2015).

Farm or animal product type	Regional land use or output ha
Weighted mean, all farms	8,400
Dairy farms	4,504
Dairy + beef farms	2,293
Beef farms	972
Swine farms	380
Other farms	251

Water quality

Despite current moderate nitrate (NO_3) fluxes and a mean nitrate concentration in rivers at the outflow of 30 mg/l (well below the European Union threshold of 50 mg/l), this catchment has experienced algal blooms along the coast since the 1970s. As usual in French coastal water, nitrate was identified as the key element that controls algal blooms, because phosphorus is already largely available in sediments and thus cannot be controlled. In the Lieue de Grève catchment, the Yar sub-catchment alone contributes up to 59% of the nitrate emitted into the bay and modelling effort was focused on the Yar sub-catchment, but all the area was concerned by diagnosis and remediation steps. Since the death in 2009 of an horse on the beach due to toxic gazes emissions (H2S) from algae decomposition, an “algae reduction plan” was elaborated in 2010 to dramatically reduce nitrate emissions below 10 mg NO_3/l (Perrot et al., 2014). The LdeG catchment has been a pilot region, as a transdisciplinary working group gathering local stakeholders had already proposed guidelines to help improvement of farm production systems including possible re-design and better management of buffer areas (Moreau et al., 2012 ; Gascuel et al., 2015).

Stakeholder Process Design

In a previous research-action program (ANR-08-STRA-01 Gascuel et al., 2015), this problem was addressed by combining agro-hydrological modelling and participatory research to accompany changes in agricultural activities, to achieve sustainable production systems with low N emissions (especially NO_3). Agro-hydrological modelling (Beaujouan et al., 2002; Moreau et al., 2013) of reactive N emissions and fluxes in the catchment including buffer zones (e.g. hedgerows around fields, wetlands) predicted that the latter could not absorb all excess nitrate produced by agricultural activities. The main way to decrease N emissions is thus to focus on these agricultural activities and decreasing environmental impacts due to agriculture is a main concern of local stakeholders and inhabitants of this region (Levain et al., 2015). The farmers aim to reduce nitrate leaching drastically by implementing at the regional and, as far as possible, at farm level, a set of co-built systemic indicators concerning N inputs, e.g. stocking rates per ha of grassland, avoiding bare soils in winter and limiting grassland renovation rates (Vertès et al., 2011). The aim was to guide production systems towards better agro-ecological performance. A working group of stakeholders (i) worked with 8 pilot dairy farms that modified their practices or production systems to implement the indicators, and (ii) extrapolated the changes to all farms in the catchment with the CASIMOD’N model, which included farmers’ main decision rules concerning land use and manure management (Moreau *et al.*, 2013). The complexity of the cooperation between stakeholders in the region, visualised in Figure 5.2, was identified as ‘territorial synergy’ (Moraine et al., 2014).

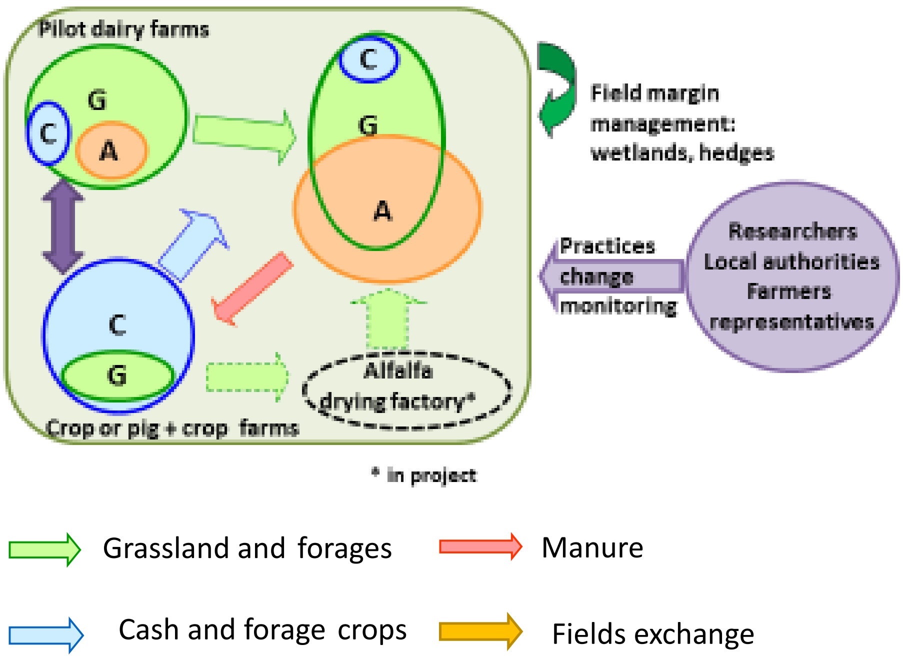

Figure 5.2. Stakeholder model of the mixed farming systems in CS Lieue de Grève (C=Crops, G=Grass, A=animal)

5.3 Methodology

5.3.1 Outline

This study makes an analysis of the nitrogen management by a group of pilot farms, after which the results are upscaled to the regional level. The impact of farm management on the soil N status is assessed with the CASIMOD'N model. From the modelling results an assessment is made of the changes in SOC.

5.3.2 Selection of baseline and innovations

For this study, the baseline scenario "Business as usual" was identified as the farms as they existed when data were collected in 2007 (Table 5.2). A first innovation (S1) consists of the mitigation options identified by stakeholders, i.e. reduction of N inputs, improvement of N recycling and suppression of risky practices. As the result of the co-creative process, a scenario was proposed to drive changes by selected indicators that are easy to understand, compute and control. This scenario was implemented at farm and watershed scales, with a strict respect of thresholds at district scale (in particular the stocking rate par ha grasslands) more or less attained at farm scale. Total milk production was maintained, although milk per cow decreased to reinforce the link between crop-grassland and animal production (link to soil). This led to increase the number of dairy cows by 15% (more meat produced) and to increase the part of grassland in AA, while cash crops area decreased. The few other farm types (specialized in crops, pig + crops or poultry) were unchanged.

The co-build innovative scenario proposed to drive changes by 5 indicators that are easy to understand, to compute and to control:

- stocking density to 1.4 livestock units (LSU)/ha of grassland;
- Σ N inputs < 100 kg/ha (N inputs = Nfert + N food * .65(pigs) or .75 (cows) + net Nmanure);
- 100% efficient cover crops in winter;
- grassland destruction (renovation) rate < 5%; and
- no "parking" grasslands for cows (homefield muddy patches).

Table 5.2. Typology of baselines and innovation.

Typology	Farm types
S0-Baseline 1: Business as usual	Farms as they existed when data were collected (2007), 85% cattle farms, about 50% AA as grassland, 23% maize, 27% crops
S1-Innovation: Improved N-management	Limit stocking density to 1.4 livestock units (LSU)/ha of grassland Limit net input of N (fertilizer, feed) to 100 kg N/ha UAA, while keeping mean milk production/ha constant (decrease of cash crop area, increase of number of dairy cows

This scenario was implemented at farm and watershed scales, with a respect of thresholds at district scale (i.e. stocking rate per ha grassland) attained at farm scale. Total milk production was maintained, although milk per cow decreased to reinforce the link between crop-grassland and animal production (link to soil). This led to increase the number of dairy cows by 15% (more meat produced) and to an increase in the part of grassland in AA, while cash crops area decreased. The few other farm types (specialized in crops, pig + crops or poultry) were unchanged.

5.3.3 Data collection

To provide input data and assess model predictions, three datasets were used (see details in Moreau et al., 2013), e.g. on farming systems and their management practices from extensive farm surveys (2007), on land use for 1996-2006 from remote sensing data, and a reference dataset of management practices (Salmon-Monviola et al., 2012). Survey data on the farming systems themselves were used as input data, while the observed dataset (survey data on the management practices, remote sensing data) and the reconstructed dataset were used to assess CASIMOD'N predictions.

For the 8 pilot farms, data collection was done by monthly enquiries on agricultural practices and herd management during 3 years (Table 5.3). The results of the pilot farms were used for prediction of N fluxes at the catchment level assuming full implementation of the innovations, i.e. target values of indicators (stocking rate: ≤1.4 livestock units (LU) ha^{-1} grassland, N input: ≤ 100 kg N ha^{-1}). In addition, a network of fields (under maize, wheat or grasslands) was studied to quantify productions, N inputs and uptake, and N mineral in soils in autumn, and net N mineralisation per year. Some of those data were being used to adjust parameters of the model and to validate some intermediate model outputs.

Table 5.3. Pilot and catchment data.

Result	Target	Pilot farms		Catchment (per ha)	
Year	value	2007	2011-13	2007	2020
Stocking rate/ha grassland	1.4	2.5	2.0		1.4
N input indicator (kg N/ha)	100	91	68		
Grassland % of agricultural area (AA)	(80)	53	65	54	68
Maize/cereal % of AA		17/11	9/7	17/25	9/20
Milk production (t/year/farm)		368	431		
Mean [NO_3] outlet (mg/L)	10			28	20
Soil N balance without SOM change (kg N/ha AA)			45	36	25

Simulating attainment of target values by all dairy farms at the catchment level predicted a strong decrease in nitrate concentration in water at the outlet (from 28 mg NO_3^- l^{-1} in 2007 to 20 in 2020), although still far from the target value of 10 mg NO_3^- l^{-1}. Results also show that the mean of soil N balances of pilot farms were higher than the mean soil N balance predicted at the catchment level. No explanation for this can be given. This preliminary result has to be confirmed by continued work at farm and catchment levels, as models are sensitive to estimates of N and C inputs and the percentage of stable organic matter in total soil organic matter.

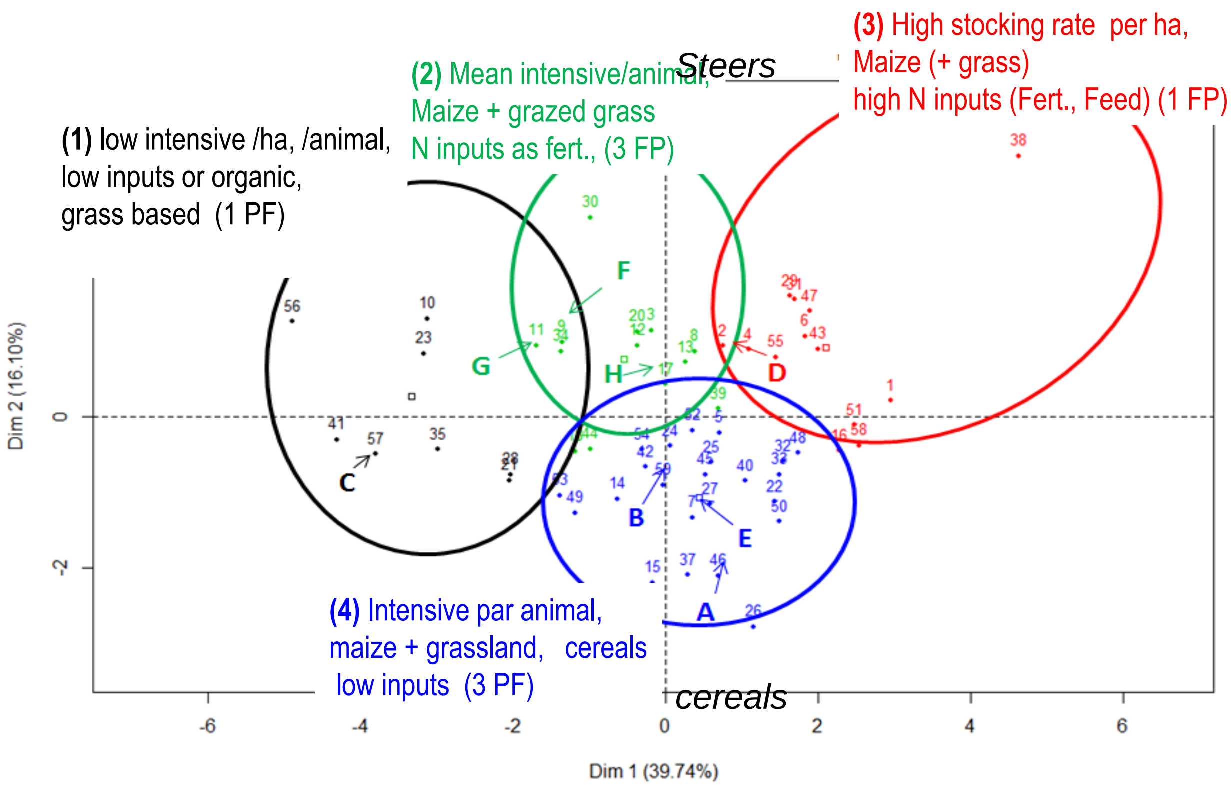

Figure 5.3. PLS Farm typology of dairy production systems in CS Lieue de Grève (Green algae plan survey, 2011) including the 8 pilot farms.

For upscaling of results, a dataset was constructed consisting of 59 farms producing milk, specialised or not, and using a typology that distinguishes between specialised and mixed farming systems.

The dataset was analysed with PCA regarding farm characteristics and the ways to implement changes that would improve the value of indicators (Figure 5.3). Four main types are identified combining 2 main factors that discriminate the part of grass in AA (1st axis) and the second main production (meat vs crops for axis 2). The 8 pilot farms were spread in all types, and could be expected to represent the diversity of structure and functioning.

Some characteristics of the four types are given in Table 5.4.

Table 5.4. Characteristics of the 4 groups of farms obtained in the PCA analysis (Full details in Appendix C).

Features	Specialised Dairy		Mixed dairy	
	1. Grass based (nobs=9)	2. Grass + maize (nobs=13)	3. Milk + Meat (maize+grass) (nobs=13)	4. Milk + cash crops +(grass + maize) (nobs=21)
Area				
AA (ha)	76.6	72.2	96.3	81.7
Grassland % AA	75.3^{a}	58.7^{b}	48.4^{c}	45.9^{c}
Maize % AA	11.4^{c}	27.3^{bc}	32.0^{a}	24.8^{b}
Maize %fodder area	12.7^{c}	31.1^{b}	39.6^{a}	34.5^{ab}
Fodder area % AA	89.6^{a}	88.1^{a}	81.1^{a}	72.9^{b}
Cash crops % AA	9.1^{b}	10.4^{b}	16.5^{b}	26.4^{a}
Indicators				
N concentrates per ha	16^{c}	45^{b}	65^{a}	38^{b}
N mineral per ha	12.1	7.4	12.9	8.9
Net organic N per ha	22^{c}	60^{ab}	77^{a}	51^{b}
Indicator LSU per ha grassland	46^{b}	^{b}	139^{a}	^{b}
Indicator "N inputs" per ha AA	1.5^{c}	2.3^{b}	3.0^{a}	2.3^{b}

Letters a, b, and c indicate similarities or differences for each variable between the 4 types of farms.

The inventory shows that grass-based systems offer the best results in terms of both the indicators N inputs and LSU/ha grass. At considerable distant the mixed farming system with grass, maize and cereals is second best as far as input of N is concerned. The mixed milk+meat farming system performs lowest for both indicators.

5.3.4 Modelling

The Casimod'N model does not simulate changes in organic N in soils, mean local references values for mineralisation rates being an input to the model (Beaujouan et al., 2002; Moreau et al., 2013). As it was not possible to use Roth-C on this case study, a simple approach was used to infer changes in SOC from the results of the 8 pilot farms regarding N fluxes characteristics and land use (crop vs grass). These calculations were made by assuming, in a first step, various figures for loss or gain of N and C in soils and assess N-leaching. In a second step, the calculated results were compared to measured values and the best fitting input data on C loss or gain taken for further elaboration. The following values for soil N (or C) changes were used:

- crop land: 0, -35 or -70 kg N per ha per year (-350 or -700 kg C)
- grassland area were 0, +25 or + 50 kg N per ha per year (+ 250 or + 500 kg C)

High values for C changes correspond to Roth-C simulation in a neighbouring situation (Viaud et al 2014) and other literature and/or local experimental data (Vertès and Mary, 2014) and were consistent with those proposed by Vleeshouver and Verhagen (2002). The calculations were made by Doussal (2014) to refine the estimation of N leaching risk calculated as proposed by the Dairyman project adapted to local situation.

5.3.5 Upscaling of results

The results in C-stock change are aggregated to the catchment level by multiplication, per farm type, of the respective C-stock change and the total number farms of that type in the catchment. As changes in production system and land use implemented in the farms are only a part on the way to reach the reference values of indicators, calculation will give an intermediate point. Moreover N fluxes modelling concerns the whole watershed, including forest and buffer areas, while extrapolation of farm results concerns the agricultural area.

5.4 Results

5.4.1 Pilot farms

Over the experimental period, most dairy farms in the catchment chose to maintain or increase milk production (from a mean of 370 to 430 t year^{-1} farm^{-1} for the eight pilot farms), became more grass-based, and decreased bull fattening and maize or cereal area. Average fluxes are detailed in Figure 5.4, with a mean leaching risk of 39 kg N-NO_3 ha^{-1} year^{-1}. For an overview of all results of the Casimod'N modelling, see Appendix C, Table C.1.

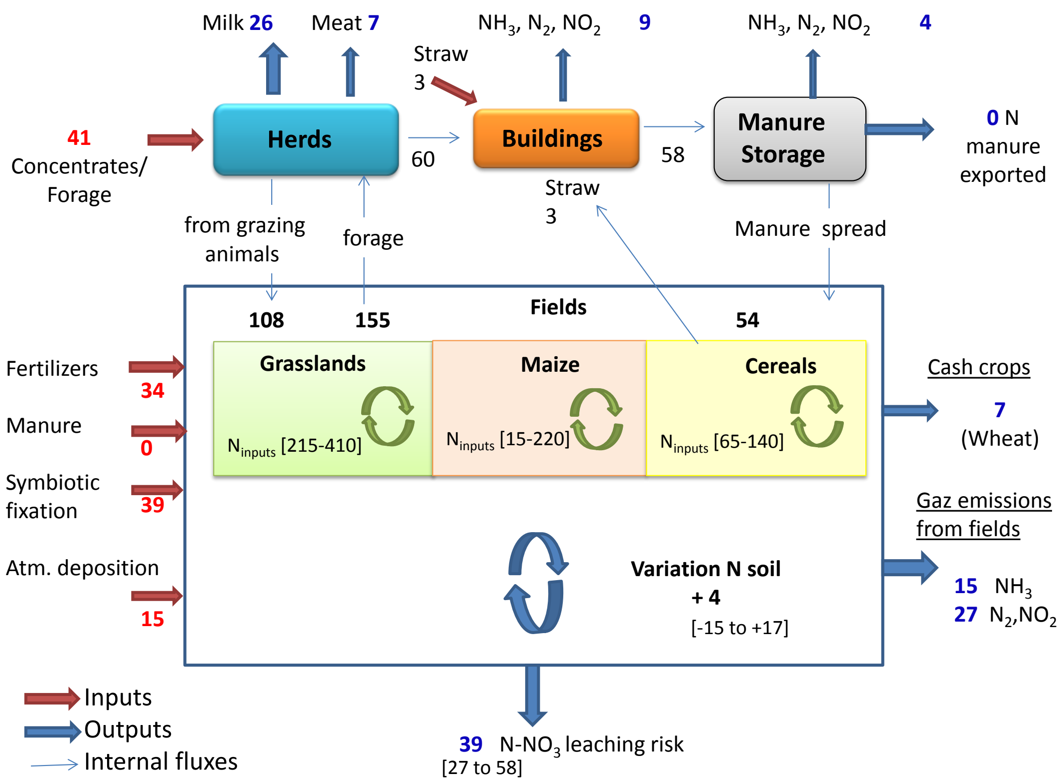

Figure 5.4. Calculation of main N fluxes, including N leaching risk. Data correspond to mean values of N fluxes for the 8 farms dairy pilot farms.

Mean values of indicators moved toward target values, decreasing for the pilot farms from 2.5 to 2.0 LU ha^{-1} grassland and from 91 to 68 N kg.ha^{-1} for the "N inputs" indicator. The percentage of grasslands increased with 11 ha (+23%), at the expense of a decline in cereals of 3.4 ha (34%) (Figure 5.5). Globally grasslands occupied 65% AA for the pilot farms vs 53% AA for the baseline.

The modelled N-fluxes included an estimate of the soil N balance for each of the pilot farms (Doussal, 2014). Assuming a constant C/N-ratio of 10, these data were used to assess the change in C-stock per hectare and per farm (Table 5.5). For this purpose, total farm size was based on the cultivated area, excluding SAU. As indicated in Figure 3.4 the mean variation of N storage in soils was about 4 kg N ha^{-1} $year^{-1}$, that corresponds to about + 40 C $kg.ha^{-1}.year^{-1}$, varying between -70 to +230 C $kg.ha^{-1}.year^{-1}$.

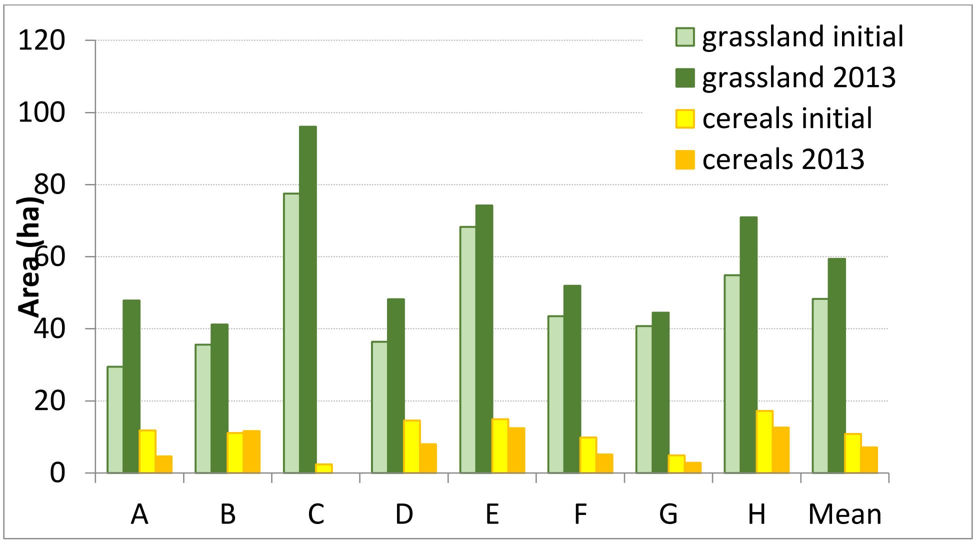

Figure 5.5. Increase in grassland area and decrease in cereal area in the pilot farms.

The BAU scenario corresponds to a weak decrease of C in most farms, and a weak storage in 3 farms with the higher value for in the farm C (grass-based system, low intensive). Increasing the part of grass leads to reduce C destorage or allow some C storage in all farms but one. On the whole area of the 8 farms, the total C storage is about 32 t, and the improved scenario corresponds to a gain an increase of 57 C $t.yr^{-1}$ compared to BAU, i.e. a mean additive storage of 75 C $kg.ha^{-1}yr^{-1}$.

Mean C storage per type of farms are + 230 , +80, +10 and -65 C kg.ha-1.yr^{-1} for type 1, 2, 3 and 4 respectively . Though some types are represented by only one farm, the results are consistent with other local references (Viaud et al.,2014, Godinot et al, 2014) and will be used in upscaling calculations.

From Table 5.4 it follows that the mean change in C-stock per ha is, in descending order:

Low intensive-1 (LU, input) > Moderate intensive-2 > Intensive-3 (input) > Intensive-4 (LU)

Table 5.5. Change in C-stock due to improved N-management for the 8 pilot farms.

Farm	Farm type	C-change (kg.ha^{-1}.yr^{-1})			Area	C-stock (t.farm^{-1}.yr^{-1})	
		BAU	Innovation	Change	ha	Final	Change
A	intensive LU, grass, maize, cereal (4)	-148	-90	+58	76	-6.8	4.4
B	intensive LU, grass, maize, cereal (4)	-64	-40	+24	70	-2.8	1.7
C	low intensive (1)	21	230	+209	127	+29.2	26.5
D	high stocking rate (3)	-96	10	+106	79	0.8	8.4
E	intensive LU, grass, maize, cereal (4)	-21	-70	-49	125	-8.8	-6.1
F	moderate intensive (2)	12	30	+18	81	+2.4	1.5
G	moderate intensive (2)	13	70	+57	66	+4.4	3.8
H	moderate intensive (2)	-33	140	+173	98	+13.7	17.0
Mean/total		-40	35	+75	722	+32	+57

The part of grassland in farm AA decreases with the same order: 73% for type 1 > 65% (+-1.8) for type 2 > 59% (+-2) for types 3-4, increasing the part of grasslands in AA usually leading to decrease the livestock density par ha grasslands. This result is in accordance with expectations, showing that loss of C increases with level of intensity and part of crops (with low C residues as straw exported to buildings and maize harvested as silage). The impact of high livestock densities is surpassed by that of high inputs.

Calculation on N fluxes, whose average data were shown in Figure 5.5, were achieved in each farm in the initial (BAU) and final (on the way towards scenario "indicators"). Leaching risk were deduced from N balance calculations at herds, buildings, manure storage and field scales successively, each step leading to losses as proposed by Jarvis et al (2011). Remaining N at field level is potential leaching + N storage in soils, so it varies with the 5 set of hypothesis on this process. Extreme and mean results are shown in Figure 5.6, and leaching risks ranges from 10 to 80 kg.ha^{-1} yr^{-1}. Mean value of the 8 farms is 42 kg N-NO3 ha^{-1}yr^{-1} , comprised between 27 and 58 according to the set of hypothesis on SOM changes. On this set of farms the mean of the usual 0/0 hypothesis (no change of SOM) predict the same average leaching than the mean of the 5 set of hypothesis (similar results in farms D and E).

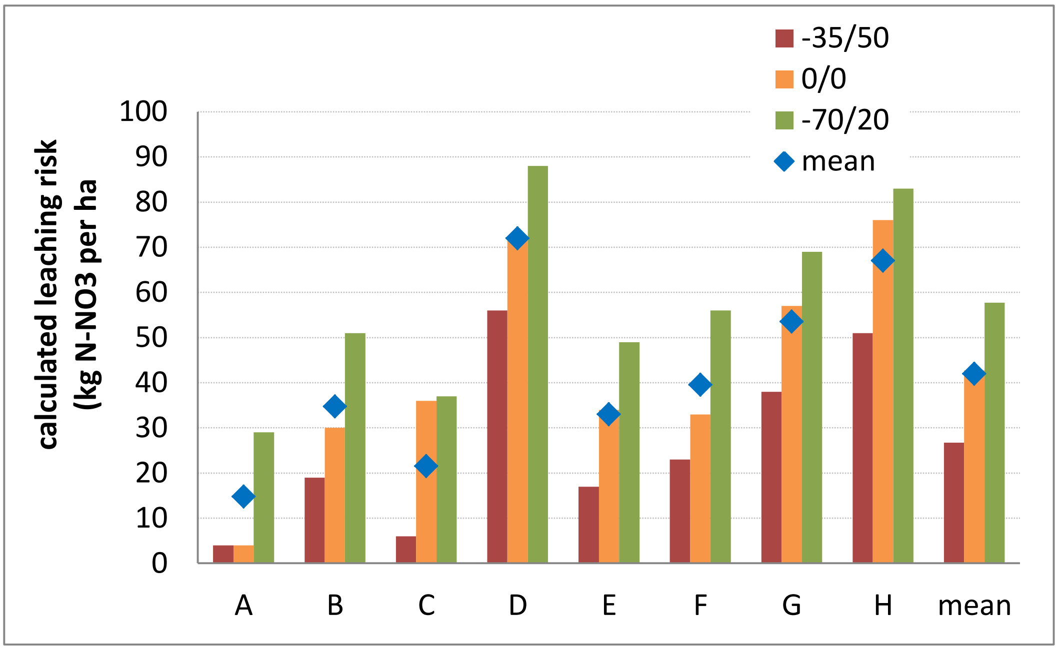

Figure 5.6. Leaching risk as assessed with different impact of SOC; legend data refer to input values for N-change.

5.4.2 Upscaling to catchment level

Combination of the occurrence of farm types in the region of Lieue de Grève and the calculated change in C-stocks shows the impact of innovative scenario on the regional C-balance over the time period 2007 – 2013 (Table 5.6). The change in C was estimated at +1.6 kt C relative to the total area of dairy and dairy + beef farms. This corresponds to a weak gain of about 0.1 t C per ha.

The slightly positive result is due to the intensive farm type, which occupies the largest area (30.4% AA) and also is responsible for the largest change in C-stock per ha (-0.065 t per ha). The results clearly indicate that for the Lieue de Grève region, in terms of C-balance, specialised dairy farming systems with a large part of grasslands in their AA are to be preferred to mixed farming systems. The same conclusion was already found for N leaching losses at watershed level (Durand et al, 2015) for Lieue de Grève as well as for another catchment in Brittany, more intensive, where the same scenarios were simulated.

5.5 Discussion

This study shows that the specialised grass-based system offers the best results in terms of N inputs, LSU/ha grass as well as change in C-stock. In contrast, the milk+meat mixed farming systems performs worst regarding all three aspects included. In terms of C-stock, the specialised grass-maize system is to be preferred to the mixed grass, maize, cereal system, though the opposite is true regarding the N-input.

The estimation of SOC changes was based assuming a constant C/N-ratio. Thus in soils with C/N-ratio < 10 and a positive N balance, less C would be sequestered than assessed whereas in soil with C/N-ratio > higher sequestration occurs. A major change in farm management is the increase in grass area at the expense of arable crops. In general, C/N-ratio in grassland is lower than in arable land. It may be assumed, therefore, that C/N-ratio be reduced and the calculated amount of C sequestered must be seen as maximum for this case study.

In considering implementation of the innovation at a wider scale and/or extrapolating to other areas, the ending of the EU milk quota system must be taken into account. Many dairy farmers consider increasing milk production to increase revenues, either with more dairy cows or by feeding more maize silage and concentrated feed to the same number of cows. These are obstacles to adopting the innovation scenario, such as limits to increasing the sizes of herds, access to enough nearby pastures to meet cows' grass requirements, and the acceptability of grass-based dairy systems.

Collaboration among farms would help to address some of these issues, for example by exchanging pastures or developing a contract-based "fodder bank", but these have yet to emerge. These may lead to alfalfa/high quality grass in cattle or crop farms, to be processed at a local drying unit (using heat from a biogas unit). This may in turn stimulate the exchange of land between farms to improve farm structure and grazing potential. Unfortunately, the government's action plan to decrease algal blooms politicised discussions between farmers and researchers in the Lieue de Grève, making some of the former less open to adopting changes now seen as more prescriptive than co-constructed (Levain et al., 2015). Nonetheless, other dairy farmers in Lieue de Grève and other parts of Brittany remain willing to render their farms more grass-based, i.e. less mixed.

Table 5.6. Regional C-balance in region Lieue de Grève, on the 6800 ha AA occupied by the 4 types of dairy farms (81% of the whole AA of Lieue de Grève watershed).

Farm type	Description	Leaching risk kg N-NO_3 per ha (mean)	Mean size (ha/farm)	Total AA %	Change C kg.ha^{-1}. yr^{-1}	Change C t. yr^{-1}	Δ Regional C balance period 2007-2013 t C
1. Grass based, specialised (c)	low intensive	21	76.6	13.1	230	253	1 772
2. Grass + maize, specialised (f,g,h)	moderate	53	72.2	18.8	10	16	111
3. Maize + grass, mixed (d)	intensive (input)	72	96.3	18.8	80	126	885
4. Milk + cash, mixed (a,b,e)	intensive (LU)	28	81.7	30.4	-65	-166	-1 162
Total				81		229	+ 1 606

5.6 Conclusions

At field and farm level, it was assessed that the success of the improved N management may lead to loss of carbon, assuming C/N-ratios in soil are constant. However, the innovation is such that at farm level, the proportion of grass increases. This may have a positive impact on soil organic matter since grass roots contribute more fresh organic matter to soil as compared to arable crops such as maize.

For the Lieue de Grève region, the specialised grass-based dairy system is to be preferred to mixed dairy system if 'mixed' refers to raising beef. The transition to a grass-based system may be offset by current policies that indirectly lead to an increase in dairy herd and the proportion of maize in the dairy diet. This shows the need for continuation of the improved N management programme.

6. General discussion

6.1 Effects of land sharing on regional soil organic carbon contents

In this study a quantitative assessment was made of the effect of ‘land sharing’ on soil organic carbon stocks at regional scale in three case studies. Large difference were shown in absolute terms in change in C-stock both within and between regions (Table 6.1), ranging from -474 $kg.ha^{-1}.yr^{-1}$ in the specialised arable system in CS Winterswijk to 230 $kg.ha^{-1}.yr^{-1}$ in the specialised grass based dairy systems in CS Lieu de Grève. Another occurrence of negative change in C-stock was found in the mixed farming system with cash crops (-65 $kg.ha^{-1}.yr^{-1}$) in CS Lieue de Grève. In contrast, more C was sequestered in the arable mixed farming system as compared to specialised arable system in CS Dolnoslaskie, 120 and 18 $kg.ha^{-1}.yr^{-1}$, respectively. In CS Winterswijk, C-change in the specialised arable system was negative whereas the specialised and mixed dairy system sequestered similar amounts of C (mean 178 $kg.ha^{-1}.yr^{-1}$). These regional approaches clearly indicate difference between region and cultivations. However, when looked upon from a European level, differences between the regions may be unnoticed. According to the SMARTSOIL classification of SOC balances at the European scale, the three regions have been grouped in the same, intermediate, class (Merante et al., 2015). Such differences between the regional and the European scale demonstrate the need to spatially zoom in and out when contemplating the relative importance of changes in SOC. Also, the “4 ‰ initiative” as launched by the French government during COP21 stimulates local and regional stakeholders to cooperate in increasing carbon sequestration and SOC-contents. The 4 ‰ annual growth rate of the soil carbon stock would make it possible to stop the present increase in atmospheric CO2. The bottom line in Table 6.1 shows that the results of the three regional case studies indicate that several mixed farming systems could make a modest contribution to the “4 ‰ initiative”.

The base for evaluation of SOC at regional level is the involvement of SOC in soil ecosystem services and the need for external sources of organic matter to replenish carbon loss. Concerning the latter, regional inventories could made of potential sources of organic matter that may be used. For instance, this would be useful for the Dolnoslaskie region, where due to a lack of livestock, current availability of manure is too low for the development of mixed farming systems. As other sources of organic matter may become available from regional or local industries, modelling may be used to ascertain best options to increase production while maintaining regional soil and water quality.

6.2 Reduction of N- and P-losses

All farming systems that were evaluated for both C and mineral losses showed positive results for both indicators. This finding shows that it is possible, at a regional scale, to reduce mineral losses while maintaining or increasing carbon stocks. As the combined selection of measures determines overall results, both farmers and other stakeholders need to be involved in the selection of practices. It was also shown that the effects on mineral losses and carbon changes were not proportionally throughout all farming systems. For CS Lieue de Grève, the order of the four farm typologies is the same for both indicators with the specialised grass-based dairy farm performing best in terms of both reducing N-leaching (20 kg .ha^{-1}.yr^{-1}) and C-sequestration 230 kg.ha^{-1}.yr^{-1}. In contrast, in CS Winterswijk, the farming system with the best results in terms of reducing N- and P-losses (28 N kg .ha^{-1}.yr^{-1} and 70 P_2O_5 kg .ha^{-1}.yr^{-1}) scores lowest in C-sequestration (143 C kg .ha^{-1}.yr^{-1} ; measure 'no FYM where P is high'). This results raise questions as to the suggestion that reducing N- and P-losses is coupled to C-sequestration. It may very well depend on the type of measures applied. Considering individual measures in CS Winterswijk, the best measure for both indicators is 'cultivation of a good catch crop in maize'. In order to evaluate the capacity of specific land uses including land sharing to deliver soil ecosystem services, a further partitioning of (the significance of) SOC in terms of, e.g. nutrient supply, moisture holding capacity, built up of soil structure, etc. may be required. In addition, it may be useful to include representative SOC balances from typical farming systems in the evaluation of nitrogen management.

The technical results of the case studies in Winterswijk and Lieue de Grève show that Intensive dairy farms that undertake practices to maintain landscape quality and/or improve water quality can be regarded as a specific type of MFS. Adjusting the management of intensive dairy farms to maintain nature values and abiotic ecosystem boundaries of the regional landscape was achieved by applying a wide range of practices. Some of these practices were economically viable, others were not. Payments for specific ecosystem services could stimulate farmers to implement the latter practices as well. For further development of the MFS studied, ecological intensification applied at the regional level is advocated. For this, farm prototyping, networks for knowledge exchange and collective design and trials of innovative practices could be organized to move towards more integrated systems (Lantinga et al., 2013, Levain et al., 2015, Duru et al. 2015).

6.3 Crop rotations

The positive effect of the cultivation of cereals on C-stock in soil ranges from 9 kg.ha^{-1}.yr^{-1} in CS Winterswijk to 18 – 120 kg.ha^{-1}.yr^{-1} in CS Dolnoslaskie. Total C-input for the cultivation of cereals is larger in CS Winterswijk than in CS Dolnoslaskie, with 5 t C for residue and 0.99 t C from FYM in Winterswijk and 1.78 t C and 0.34-0.07 t C from manure in Dolnoslaskie. Despite the lower C-input, the largest change in C-stock was modelled for CS Dolnoslaskie. The main reason for the larger sequestration is probably the lower C-stock at the beginning of the modelling period. In addition, weather conditions in CS Winterswijk may favour mineralisation process as compared to those in CS Dolnoslaskie.

However, the EU greening policy may have adverse effects on carbon building farming practices within mixed farming systems. A first instant concerns the cultivation of cereals to stimulate biodiversity in the CS Winterswijk and the implementation of the new CAP-measures which does not include cereals, and the new derogation requirements of 80% grassland. It is expected that as a result of these regulations, the cultivation of cereals in the region will be discontinued. A second instant concerns the lay-arable rotation and, also, the new CAP. The obligation to have permanent grassland instead of temporary grasslands diminishes the possibility for grass ley – arable rotation, which may affect income and/or production negatively, e.g. in CS Lieue de Grève.

6.4 Role of grassland

Modelled C-change in the specialised and mixed dairy systems in CS Winterswijk range from 150 to 199 kg.ha^{-1}.yr^{-1}, lower than the maximum in CS Lieue de Grève, i.e. 230 kg.ha^{-1}.yr^{-1} in the specialised dairy system. This result is remarkable obtained given that the proportion of grasslands is similar, 73 % and 70% for CS Lieue de Grève and CS Winterswijk, respectively, and initial SOC is similar as well. A first possible explanation for the modelled difference may be the age/duration of the temporary grasslands. Annual carbon storage in temporary grasslands increases with age, and also depends on the preceding crop, e.g. after conversion from crops to grassland more C is sequestered and for a much longer period of time, than after grassland renewal. According to IPCC 2006 calculations (revised by Dollé & Klumpp 2015), net storages begins when grassland age is > 3 years (Figure 6.1), the effect being larger in soils with high C-stock. Since soils in both Lieue de Grève and Winterswijk are relatively rich in C (rather 50 than 35 t C in the first 30 cm), differences in grassland duration might partly explain the difference in change in C-stock. In Dutch dairy systems and in CS Winterswijk in particular, mean duration of temporary grasslands is lower than in CS Lieue de Grève, with ca.45% of the grasslands area is over 5 years of age. The assessment for CS Lieue de Grève was based on calculations of the soil N balance in which grassland duration is taken into account. For CS Winterswijk the assessment was based on calculations with standardised C-input of a 3-year old grassland which is in accordance with regional agricultural practice.

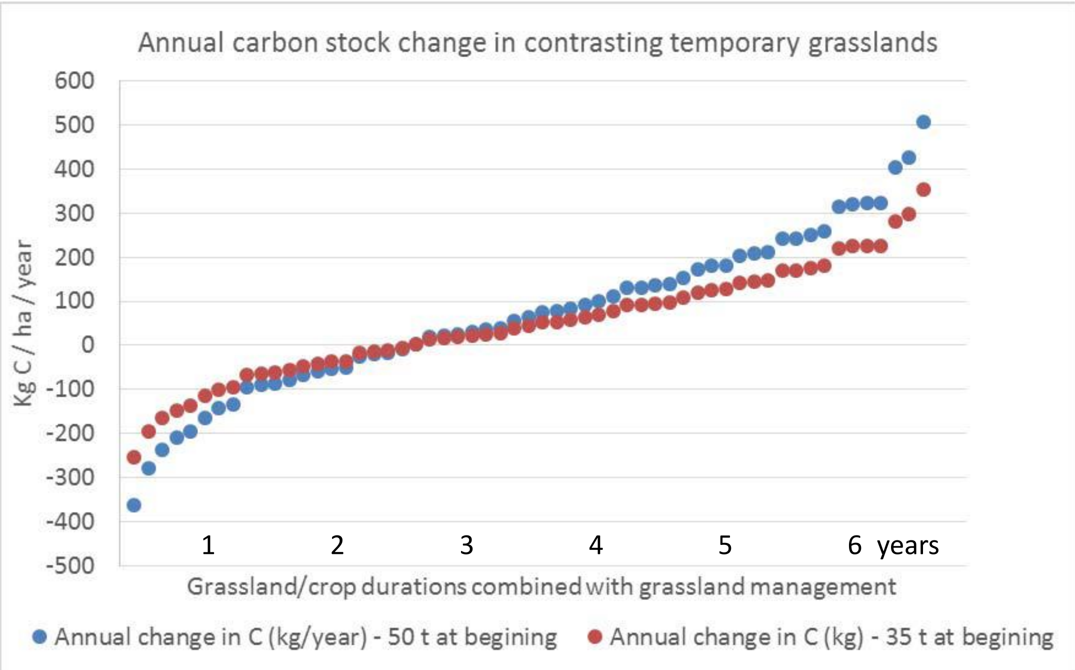

Figure 6.1. Annual carbon stock change in contrasting temporary grasslands (Dollé & Klump, 2015).

A second possibility that might explain the observed differences is the grazing and mowing regime applied at the grasslands. The amount of biomass (leaves, roots) returned to the soil is strongly related to the level of defoliation. A third possibility explaining higher C-sequestration is the grass-based specialised dairy system in CS Lieue de Grève is the proportion of other crops in the rotation. In the specialised dairy system of CS Winterswijk, 30% of the UAA is cropped with maize, one of the major crops accountable for C-losses. It is likely that the specialised system in Lieue de Grève includes a smaller proportion of maize in the rotation in favour of cereals. Thus the differences in carbon storage between CS Lieue de Grève and CS Winterswijk may be explained by differences in grassland age, grazing and mowing regime, and crop rotation. A first condition to gain more insight in these differences would be to apply the same method in both regions.

6.5 MFS and climate change

Modelled results on the change in C-stock for the year 2050 show that in CS Dolnoslaskie small increase in SOC is achieved. In CS Winterswijk a similar small increase occurs in grassland, however in maize field the loss amounts over 12 kton.ha^{-1} (Figure 6.2). In other words, over time the gain in C may be little but the loss in C may be substantial. It has to be noted that these results were obtained using current weather conditions and disregarding effects of grassland renewal.

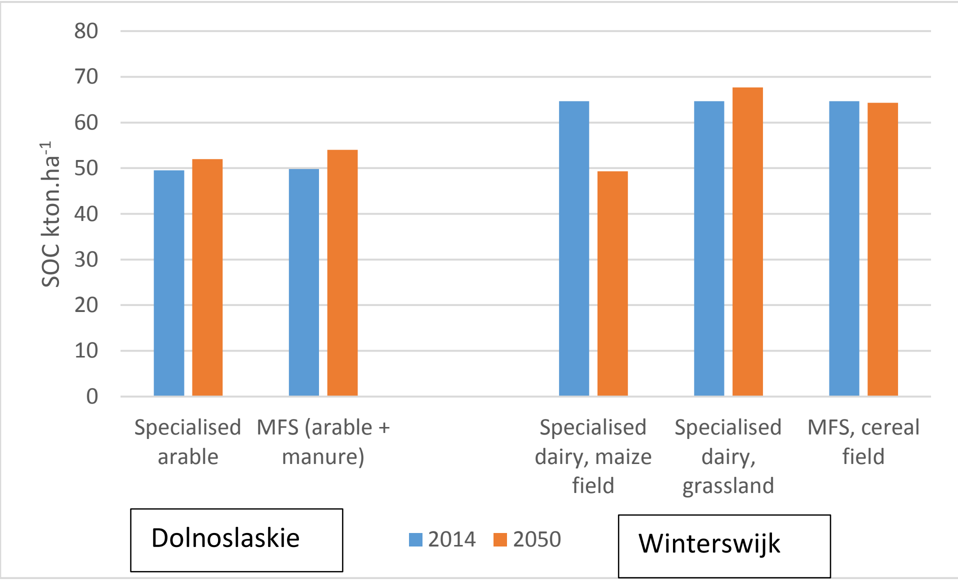

Figure 6.2. Change in C-stock in specialised and mixed farming systems over time.

The implications of the modelled SOC-changes at regional level could be assessed providing necessary additional data would be available. This would require information on the changes in area sizes of each crop, as well as the availability of manure. A matter of concern is that the decline in SOC as modelled for the maize field, would also apply to other arable crops such as potatoes and sugar beet. Thus while intensification of arable farming on soils low in SOC may improve soil quality, the opposite is true for soils high in SOC. The loss in SOC is likely to be accompanied by added nitrate leaching from increased mineralisation in addition to its contribution to global warming.

Table 6.1. Summary of mean annual C-change in specialised and mixed farming systems in the three case studies.

CS Dolnoslaskie Farming System	C change $kg.ha^{-1}.yr^{-1}$	CS Winterswijk Farming System	C change $kg.ha^{-1}.yr^{-1}$	CS Lieue de Grève Farming System	C change $kg.ha^{-1}.yr^{-1}$
S01-"as was" transition	18	S01-BAU Specialised arable: potato	-474	S01-Grass based (60%), specialised	230
S02-Mixed agriculture	80	S02-BAU Specialised dairy (grass 70%)	186	S02-Grass + maize, specialised	10
S1-Specialised arable: cereal	71	S1-Dairy mixed with crops (grass 70%)	150	S1-Maize + grass, mixed	80
S2-Return to MFS: manure	120	S2-Dairy mixed with services (grass 70%)	199	S2-Milk + cash, mixed	-65
Soil depth (cm.)	28	Soil depth (cm.)	20	Soil depth (cm.)	30
Initial C-stock ($t\ ha^{-1}$)	49	Initial C-stock ($t\ ha^{-1}$)	65	Initial C-stock ($t\ ha^{-1}$)	101
Max. change (‰)	2.5	Max. change (‰)	3.1	Max. change (‰)	2.3

7. General conclusions

This study focused on the effects of specialised and mixed farming systems with varying levels of intensification. It provided evidence from model calculations that land sharing, as part of a mixed farming system, at the regional level does not necessarily lead to higher SOC than specialised farming systems, but it can contribute to SOC irrespective of its primary aim to increase crop production, biodiversity and/or to reduce mineral losses. Results indicate that in intensive arable systems on soils low in SOC, the amount of C-input from crop residues and/or manure is of more importance for increasing SOC than the specialist (cereal-based) or mixed character of the farming system. However, the Roth-C model calculations also showed that this contribution may be higher in mixed arable systems than in specialised arable systems. At soils high in SOC, specialised (potato-based) arable systems lead to significant carbon loss over time. In contrast, the specialised dairy farms as well as the mixed dairy farms increased SOC. Concerning the latter, mixed systems with cereal cultivation to stimulate biodiversity provided more carbon than mixed systems with measures to reduce mineral losses to ground- and surface waters. However, results based on CASIMOD'N show that highest gain in carbon was obtained by the specialist (grass-based) dairy system at moderate production level. Thus in intensive dairy farming systems similar in SOC, C-input was proportional to grassland age which, at the high production farms, was negatively related to the grass-maize rotation.

As a conclusion, the findings suggest that the contribution of land sharing to SOC at regional level depends on 1) agro-ecological conditions; and 2) production goal. This paradigm of ecological intensification may constitute a base for further elaboration of mixed farming systems. For land sharing to have potential as a blueprint for ecological intensification, specific regional incentives may be needed to arrive at the optimal combination of the driving forces, both economically and ecologically.

References

Anonymus (2008) Ontwikkelen van een expertsysteem voor het adviseren van het koolstofbeheer in de landbouwbodems (Development of an expertsystem for recommendations of carbon management in agricultural soils). Bodemkundige Dienst van België / Universiteit Gent, Vakgroep Bodembeheer en bodemhygiëne. Gent (BE).

AGRESTE (2011) Agreste Bretagne: Statistique Agricole Annuelle 2010. Rennes: Direction Régionale de l'Alimentation de l'Agriculture et de la Forêt, Service Régional de l'Information Statistique et Economique.

Aurousseau & Squividant (1996) Aurousseau, P., Squividant, H., 1996. Use of Tree Graph Structures for Computation. Modeling of Derived Variables in Digital Elevation Model software. <http://viviane.roazhon.inra.fr/spanum/publica/dem/dem2.ht m>.

Avadi A, Nitschelm L, Corson M & F. Vertès (2016) Data strategy for environmental assessment of agricultural regions via LCA: case study of a French catchment. The International Journal of Life Cycle Assessment, accepted jan. 2016.

Beaujouan V, Durand P & L Ruiz (2002) A hydrological model dedicated to topography-based simulation of nitrogen transfer and transformation: Rationale and application to the geomorphology-denitrification relationship. Hydrological Process 16:493–507.

BDAT, 2011. Base de DonnéesAnalyse des Terres. <http://www.gissol.fr/programme/bdat/bdat.php>

Bechini L, Castoldi N & A Stein (2011) Sensitivity to information upscaling of agro-ecological assessments: Application to soil organic carbon management. Agricultural Systems 104:480-490.

Bellamy PH, Loveland PJ, Bradley RI, Lark RM & GJD Kirk (2005) Carbon losses from all soils across England and Wales 1978-2003. Nature 437 pp. 245-248.

Berland J &M Salaün (2014) Report on energetic efficiency of system tested in subtask 3.3.2: Co-generation of renewable energy. Deliverable 3.4 CANTOGETHER Project Report.

Chardon X, Raison C, Le Gall A, Morvan T & P. Faverdin (2008). Fumigene: A model to study the impact of management rules and constraints on agricultural waste allocation at the farm level. Journal of Agricultural Science, 146, 521-539.

Coleman K & DS Jenkinson (1999) Roth-C-26.3 - A Model for the turnover of carbon in soil. Rothemsted, Harpenden.

Dollé JP & K Klump (2016) Carbon sequestration / release in grassland systems. in: Default approaches for cross-cutting issues for the cattle related product environmental footprint pilots. Tuomisto HL, Saouter E & R Plant (Eds.) JRC Technical Report 94878, ISPRA, European Commission.

EC (2011) Cap Reform – an explanation of the main elements. Memo/11/685. 12 October 2011. European Commission, Brussels.

Egan JF & DA Mortensen (2012). A comparison of land-sharing and land-sparing strategies for plant richness conservation in agricultural landscapes. Ecological Applications, 22: 459–471.

FAO/USDA Soil Classification System.

Description of Work (2011) EU-Project CANTOGETHER. INRA, Paris.

Den Boer DJ & B Zandstra (2013). Landbouwkundige maatregelen & betere waterkwaliteit in grensoverschrijdend project Winterswijk-Oeding (Agricultural practices & improved water quality in the crossingborder project Winterswijk-Oeding, *in Dutch*). NMI-report 1351, Nutrient Management Institute, Wagenigen.

Den Boer DJ & MJG de Haas (2013) Mogelijkheden gemengde bedrijfssystemen en beperken N- en Pverliezen in de regio Winterswijk (Options for mixed farming systems and reduction of N and P-losses in the area Winterswijk in the Netherlands, *in Dutch*). NMI-report 1425, Nutrient Management Institute, Wageningen.

Diaz Ismael A (2012) Nitrogen surplus and soil quality assessment of three dairy farms at the region of Winterswijk, the Netherlands. Internship report. Nutrient Management Institute / Wageningen University.

Donzallaz G (2012) A methodology to compare specialised and mixed farming systems. Master Thesis, ISARA, Lyon.

Doussal E (2014) Analysis and evaluation of systemics changes aiming at limiting nitrate losses in a network of 8 pilot farms on the Lieue de Grève watershed. Master 2 report, ESA Angers, 77 p.

Duru M, Therond O, Guillaume M, Martin-Clouaire R, Magne MA, Justes E, Journet EP, Aubertot JN, Savary S, Bergez JE & JP Sarthou. (2015) How to implement biodiversity-based agriculture to enhance ecosystem services: a review. Agronomy & Sustainainable Development.

Falloon P & DS Powlson (2004) Managing field margins for biodiversity and carbon sequestration: A great Britain case study. Soil Use & Management 20:240-247.

Feldwisch N (2013) Minimierung von Nährstoffeinträgen aus diffusen Quellen im Einzugsgebiet der Schlinge. Ingenieurbüro Feldwisch / Royal Haskoning DHV. Bergisch Gladbach.

Franko, U (1997) Modelling of soil organic matter turnover. Amsterdam.

Garcia F, Faverdin P, Delaby L & JL Peyraud (2005). Tournesol: amodel to simulate cropping plans in dairy production systems. Renc. Rech. Rum. 12: 195–198.

Gascuel C, Ruiz L & F Vertès (2015) Comment réconcilier agriculture et littoral? Vers une agroécologie des territoires (Reconciling agriculture and coastal areas? Towards territorial agroecology). Quae Editions, Versailles, 150 p.

Godinot O, Carof M, Vertès F & P Leterme (2014) SyNE: An improved indicator to assess nitrogen efficiency of farming systems. Agricultural Systems 127: 41–52.

Górski T & A Zaliwski (2002) Model Agroklimatu Polski, Pam. Puł., 130 (1), 251-260.

Gras et al (1989) in: Van der Werf & Petit (2002) Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agriculture, Ecosystems & Environment 93:131-145.

Halberg N, Van der Werf HMG, Basset-mens C, Dalgaard R & IJM de Boer (2005) Environmental assessment tool fort the evaluation and improvement of European livestock production systems. Livestock Production Science 96: 33-50.

Hanegraaf MC, Vertès F, Corson MS, Den Boer DJ, Moraine M & H. Korevaar (2015) Developing mixed farming systems in a regional approach: examples from intensive dairy farming. Proceedings of the 18th Symposium of the European Grassland Federation, Wageningen, the Netherlands, 15-17 June 2015.Grassland science in Europe, Vol. 20, pp. 96-98.

Korevaar, Hein, Rob Geerts, Jan Stronks & Arie Schoemaker (2014) Various perceptions of a cultural landscape. Results and experiences of the Winterswijk CAP-pilot 2011-2013. Stichting WCL-Winterswijk, Winterswijk.

Korevaar H & Geerts RHEM(2012) Experiences with ecosystem services on farms; a pilot study towards CAP reform. Grassland Science in Europe, vol. 17: 756-758.

Korevaar H, Geerts RHEM, De Visser W & E Koldewey (2008) Vier jaar multifunctionele gras- en bouwlanden in Winterswijk: gevolgen voor economie en ecologie op de bedrijven (Four years multifunctional grass- and arable lands in Winterswijk: consequences for economy and ecology at the farms. *In Dutch*.) Report 115, Plant Research International / LTI Noord Projecten,

Wageningen.
Korevaar, H. & R.H.E.M. Geerts. 2007. Productivity, biodiversity and nitrate in groundwater of multifunctional grasslands. In: High Value Grassland. Providing biodiversity, a clean environment and premium products. Occasional Symposium 38 British Grassland Society, Cirencester, UK: 64-69.
Kuikman P, Ehlert PAI, Chardon WJ, Van Beek CL, Tóth G. & O Oenema (2008) Current status of risk assessment methodologies for soil organic matter decline RAMSOIL report 2.5.
Lacoste M., Viaud V., Michot D.,Walter C. (2015) Landscape-scale modelling of erosion processes and soil carbon dynamics under land-use and climate change in agroecosystems. European Journal of Soil Science, July 2015, 66, 780–791.
Lantinga EA, Boele E & R Rabbinge (2013) Maximizing the nitrogen efficiency of a prototype mixed crop-livestock farm in The Netherlands. Wageningen journal of life sciences, NJAS 66:15–22.
Levain A, Vertès, Ruiz L, Delaby L, Gascuel-Odoux C & M Barbier (2015) 'I am an Intensive Guy': The Possibility and Conditions of Reconciliation Through the Ecological Intensification Framework. Environmental Management DOI 10.1007/s00267-015-0548-3.
Lima Paris Agenda for Action (LPAA) (2015) The "4‰ Initiative: soils for food security and climate". French Ministry for Agriculture, Food and Forests, Paris.
Leifeld J, Zimmermann M & J Fuhrer (2008). Simulating decomposition of labile soil organic carbon: Effects of pH. Soil Biology & Biochemistry 40 (2008) 2948–2951.
Levain A, Vertès F, Ruiz L, Delaby L, Gascuel-Odoux C & M Barbieret (2015) 'I am an Intensive Guy': The Possibility and Conditions of Reconciliation Through the Ecological Intensification Framework. Environmental Management DOI: 10.1007/s00267-015-0548-3.
Lityński T, Jurkowska H & E Gorlach (1976) Chemico- Agricultural Analyzes, Soil and Fertilizers. PWN.
Merante P, Dibari C, Ferrise R, Bindi M, Lesschen JP, Kuikman P, Sanchez B & A Iglesias (2015) Report on critical low soil organic matter contents, which jeopardise good functioning of farming systems. Report 2.4, EU-project Smartsoil.
Moraine M, Duru M, Nicholas P, Leterme P & O Therond (2014) Farming system design for innovative crop-livestock integration in Europe. Animal 8, 1204–1217, doi:10.1017/S1751731114001189.
Moreau P, Ruiz L, Mabon F, Raimbault T, Durand P, Delaby L, Devienne S & F Vertès (2012) Reconciling technical, economical and environmentalefficiency of farming systems in vulnerable areas. Agriculture, Ecosystems and Environment 147:89-99.
Moreau P, Ruiz L, Vertès F, Baratte C, Delaby L, Faverdin P, Gascuel-Odoux C, Piquemal B, Ramat E, Salmon-Monviola J & P Durand (2013) CASIMOD'N: An agro-hydrological distributed model of catchment-scale nitrogen dynamics integrating farming system decisions. Agricultural Systems 118, 41-51.
National Agricultural Census of Poland.
Oehler F, Durand P, Bordenave P, Saadi Z & J Salmon-Monviola (2009) Modelling denitrification at the catchment scale. Sci. Total Environ. 407: 1726–1737.
OstrowskaA, Gawliński S & Z Szczubiałka (1991), Methods for analyzing and assesing the properties of soil and plants. Instytut Ochrony Środowiska, Warszawa, Poland.
Phalan B, Onial M, Balmford A & RE Green (2011) Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared. Science 333, 1289-1291.
Kaczynski R, Siebielec G, Galazka R, Niedzwiecki J & S Polakova (2013) Assessment of soil organic carbon status and changes in soils of Polish-Czech borderland. Central Institute for Supervising and Testing in Agriculture (ÚKZÚZ), Institute for Soil Science and Plant Cultivation (IUNG).
Rutgers M, Van Wijnen HJ, Schouten AJ, Mulder C, Kuiten AMP, Brussaard L & AM Breure (2012) A

method to assess ecosystem services developed from soil attributes with stakeholders and data of four arable farms. Science of the Total Environment 415:39-48.

Salmon-Monviola J, Durand P, Ferchaud F, Oehler F & L Sorel (2012) Modelling spatial dynamics of cropping systems to assess agricultural practices at the catchment scale. Comput. Electron. Agric. 81, 1–13.

Stuczyński T (2007) Przyrodnicze uwarunkowania produkcji rolniczej w Polsce. W: Współczesne uwarunkowania organizacji produkcji w gospodarstwach rolniczych. Studia i Raporty IUNG-PIB, Puławy, 7,pp. 77-115.

Van den Ham A & HH Luesink (2012) Developments in mineral surpluses and water quality in the Dutch dairy sector, 1960-2010. Factsheet LEI Wageningen UR.

Van Keulen H & H Schiere (2004) Crop-livestock systems: old wine in new bottles? Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia.

Vellinga TV & IE Hoving (2010) Maize silage for dairy cows: mitigation of methane emissions can be offset by land use change. Nutr. Cycl. Agroecosyst DOI 10.1007/s10705-010-9405-1.

Vertès F & Mary B (2014) Grassland frequency in ley-arable rotations is a proxy for predicting SOC changes on the long term. 18th Nitrogen Workshop.

Vertès F, Delaby L, Ruiz L, Moreau P & P Gascuel-Odoux (2011) Une méthode pour co-construire et évaluer des options de réduction de pertes N en exploitations sur des bassins-versants côtiers vulnérables. Renc. Rech. Rum. ,12: 7-8.

Appendices

Appendix A: Dolnoslaskie

Correction for ploughing depth

The initial SOC content was corrected for change in ploughing depth. The historical SOC data represent 60 and 70s of the last century when the depth of soil conversion was smaller than presently. Because in the 70's, an average depth of ploughing has increased, which was associated with intensive mechanization of agriculture, the initial organic matter content has been diluted as a result of mixing humus horizon with the subsoil. The change concerned ploughing depth of 25-30 cm. It was assumed that, prior to mixing 0 – 25 cm and 25 – 30 cm layers, organic matter content in the layer of 25-30 cm was half of the content in the top layer.[1]

The following equation was used for the correction:

$$OC_i = \frac{25 \cdot OC_i^m + 5 \cdot 0{,}5 \cdot OC_i^m \cdot Max\left(0; Min\left(1; \frac{1982 - sampl.year}{1982 - 1972}\right)\right)}{30},$$

Where :

OC_i - organic carbon content diluted,

OC_i^m - measured organic carbon content

25 - historical depth of ploughing [cm]

5 – seize of enlargement of ploughing horizon [cm] between 1972 and 1982

Appendix B: Winterswijk

Figure B.1. Description of the stakeholder process.

Phase 0

In 1975, Winterswijk was mentioned by the Dutch government as one of the potential new national countryside parks (CRM, 1975). This resulted in the beginning of the 1980s in severe protests by farmers against the consequences for environmental and nature-related claims on land, while the size of most farms was too small for further development of the farms. Around 1990, the local farmers' organization, a platform of local nature and environmental groups, the municipality of Winterswijk and the Ministry of Agriculture, Nature and Fisheries joined in a number of surveys 'to maintain the beautiful landscape of Winterswijk, develop theagricultural infrastructure and improve the ecological values of the region'. The surveys were successful. In 1993, Winterswijk became one of the 11 Dutch Valuable Man-made Landscapes (WCL). A foundation was set up (WCL Winterswijk) in which the municipality, the farmers' organization, owners of small estates, local nature and environmental groups, the recreation and tourism sector and local industries cooperated. This foundation became a driving force behind regional development.

Phase 1

In 1997, the region was selected for the Dutch research programme "Multiple Sustainable Land Use" (MDL), which led to the study of the major farm types (2002-2005). The results indicated that a combination of agronomic, ecological and environmental goals would be possible and that there are possibilities to combine high biodiversity with a rather high production level (Korevaar and Geerts, 2007). This in turn would offer good opportunities to create extra income from recreation and tourism. However, it was shown that in most cases multifunctionality is not profitable for the individual farmer.

Phase 2

At the request of farmers a rewarding system for ecosystem services was developed and tested (2007 - 2008). Activities or ecosystem services that would be rewarded were chosen at the local level, including a number of typical features for that region, like restoration of old arable fields and adjacent (steep) edges. The activities were valuated with points, depending on their importance for landscape and/or community, and the acreage or intensity of that activity. Scores were multiplied by a payment per point which results in total payment to the farmer. The incentive was to reward farmers for their efforts instead of compensating them for production losses, which is the case in most agri-environmental schemes. WCL Winterswijk adopted this payment system and launched a countryside fund to reward farmers for offering ecosystem services in December 2008. Later on the development of the system stuck due to on-going debate on the terms under which the public budget could become available.

Phase 3

The eastern part of the region became involved in actions directed at improvement of the water quality (2010-2012). This was initiated by regional water board organisations in the Netherlands and Germany. On their behalf, the participating farmers (c. 10) were supported with knowledge, advice and intensive monitoring to improve nutrient use efficiency and reduce nutrient losses. The focus was on measures that increase the utilisation of N and P input and/or reduce the losses of nutrients to streams and small rivers in the area. In addition, surveys were carried out covering 62 dairy farms in the Winterswijk region.

Phase 4

The region served as a pilot for the CAP reform for the Dutch Ministry of Economic Affairs (2011 – 2014). About half of all farms in the region have been participating with a number of activities for 'greening' and making the region more sustainable. These included cultivation of more grains to produce part of the concentrates on-farm, nature conservation on farm land as well as conservation of the landscape (Korevaar & Geerts, 2012; Korevaar et al., 2014).

Appendix B, continued.

Table B.1. Green-blue services on the farms participating in the CAP-pilot in Winterswijk in 2011 (Korevaar & Geerts, 2012).

Service/activity	Number of farms	Units	Area (ha) or length (km)	Payment (€) per unit	Total costs (1000 €)
Biodiversity					
Preservation of small fields	97 (= all farms)	ha	945.0	50 field 2-3 ha 125 field 1-2 ha 250 field 0.5-1 ha 400 field < 0.5 ha	20.3 49.0 28.8 12.7
Cleaning grassy field margins along forests and hedgerows	76	km	101.6	500	50.8
Reintroduction of cereals	**19**	**ha**	**31.4**	**500**	**15.7**
Sowing arable field boundary species	12	ha	5.5	2,000	11.0
Unharvest cereal crop	4	ha	1.8	1,400	2.6
Overwinter stubbles	7	ha	10.1	250	2.5
Reintroduction of species-rich grasslands	7	ha	9.4	1,400	13.2
Preservation of old meadows	62	ha	538.5	50	26.9
Sowing species rich margins along grasslands	2	ha	0.5	1,500	.8
Introduction of grass-clover swards	**15**	**ha**	**36.4**	**250**	**9.1**
Landscape					
Maintenance of woodlots < 0.5 ha	28	ha	7.3	5,000	36.3
Maintenance of solitary trees	28	number	110	50	5.5
Fencing solitary trees	14	number	47	100	4.7
Conservation of steep margins along arable fields	21	ha	1.8	5,000	9.0
Maintenance of sheltered fruit trees	21	number	315	20	6.3
Water quality					
Introduction of catch crops	**21**	**ha**	**51.3**	**250**	**12.8**
Education and open farms					
Education and farms open to visitors	22	hours	170	50	8.5
Footpaths over farm land	8	km	7.3	500	3.6
Total costs					330.1

In bolt: measure with effect on soil organic matter.

Appendix B, continued.

Table B.2. Regional upscaling of effects of mixed farming with services (Den Boer & De Haas, 2013).

Measure	Crop	# ha	Reduction potential loss (kg)			
			Per ha		WRIJ area	
			N	P_2O_5	N	P_2O_5
Manure in the row	maize	1,000	46	26	43,010	24,310
No manure if soil-P is high	maize, arable, grass	507	28	67	3,015	41,686
Postpone manure appl. if water table is high	grass	1,565	4,3		6,730	
No manure as from August	grass	2,275	6,2		17,081	
Nitrificatieremmer with mineral fertiliser	gras	2,850	12		34,200	
Green crop	maize	1,000	16.5	5.5	16,500	5,500
Raise pH	maize	405	7	3	2,566	979
Total area (kg)					123,102	72,475

In bolt: measure with effect on soil organic matter.

Appendix B, continued.

Table B.3. Basic data on fertilisation management at model farms.

Crop	Dairy Farmyard Manure		Crop residue	
	Amount	Month	Amount	Month
	$m^3.ha^{-1}$		C $kg^3.ha^{-1}$	
potato	30	March	1,790	October
winterwheat	30	February	5,700	October
maize	30	April	900	October
-catchcrop: ryegrass (poor)	0		250	April
-catchcrop: ryegrass (good)	0		1,000	April
grass	30	February	4,725	per month
	15	May		
	15	June		
grassclover	30	February	4,544	per month
		May		
	15	June		

Appendix C: Lieue de Grève

Phase 1 : Lieue de Grève Bay has been strongly affected by significant algal blooms since the 1970's. This "*catastrophe*" negatively affect seaside tourism and the economic development of the bay. An agrarian diagnosis and land use reconstitution through remote sensing (1950 until now) highlighted the key changes leading to large release of nitrate: permanent grassland and moors cultivation, correction of pH deficiencies, induced a large mineralization of high soil organic matter stocks in the 60's. Over-fertilisation of the new temporary grasslands and cultivation of maize (from the 1970's) leaving bare soils in winter which increased the losses (of N and P).

Phase 2 : Not to give up the idea of agriculture contributing to the common good, nor ignore the coastline damages created a tension that led to the creation of a Comite´ Professionnel Agricole (CPA), through the initiative of a local representative and a local leader of the main agricultural union, the Federation des syndicats d'exploitants agricoles (FNSEA). Institutionalization of such a cooperation system required accepting the idea of sharing, beyond the main ''union family'', the concerns that environmental issues posed for Breton agriculture. In this area farmers are expected to make more effort than elsewhere to reduce N emissions: the water quality objective proposed is approximately 10 mg/l NO3 at watershed outlets, i.e. 20 % of the limit defined by EU policies. For the local stakeholders who were largely excluded from agricultural politics and had very few tools to change agriculture, the CPA was a gamble that opened an unprecedented field of possibilities, since the organization guaranteed them stable spokespersons representing the diversity of the farmers.
This CPA obtained the participation of researchers by involving them in the reflection and diagnosis that was part of the first so-called ''preventive'' control programs in the late 1990s. This partnership provided support for better adjustment of agricultural practices (eg optimize fertilization) and access to new knowledge, but also afforded a different viewpoint of empirical situations.

Phase 3 : A new working group was organized around three complementary objectives: (i) improve understanding of mechanisms influencing the nitrogen cycle in the landscape; (ii) model nitrate emissions from the watershed, integrating constraints of livestock farming systems in a model coupling agro-hydrological and farm functioning; and (iii) co-construct, with farmers and local stakeholders, scenarios combining improvement in N management, and social acceptability, and evaluate their impacts. A conceptual framework was shared on long response time of water quality to agricultural fluxes changes, and an available model allowed to assess ex-ante the effects of scenarios on results rather than means. The CPA asked researchers to deepen the diagnosis and help to open new ways to reduce nitrate losses, given new room for manoeuvre: changes in production systems could be considered, and not simply optimization of present ones.

Phase 4 : 2010-2014 : after co-construction of a set of indicators to guide evolution and of specific scenario per farm, a group of 9 pilot farms implemented changes toward N inputs reduction, increased link between animal and crop production, increased part of grasslands in landscape and better nutrient recycling and use efficiency. The design process and changes implemented were observed and measured, and used as input data in the model to assess at the territory level the impacts of changes (each farm being a "type farm").

Figure C.1. Description of the stakeholder process.

Appendix C, continued.

Table C.1.

	Specialised Dairy		Mixed dairy			
	Grass based (9)	Grass + maize (13)	Milk + Meat (maize+grass) (13)	Milk + cash crops + (grass + maize) (21)	Res. ET	Signif.
Area						
AA (ha)	76.6	72.2	96.3	81.7	23.4	NS
Grassland % AA	75.3[a]	58.7[b]	48.4[c]	45.9[c]	8.9	***
Maize % AA	11.4[c]	27.3[bc]	32.0[a]	24.8[b]	5.9	***
Maize %fodder area	12.7[c]	31.1[b]	39.6[a]	34.5[ab]	7.5	***
Fodder area % AA	89.6[a]	88.1[a]	81.1[a]	72.9[b]	8.7	***
Cash crops % AA	9.1[b]	10.4[b]	16.5[b]	26.4[a]	8.0	***
Grazing						
Accessible area/DC (ares)	78[a]	48[b]	43[b]	49[b]	21.8	***
Grazed area / DC (ares)	60[a]	30[bc]	22[c]	34[b]	12.8	***
Labor						
Labor unit	1.5	1.8	2.2	1.9	0.8	NS
Cattle herds						
LSU	86.3[b]	97.1[b]	136.8[a]	81.3[b]	32.0	***
Dairy cow (LSU)	48.1	59.0	60.6	53.1	15.8	NS
Steers (LSU)	2.7[b]	4.6[b]	20.8[a]	2.4[b]	10.7	***
Milk production						
Milk sold (L)	225,959[a]	351,164[b]	401,428[b]	378,884[b]	106,301	**
Milk / ha AA (L)	3,176[b]	4,943[a]	4,332[ab]	4,753[a]	1,179	**
Animal performances						
Milk sold per cow	4,874[c]	5,917[cb]	6,672[ba]	7,109[a]	929	***
Concentrate per cow (Kg)	472[c]	699[b]	1,259[a]	818[b]	360	***
Ncon/l milk	4.2[c]	7.8[b]	11.8[a]	7.3[b]	2.9	***
% farmers closing maize silage silo	89	62	8	22	#	***
Age at 1st veel (months)	32.7 [a]	32.6[a]	27.8[b]	28.5[b]	3.1	***
N concentrates per ha	16[c]	45[b]	65[a]	38[b]	14.1	***
N organic per ha	12.1	7.4	12.9	8.9	25.4	NS
Net mineral N par ha	22[c]	60[ab]	77[a]	51[b]	24.2	***
Indicator "N inputs" per ha AA	46[b]	101[b]	139[a]	93[b]	25.2	***

Letters a, b, and c indicate similarities or differences for each variable between the 4 types of farms.

Appendix C, continued.

Table C.2. Results of the Casimod'N modelling (in kg N par ha watershed) : mean values for the simulation period 2008-2020.

		BAU	Indicators
inputs	N fertilizers	40	26
	N manure	26	27
	N returns at grazing	44	38
	N fixation	8	10
	N deposition	14	14
Total N inputs		132	114
Stock variation	Variation N in soils	-11	-13
	Variation N in water	0	-2
	Variation N in crops	4	4
Total variation N		-7	-11
outputs	N denitrification	6	5
	N volatilisation	9	7
	N exported by crops	81	77
	N uptake in woods/hedges	16	15
	N in rivers	26	21
Total N outputs		138	125

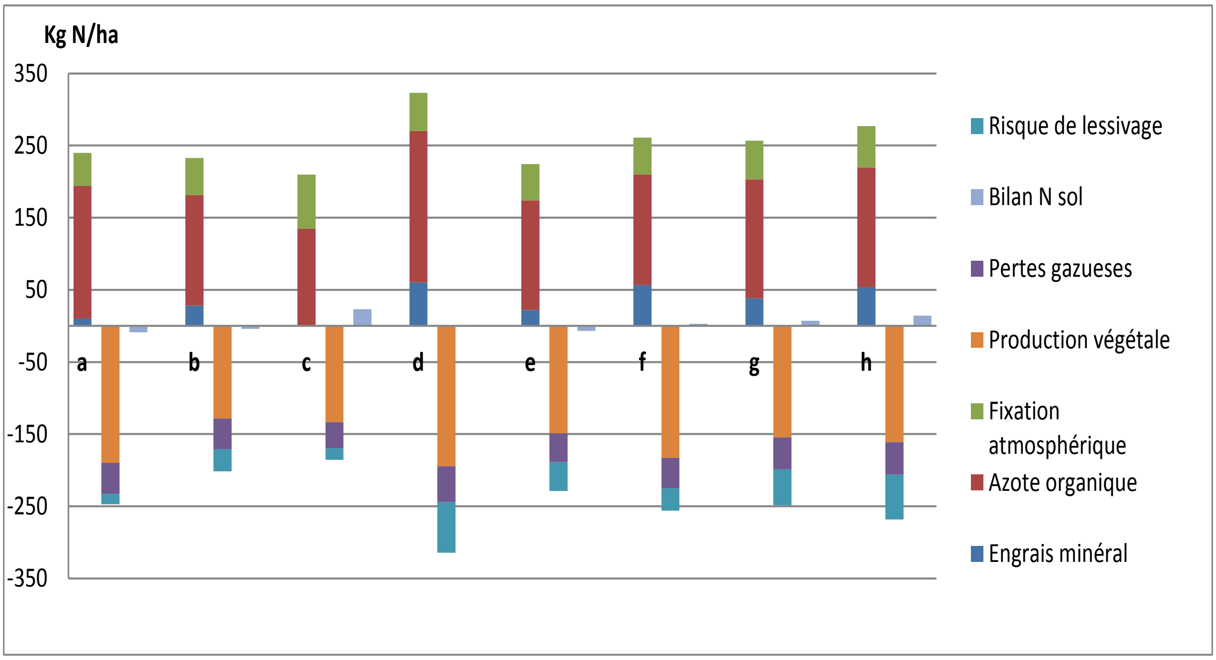

Figure C.2. Results Casimod'N for 8 pilot farms (Doussad, 2014).