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Integrated territorial approach for sustainable agriculture: nitrogen management and soil carbon sequestration in Lombardy region

Ph.D. Thesis

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Ph. D. Thesis
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In the last years, intensive agriculture and high concentration of livestock activities have become two important environmental concerns, being partially responsible of nitrogen pollution and CO_2 emissions caused by carbon loss from soil. That's particularly true in Lombardy region, due to the presence of more than 27% of cattle and 51% of pigs of the national livestock and due to the extent of area devoted to cereal cropping (about 63% of the utilized agricultural area - UAA). It is also to be remarked that cereals in Lombardy are commonly grown in continuous cropping systems.

In this context, the aim to encourage sustainable agriculture led European Union to introduce regulations (e.g. Nitrates Directive 91/676/EEC), to define mandatory standards, and measures (Common Agricultural Policy), to promote the implementation of best management practices. Consequently, assessing the potential effects of different policies, prior to their introduction, has become very important. Several methods (direct measurements, simulation models, simple and composite indicators) have been developed and applied by traditional agronomic research, however there is still a need of up-scaling experimental results from the farm to the landscape scale. Moreover, it has to be taken into account that the impact of these measures also depends on the interaction between type of action, pedo-climatic factors and farm characteristics. An effective tool for territorial management and planning is then particularly needed in Lombardy, since the

territorial approaches, supported by robust methodologies (e.g., extensive databases, models and geographical information systems (GIS)), have become more and more central in European policies.

The aim of this work is to assess and investigate the important outcomes of a more territorially based approach, analysing the most important environmental issues, related to agriculture in Lombardy: manure management, nitrogen leaching and carbon sequestration by soils. Three examples of tools and applications are presented: i) Decision Support System (DSS) ValorE, to analyse and to evaluate manure management and technological alternatives, available for the entire supply chain from animal feed to the distribution in the field; ii) application of the ARMOSA cropping system simulation model to assess the potential risk of nitrate leaching towards groundwater in 3 Nitrate Vulnerable Zones (NVZs); iii) application of ARMOSA to evaluate carbon sequestration capacity of regional soils, under current and alternative scenarios, focusing the attention on the impact of different spread levels of conservation agriculture.

The territorial approach proposed in this thesis, was based on robust methodologies, extensive databases, stand-alone models (e.g. ARMOSA), more complex structures (ValorE DSS) and GIS techniques. All these components led this approach to be an effective solution for investigating and supporting the regional agricultural management, as well as for assessing the potential impact of the regional policies, always keeping in mind that agricultural sector plays a key role in the climate change mitigation and in the environmental protection from biodiversity loss and from N pollution.

Credits evaluation

Courses:

- Elements of statistics.
- Geographical Information System

Attendance at international/national congress:

- 13th Italian Association of Agrometeorology Congress: Agrometeorologia nella gestione integrata dei sistemi agro-forestali dell'ambiente. 8-10 June 2012, Bari, Italy.

Oral presentation at technical workshop:

- Presentazione Sistema Esperto Valore. Regione Lombardia, 11 November 2011.
- Deroga Nitrati. Regione Lombardia – Brescia, 15 December 2011.
- Deroga Nitrati. Regione Lombardia – Mantova, 11 Junuary 2012.
- Deroga Nitrati. Regione Lombardia – Milano, 26 Junuary 2012.
- Sistema Esperto Valore – alcune applicazioni. Regione Lombardia – Bergamo, 30 Junuary 2012.

Teaching activities:

- Training courses (16 hours) on ValorE software held by Ordine degli Agronomi di Milano.
- Practical lessons in Agricultural Ecology
- Practical lesson in Agronomy

Attendance at seminars:

- Measuring The Drivers Of Global Climate Change: Using Of Quantum Cascade Lasers To Quantify Atmospheric Greenhouse Gases. 4 April 2011, Milano
- Water management and Nonpoint Source Pollution. 7 October 2013 Milano
- "Sviluppo di modelli per la simulazione degli agro-ecosistemi" organized by AIAM Associazione Italiana di Agrometereologi. 13-17 February 2012, Firenze

Poster presentation at international/national congress:

- **Giussani A.**, Alfieri L., Fumagalli M., Perego A., Carozzi M., Chiodini M., Sanna M., Rocca A., Acutis M., 2013. ValorE: a decision support system to enhance livestock manure management and reduce nitrogen pollution.

EFITA-WCCA-CIGR: Sustainable Agriculture through ICT innovation. Torino (Italy), 23rd-27th June 2013.

- **Giussani A.**, Perego A., Alfieri L., Carozzi M., Chiodini M., Fumagalli M., Rocca A., Sanna M., Brenna S., Corsi S., Tosini A., Acutis M., 2013. AgriCO$_2$ltura: Evaluation of techniques for increasing soil carbon sequestration and reducing CO2 emission in agricultural system. XVI National congress of Agrometeorology. Firenze (Italy), June 4th– 6th, 43-44.
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- Acutis M., Alfieri L., **Giussani A.**, Provolo G., Di Guardo A., Colombini S., Bertoncini G., Castelnuovo M, Sali G., Moschini M., Sanna M., Perego A., Carozzi M., Chiodini M E., Fumagalli M., 2013. Land Use Policy (Accepted).
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CONTENTS

Chapter 1

GENERAL INTRODUCTION

1.1. **Characterization of the Lombardy region**

The agricultural sector is involved in the three major threats to our planets identified by Giles (2005) in climate change, biodiversity loss and nitrogen (N) pollution.

First, the long-term changes in temperature and precipitation are expected to have a significant weight on the form, scale, and spatial and temporal impact on agricultural productivity (Kurukulasuriya and Rosenthal, 2003). On the other hand, agriculture is a key source of global greenhouse-gas emissions: it accounts for about 5.1 to 6.1 giga tonnes (Gt) of CO_2-eq y^{-1} in 2005, which represents the 10-12% of the total anthropogenic emissions (Metz et al., 2007).

Moreover, agriculture and biodiversity conservation have been traditionally viewed as incompatible (Tscharntke et al., 2005), nonetheless agricultural activity might contribute critically to biodiversity, affecting large parts of the world's land surface.

In addition, N supply is the most important factor affecting yield and, as consequence, N pollution has become an issue of environmental concern, particularly since the amount of global reactive N level started to rapidly increase in the '70s. (Zavarotto et al., 2012). As agriculture is getting more and more intensive, the amount of N added to soils as fertilizer and animal manure increases and exceeds the uptake capacity of crops. The resulting N surplus can be lost to the environment and, therefore, it can causes several problems, related to ecosystem vulnerability (Velthof et al., 2009).

In this context, Lombardy region is an ideal case study, because of its high intensive agricultural and livestock activities. The livestock density in Lombardy accounts for a big part of the entire national livestock, with more than 27% of cattle and 51% of pigs. Furthermore, the average nitrogen load at municipality scale originating from livestock manure is about 141 kg N ha^{-1}(Figure 1.1.1). In the western area where cereal farms are dominant, the average nitrogen load is generally low, whereas in the central and eastern parts the concentration of livestock farms leads to high nitrogen loads (from 150 to 450 kg ha^{-1}) (SIALR, 2012). Lower loads are detected in the western area, where cereal farms are dominant; on the other hand, greater loads are typical of the central and eastern zones, where most of the livestock farms are located (Fumagalli et al., 2011). N loads from mineral fertilization are also remarkable, even though N mineral fertilization is only used where manure is not available or is not enough to fully meet the crop N requirement. It is worth to remember that the municipality mean load of mineral N fertilizer in Lombardy plain is about 74 kg N ha^{-1}, ranging from 0 to 300 kg N ha^{-1} (SIARL, 2012).

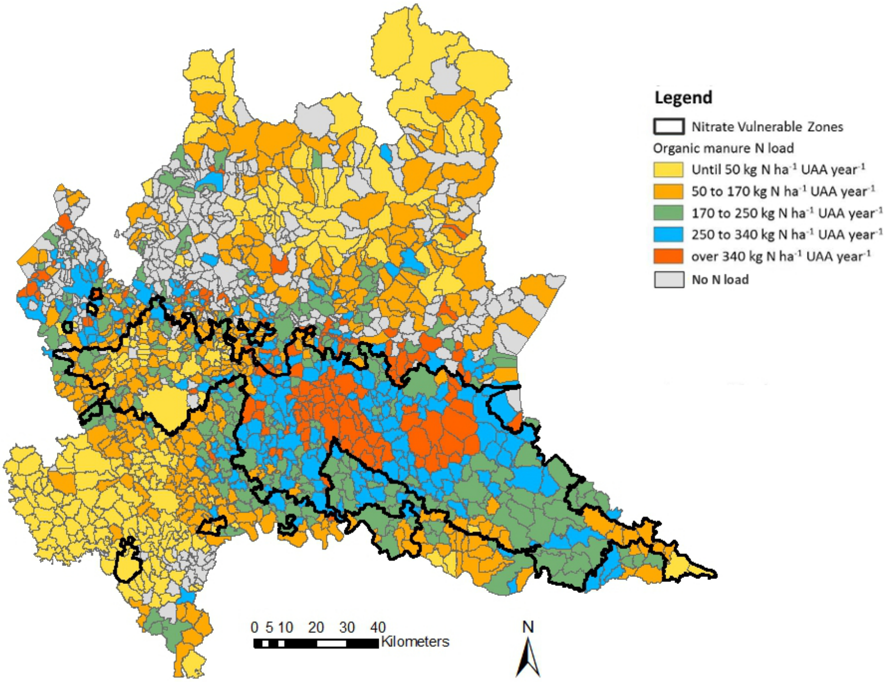


Figure 1.1.1. N load from livestock manure (kg N ha^{-1}) aggregated at municipality scale and the Nitrate Vulnerable Zones (NVZ).

In Lombardy region, more than 72% of the utilized agricultural area (UAA) is classified as arable land, cereals are the most cultivated crops, representing the

63% of UAA (ISTAT, 2013) and they are commonly grown in continuous cropping systems (Zea mais L., Oryza sativa L. and Triticum aestivum L. or autumn-sown Italian ryegrass, Lolium multiflorum Lam., followed by spring-sown maize, both used for silage) (SIARL 2012).

As stated before, high N input (e.g. from continuous cropping systems) can result in high N surplus. Such surplus in Po Valley was estimated to range from 40 to 150 kg N ha^{-1} by EU. In Fumagalli et al. (2011) during a farm surveys carried out across Lombardy plain , the nitrogen surplus calculated at field scale ranged from low (27 kg N ha^{-1}) to high (339 kg N ha^{-1}) values, depending by the amount of chemical and organic fertilizers applied. A mid-term trial, performed at six monitoring sites in Lombardy, pointed out N surplus varying from 30 to 600 kg N ha^{-1} (Perego et al., 2012).

Several studies relate high N surplus at soil with groundwater nitrate pollution, since nitrate builds up in the soil solution and it is leached by draining water, without crop uptaking (Aronsson and Stenberg, 2010; Mantovi et al., 2006; Grignani and Zavattaro, 2000; Simmelsgaard and Djurhuus 1998). This relationship was investigated by Perego et al. (2012), analyzing the relationship between N surplus and the estimated NO_3-N leaching losses (kg NO_3-N ha^{-1}year^{-1}). A significant correlation ($p<0.01$) was detected, as shown in (Figure 1.1.2).

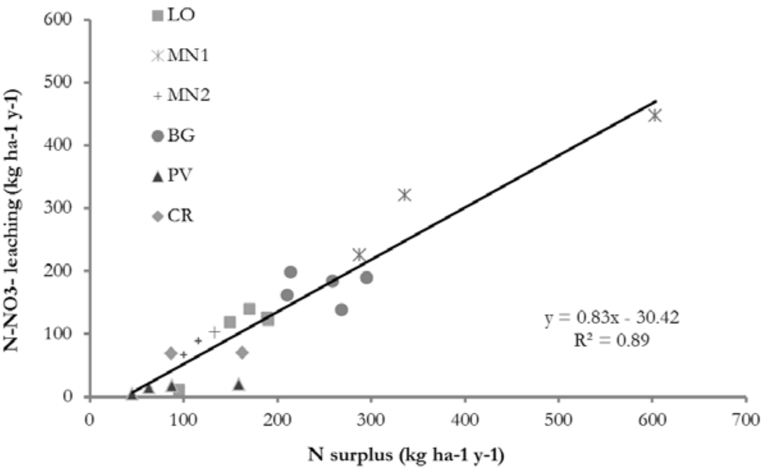


Figure 1.1.2. Significant relation between yearly mean N surplus (kg N ha^{-1} y^{-1}) and yearly mean NO_3-N leaching (kg NO_3-N ha^{-1} y^{-1}) (Perego et al., 2012).

Remarkable N losses may also be due to NH_3 volatilization, and N_2O, NO, and N_2 emissions. Emissions of gaseous N compounds usually occur from feces and urine under housing treatment, storage processes and application of manure and mineral N fertilizers (Freibauer, 2003; Carozzi et al., 2013).

Coming to the rule of agriculture as a source of global greenhouse-gas emissions, numerous studies highlight that intensively managed cropping systems cause C loss from soil and CO_2 emission to the atmosphere, being characterized by continuous removal of crop residues and tillage till 30-40 cm depth. It is also known that since 1850 the main sources of CO_2 have been fuel combustion and land use change, including deforestation, and soil tillage (Lal, 2004).

Croplands are estimated to be the largest biosphere source of C lost to the atmosphere in Europe (300 Mt C y^{-1}). That is because soil represents the largest C sink and, therefore, severe depletion of the soil organic carbon (SOC) pool might: (i) degrade soil quality, (ii) reduce biomass productivity, (iii) improve CO_2 emissions and eventually (iv) affect global climate. Furthermore, N surplus in soil can determine an increase in mineralization rate of organic carbon (C), leading to higher C losses from soils. As previously discussed, maximum nitrogen values are reported in areas with high livestock populations and intensive cropping systems, particularly tillage and fertilizer (EEA, 2010).

A possible solution to this issue is the control of SOC or its increase throughout the C sequestration, which can reduce CO_2 emission to purposes of global warming mitigation (Six et al., 2004). Soil C sequestration is known to cause atmospheric CO_2 transferring into long-lived pools, where it is securely stored and it cannot be immediately re-emitted. Since world potential soil C sequestration capacity ranges from about 55 to 78 Gt (Lal, 2004), it has indeed to be considered as an effective mitigation strategy.

Starting from all these points, the adoption of Conservation Agriculture (CA) can undoubtedly produce good results and it has to be encouraged. FAO defined CA as an agricultural production system, aiming to achieve production intensification and high yields, enhancing, at the same time, natural resource base, in compliance with three interrelated principles: (i) minimum mechanical soil disturbance (minimum tillage or sod seeding); (ii) permanent soil organic cover with crop residues and/or cover crops (iii) species diversification through crop associations and/or rotations. CA can also become an opportunity for farmers, since several study show higher rates of soil C sequestration (0.1 to 0.5 t C^{-1} ha^{-1}), comparing with traditional or tillage agriculture (TA) (Freibauer et al., 2004; Alvarez, 2005; Oorts et la., 2007; Smith et al., 1998). Moreover, CA allows to reduce fuel consumption, to improve soil fertilizer and N efficiency and to decrease N fertilization and soil erosion (Daraghmeh et al., 2009; Christopher and Lal, 2007; Ball et al., 1999)

1.2. **Territorial analysis: an approach to assess and improve agricultural management and policy**

The aim of European Union (EU) is to promote agricultural activities able to guarantee a viable food production, a sustainable management of natural resources and climate action and a balanced territorial development. In details the purpose is to realize an agriculture that improves its environmental performance through more sustainable production methods.

The EU also supports studies and monitoring activities to analyze the environmental status, to check the use efficiency of production factors in agro-ecosystem and to assess the risk of pollution. For example in the case of the nitrate leaching issue mandatory standards that the Member States has to comply, were introduced. A specific monitoring plain of groundwater and surface water has been defined indicating the maximum permissible nitrate concentration of 50 mg L^{-1} and defining the maximum amount of 170 kg N ha^{-1} y^{-1} for livestock manure (Nitrates Directive 91/676/EEC).

Together, the Common Agricultural Policy (CAP) over times has assumed an important role in payments for land management linked with environmental benefits. European Rural Development Programme (RDP) is an instrument to provide payments and it consists of a wide range of measures which have been defined to protect and enhance rural environment, contributing to the development of a competitive and sustainable farm and improving quality of life of rural communities. Most of these measures consist of the implementation of best management practices (BMPs) that act mainly on two stages of the diffuse pollution process by reducing i.) the transport and ii.) the amount of potentially transportable pollutants (Morari et al., 2004). The BMPs that affect the water cycle mainly influence the first stage, while those that optimize fertilization affect the second stage. Other BMPs, like CA, influence both stages.

In this context, assess the strength, weakness and desired effects of such measures, prior to their introduction, becomes crucial. Ex-ante integrated assessment could greatly enhance the measures effect (Van Ittersum et al., 2008) as well as, when BMPs are already implemented, their effectiveness needs to be evaluated.

Different methods like direct measurements, simulation models, simple and composite indicators have been developed and applied in traditional agronomic research. Normally, they were applied as field and farm-based evaluating tools of cropping and farming systems sustainability.

For example, several simulation models were developed to describe crop growth and N - C and water balance (CropSyst, SWAP, CERES, SUCROS, SOILN). They are powerful tools for investigating this processes and can be used to evaluate alternative management options at field scale regarding at fertilizations, tillage, irrigations, crops rotation topics (Morari and Giupponi, 1997; Acutis et al., 2000; Confalonieri et al., 2006; Fumagalli et al., 2013). Literature shows several application at field scale used for detecting satisfactory solutions/compromises between high production levels and low environmental impact, thus providing helpful information for increasing the efficiency of the agro-ecosystem. Nevertheless, this is clearly constraining when the results acquired in field experiments are upscaled to the whole territory, as the efficiency of the BMPs depends on the interaction of the type of action with pedo-climatic factors and on farm characteristics. This aspect has strong consequences from the political point of view, since local administrations often fund general measures that do not suit the type of environment in which they are applied.

A support for territorial management and planning is needed in particular because the territorial approaches have gained ground progressively in European policies about rural development (Mantino, 2011). Moreover, as stated by Fassio et al. (2005) large-scale analyses supported by robust methodologies (e.i. extensive databases, models and geographical information systems (GIS)) are needed in order to design, monitor and evaluate spatially policies.

For economic and logistic reasons, the integration of GIS and mathematical models could be an interesting approach to deal with specificities and needs of the diverse areas under investigation. Several authors have used a combination of simulation models and GIS to assess the risk of agricultural pollution and to give to the public administration a useful tool for the evaluation of agricultural policy (Morari et., 2004; Freibauer et al., 2004; Grace et al., 2011; Van der Straeten et al., 2012).

Similar but more complex instrument is the spatial decision support system (DSS) which consists in the linkage of integrated databases, computer programs, and spatialization tools. DSS is an interactive computer-based system, which is intended to help decision makers in using communication technologies, data, documents, knowledge and/or models to identify and solve problems, hence completing the decision process tasks with the overall objective of making well-informed decisions (Power, 1997). Decisions which are typically supported are tactical management (improving use of resources to increase efficiency, reducing risk or limit pollution) and strategic management (deciding on the portfolio of enterprises undertaken) (Matthews et al., 2008).

The advantage of the DSS over a single model used in a large-scale analysis is to assist stakeholders and farmers on identification, evaluation, and selection of the more suitable option of agricultural management for a specific area and aim.

Overall, the spatial and integrated approach grants the possibility to deal with conflicting objectives, interests and expectation of stakeholders involved and offers to decision-makers a comprehensive tool for improving strategy and decision making.

1.3. **Objective and organization of the research**

The intensive agriculture of our region and the relative environmental concerns largely studied through site-specific assessment (e.g. field experiments, farm surveys, model calibration and validation against experimental data) suggest the need to consider an alternative approach to evaluate and improve the sustainability of agricultural activities and to support the definition of related policies. The objective of this work is to explore the relevance of a more territorially based approach analysing the most important environmental issues related to the current regional agriculture: manure, management, nitrogen leaching and carbon sequestration by soils. The approach is based on the use of regional databases to acquire information, of simulation models to organize knowledge and test scientific hypothesis, and of GIS to handles spatially distributed information. Three examples of tools and applications are here presented:

1. Presentation of the Decision Support System (DSS) ValorE which helps stakeholders (i) to find the best option in order to minimise the risk of environmental pollution (mainly from nitrogen), (ii) to valorise the organic manure from different livestock types in environmental, technical, agronomic and economic terms, (iii) to plan the building of new plants for the manure treatment, (iv) to evaluate the effects of new technologies and to check, *ante factum*, the possible effects of new policies.
2. Application of the ARMOSA cropping system simulation model to evaluate the potential risk of nitrate leaching towards groundwater in three Nitrate Vulnerable Zones (NVZs) of the Lombardy plain under different alternative nitrogen management scenarios.
3. Application of the ARMOSA cropping system simulation model to evaluate the carbon sequestration capacity of regional soils under current and alternative scenarios as example of different diffusion levels of CA.

Chapter 2

VALORE: AN INTEGRATED AND GIS-BASED DECISION SUPPORT SYSTEM FOR LIVESTOCK MANURE MANAGEMENT IN THE LOMBARDY REGION (NORTHERN ITALY)

Marco Acutis, Lodovico Alfieri, Andrea Giussani, Giorgio Provolo, Andrea Di Guardo, Stefania Colombini, Gianpaolo Bertoncini, Marco Castelnuovo, Guido Sali, Maurizio Moschini, Mattia Sanna, Alessia Perego, Marco Carozzi, Marcello Ermido Chiodini, Mattia Fumagalli.

Submitted to Land Use Policy (under revision)

Keywords

Decision support system, GIS, Integrated evaluation, Manure management, Multidisciplinary indicators.

2.1. Abstract

Intensive agriculture and livestock breeding represent critical factors in the Lombardy region since the nitrate vulnerable zones are 62% of utilised agricultural plain area. The aim of reducing the environmental risk caused by agriculture activities (e.g. nitrogen losses into groundwater and atmosphere) can be only achieved through a critical and scientific analysis of livestock manure management in a whole-farm perspective. Keeping in mind this objective, the decision support system (DSS) ValorE was developed. It can be described as a tool able to evaluate from the environmental, technical, agronomic and economic points of view the main components of manure management (production, storage, treatment and land application) for a variety of livestock types (i.e. cattle, swine, poultry, sheep, goats and horses), under different scenarios adopted at farm and territorial scale. ValorE consists of three main components: data management subsystem, model management subsystem and two versions of user-interface, both for farm and territorial scale. Most of the inputs to the DSS comes from external databases, while a software tool developed in the .NET environment and implemented using object oriented programming (C# language), provides the logic to manage the scenario simulation of agronomic and environmental farm-scale models. Users and stakeholders can carry out comparative analysis, starting from the knowledge of the current perspective, in terms of manure management system at farm or territorial scale by interrogating the available databases. Moreover, they can generate different alternative scenarios thanks to different options for the manure handling and cropping system simulation. Then they can finally evaluate and compare different scenarios through multidisciplinary and synthetic indicators but also visualize spatial effects exploiting the coupled webGIS. ValorE is therefore an attempt to offer a comprehensive tool for improving both farm strategy and decision making process, which is

particularly important in a very intensive agricultural area, with one of the highest livestock density in the world, as Lombardy.

2.2. Introduction

Livestock production, responsible of a big part of agricultural land use for grazing and feed production, determine serious environmental problems such as greenhouse gas emissions (Steinfeld et al., 2006) and emissions of reactive nitrogen (N) in atmosphere and water (Oenema, 2006). These problems are getting much importance due to the environmental targets required by the agricultural policies and regulations for preventing pollution of land, air and water. The core of the livestock production is the manure management from the animal excretion to the land spreading, because it affects both the quality of soil, air, water and the crop growth, and consequently it bears on the farm income. The selection of livestock manure management options is becoming a strategic task that farmers and public policy makers have to handle properly. As presented by Karmakar et al. (2010), several options for manure collection, storage and land application are available. Moreover, as discussed by Petersen et al. (2007) a variety of manure treatments with a specific target has been developed as well as improvements in animal nutrition to control manure production and composition. Consequently, before investing money, it is of paramount importance to get a support tool that could assist stakeholders and farmers on identification, evaluation, and selection of the more suitable option of the manure management for a specific area and aim. In fact, each management strategy has its advantages and disadvantages when considering environmental, agronomic, technical, energetic, cost and labour issues (Fumagalli et al., 2012).

A decision support system (DSS) is an interactive computer-based system intended to help decision makers in using communication technologies, data, documents, knowledge and/or models to identify and solve problems, hence completing the decision process tasks with the overall objective of making well-informed decisions (Power, 1997). Multiple examples of the development and application of DSSs in agriculture addressing a variety of domains, such as pest management (Perini and Susi, 2004, Riparbelli et al., 2008, Calliera et al., 2013), water management (Fassio et al., 2005; Pallottino et al., 2005; Giupponi, 2007; Acutis et al., 2010), agricultural land management (Mazzocchi et al., 2013) and nutrient management (Djodjic et al., 2002; Forsman et al., 2003; De et al., 2004), are available. As reviewed by Karmakar et al. (2007) DSSs for manure management are available but most of them are addressed to the nutrient management in the agronomic planning with regard only to timing, amount and spreading method (De et al., 2004; De and Bezuglov, 2007). Only few DSSs consider the whole-farm manure management from the production to the land application providing support towards the choice of the more suitable option. Among these Karmakar et al. (2010) developed a specific DSS for swine farms of the Canadian Praires region: multiple combinations of management options can be evaluated considering different decision criteria such as environmental, agronomic, social and health, greenhouse gas emission, and economic factors, whilst the software MLCONE4 (Ogilvie et al., 2000) allows to evaluate manure-handling systems of a greater number of livestock types (i.e. swine, dairy and poultry) and it was specifically designed for Ontario Province's conditions. Similarly, Sørensen et al. (2003) developed a model to evaluate different manure handling systems for pig and dairy farms.

The use of DSSs considering manure management in a whole-farm perspective becomes a priority in areas with nutrient surplus and where farmers should define optimal strategies to reduce environmental impact following instructions from agricultural policies and regulations at a sustainable cost. In fact, in these conditions solutions often include the implementation of treatment technologies to remove nutrient surplus that entails high investment and operating costs. A good example of this condition is represented by the plain area of the Lombardy Region (northern Italy) in which the Government have developed necessary legislation including implementation of the requirements of Nitrates (91/676/EEC) and Water Framework (2000/60/EC) Directives and of Italian Regulations (Ministerial Decree of 19 April 1999 approving the Code of good agricultural practices and that of 7 April 2006 regarding criteria for manure management) into regional legislation. Specific Action Programmes for nitrate and non-nitrate vulnerable zones (D.g.r. VIII/5868/2007 and D.g.r. IX/2208/2011) together with several measures funded through the Rural Development Programme (RDP) have been implemented to control nutrient pollution of water from agricultural sources. Moreover from 2011 is in force the nitrate derogation (EC, 2011) for which eligible farmers who want to get its benefit have to respect some requirements about manure and land management.

This territory in which the nitrate vulnerable zones represent 62% of utilised agricultural area is characterised by an intensively managed agriculture with high livestock density accounting for a big part of the Italian livestock, in particular more than 27% of cattle and 51% of pigs. Recent studies confirmed the potential impacts of the agricultural and livestock activities. Fumagalli et al. (2011 and 2012) highlighted the high use of production factors such as N, fossil energy and plant protection products to sustain animal and crop productions. Perego et al. (2012) reported how the intensive maize-based cropping systems based on the use of organic and inorganic fertilisers could determine high risk of nitrate pollution as well as Carozzi et al. (2012 and 2013a, b) showed how alternative low-ammonia emission techniques have to be prescribed during manure distribution on fields. Provolo et al. (2005) showed the negative environmental impact of some manure management systems by mapping some indicator results such as the livestock manure production, the ratio between nutrients brought to the land and the uptake of the crop and the amount of N applied per hectare.

The awareness of the environmental concerns related to livestock activities with whole-farm perspective led to the development of a DSS able to provide the stakeholders, such as policy makers, farmers and their consultants, with an assessment tool to evaluate the introduction of different livestock manure management systems. The design and evaluation of different scenarios could allow the identification of the best management which could be characterized by available techniques and technologies.

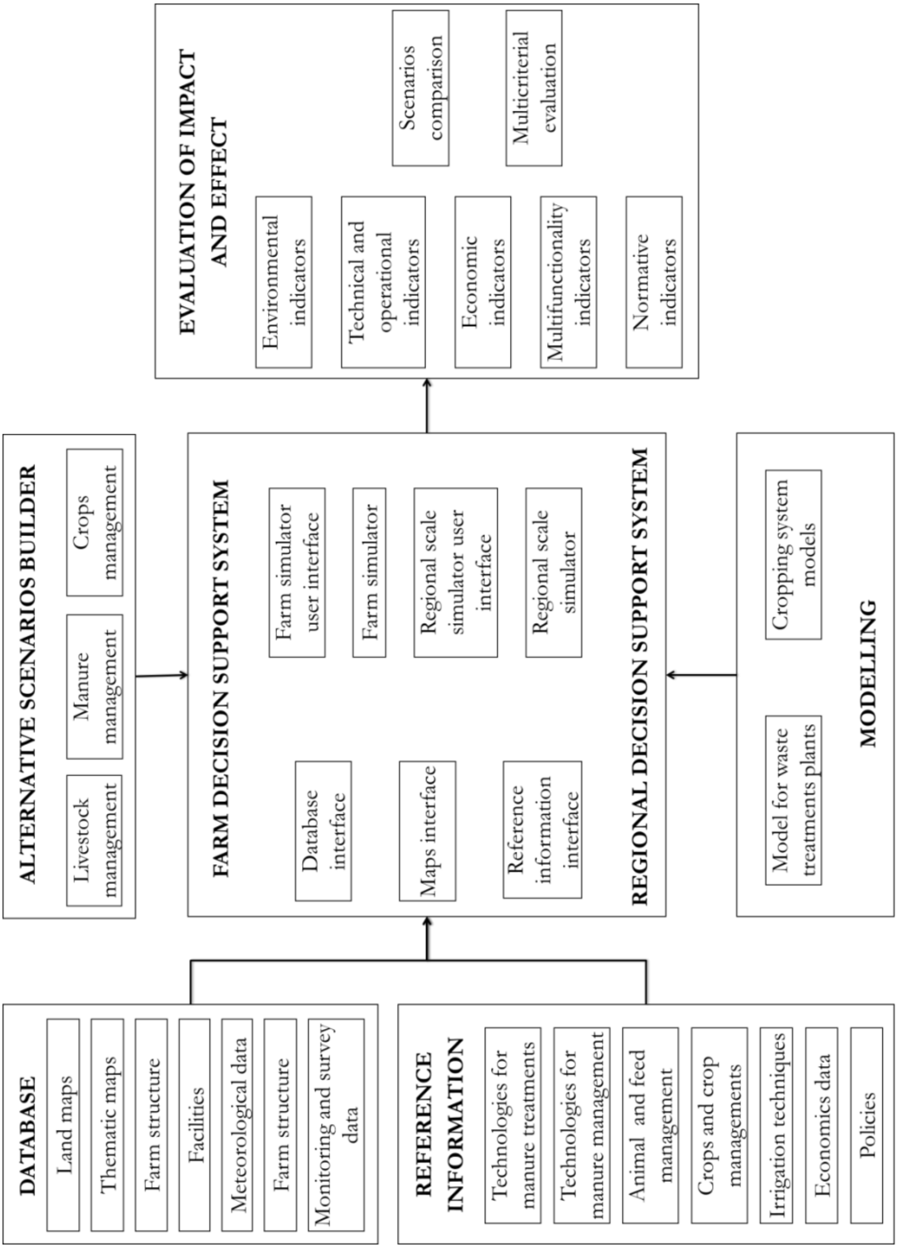
An integrated decision support system is here presented to be used in the Lombardy region to address all the major components of manure management (production, storage, treatment and land application) for a variety of livestock types. It was developed on the basis of the previous experience carried out by Provolo et al. (2005) who evaluated different livestock manure managements. The DSS allows an integrated assessment at farm and territorial scale using two different tools aimed at two different stakeholders.

The objective of this work is to present the DSS ValorE, which helps stakeholders (i) to find the best option for minimising the risk of environmental pollution (mainly N), (ii) improving the value of manure from different livestock in environmental, technical, agronomic and economic terms, (iii) planning manure treatment plants, and (iv) evaluating the effects of new technologies on farm management as well as checking, *ante factum*, possible impacts of new policies.

2.3. ValorE: a DSS to enhance livestock manure management

ValorE (Valorisation of Effluents) is a user-friendly software developed to cope with different livestock (i.e. cattle, swine, poultry, sheep, goats and horses) and to suggest and analyse alternative manure management options at farm and territorial scale. Such DSS consists of three main components: data management subsystem, model management subsystem and user-interface. A simple representation of the DSS structure is reported in Figure 2.3.1. Several external databases are directly linked and periodically interrogated in order to supply the DSS database management system with the relevant input, while a software tool developed in the .NET environment and implemented using object oriented programming (OOP - C# language), provides the logic to manage the scenario simulation linking agronomic and environmental farm-scale models. The two interfaces allow managing the simulation at farm and territorial scale respectively. The territorial interface is a web portal connected to a WebGIS (geographical information system) handling the spatially distributed inputs and outputs of the DSS. All the maps and tables produced by the software are in Italian language since an English version has not yet been released.

Figure 2.3.1. Schema showing the general structure of the ValorE DSS.



2.3.1. Databases and reference information

All information needed to run the system are stored on databases provided by the Lombardy Regional Government. Such data include (i) farm structure, (ii) meteorological data at daily time step, and (iii) pedological characterization of the whole region.

Another database created by the team group contains several tables of default data called thereafter "reference tables".

Farm structure

The database of the Agricultural Informative System of Lombardia Region (SIARL) contains data related to the farm structure for the whole region. All information are periodically updated by farmers. In particular, farmers have to provide details about the regulatory compliance on the matter of N management (Provolo, 2005). This database collects information of 87% of farms surveyed by the Italian institute of statistics during the 6th Agricultural census launched in 2010. The database includes information on distribution of the herd according to animal age categories, animals housing, manure and slurry storage and treatment. Moreover, land use data of every cadastral plot are stored for each farm providing information on the area allocated to the different crops over the years.

Meteorological database

The Lombardia Region has made available twenty-year time series of daily meteorological data such as maximum and minimum temperature (°C) and precipitation (mm) in 14 stations representative of the regional climate zones.

Soil data

A vectorial soil map at scale 1:50000 is available, where 1038 soilscapes are defined and characterised by at least one soil profile. Soil physical and chemical properties, such as texture, structure, organic matter, pH, soil cation exchange capacity, derived from field and laboratory analysis are available for each horizon of the soil profile down to 2 m depth. The soils are classified according to the WRB classification (FAO, 1998).

Technological and agronomic management data

Only a part of the information needed to run the DSS is directly available from the SIARL database (Regione Lombardia, 2010), therefore another database containing five reference tables of default data was produced. Default data derived from existing literature, experts knowledge and farmers' interviews are:

- the technique, functional and economic features of available technologies used for the manure treatment;
- the animals ration for various livestock categories in terms of protein and phosphorous content;
- the main crops grown in the regional arable land and the related agronomic management, such as sowing and harvesting time, organic and mineral N supply;
- the irrigation techniques, the frequency and the water volumes typical of the different areas of the region;
- the current regulation on the matter of (i) Nitrate Vulnerable Zones definition, (ii) allowed timing of manure application, (iii) restriction on manure fertilisation in particular areas such as riparian zones and protected areas, (iv) guidance for manure incorporation (Regione Lombardia, 2007).

2.3.2.DSS development

The DSS has to meet a series of requirements to be useful for different kind of stakeholders (e.g. farmers and their consultants, Public Authorities, producers organizations, scientists etc.) and for an easy updating and maintenance. The territorial part of the DSS is a web portal, whereas the farm simulator can be installed and run on any computer running windows XP OS or later versions without specific hardware requirement. Moreover, the development of an easy way of operating was a main objective (no more than 5 clicks to get to a complete analysis following the suggestion of the "three click rule" for user friendly and more impactful web design) with report simulation results either in maps and tabular form.

The intended purpose of the software is to simulate at farm scale each stage of livestock excreta cycle from production by the herd to the crop N uptake as well as the N cycle and losses occurring via leaching, and gaseous emission (volatilization and denitrification). Figure 2.3.2 shows the simulated N flows at farm level.

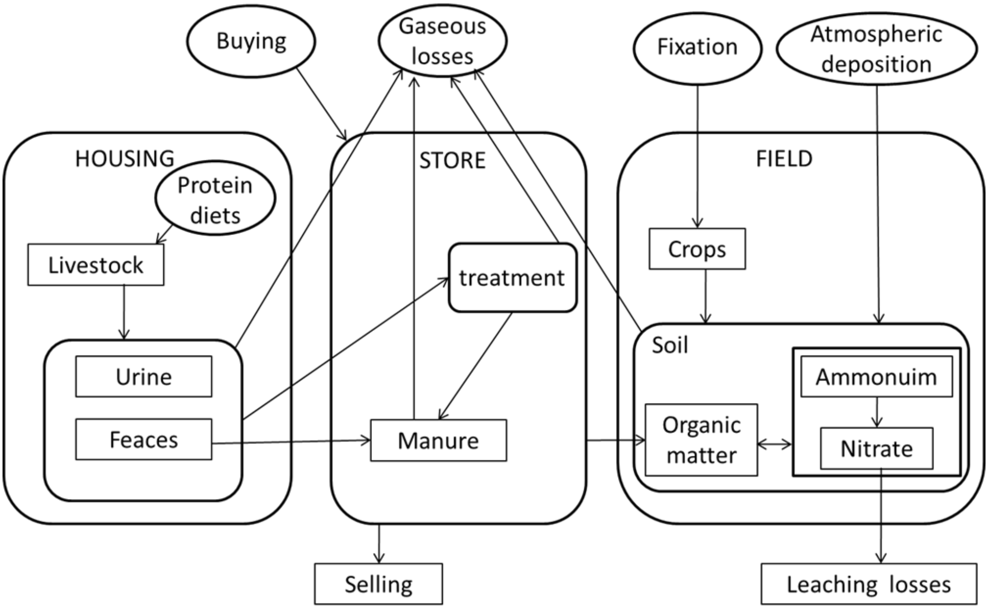


Figure 2.3.2. Schema showing the simulated nitrogen flows at farm level (modified from Bertsen et al., 2003).

The software consists of different modular components relating a specific stage of the manure production process. Each component allows for selection of strategies to simulate a specific process and each module results represent the input data for the subsequent one (Figure 2.3.3).

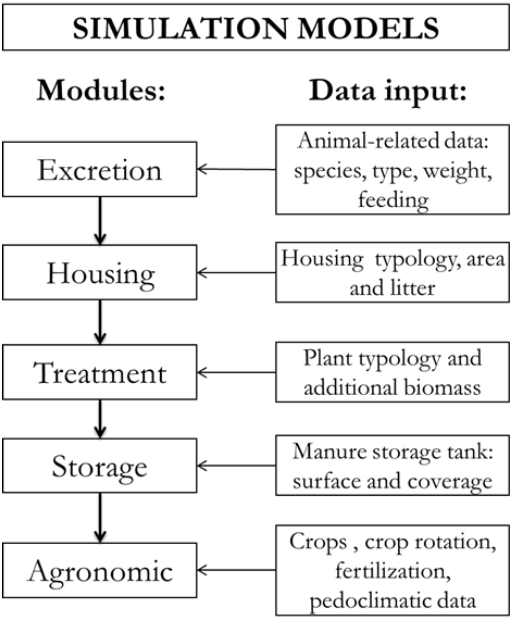


Figure 2.3.3. Modular component of the DSS relating to each specific stage of the manure production processes. Each module implements its specific simulation model.

2.3.2.1. Excretion module

In order to evaluate the impact of the different livestock rations on urine and faeces produced by cattle and swine, the excretion of N and P content is simulated as a function of feed intake and animal performance. In this analysis, dairy cattle, beef and pigs farms are considered as the main source of production of slurry in Lombardy.

With regard to cattle, the model allows estimating separately for urine and faeces, the amount of N and P excreted by quantifying the amount of manure. Instead, the amount of K excreted is estimated as a fixed percentage of live weight, as recommended by existing legislation. For dairy cattle, the excretion is computed by a sub-model from the following input variables: (i) the body weight of lactating dairy cows, dry cows, heifers and calves (ii) the milk production level, (iii) the milk fat and protein content, (iv) the dry matter intake, (v) and the protein content of feed. In particular, the dry matter intake is calculated by using the equation proposed by the National Research Council of USA (2001). The model produces the following output data: (i) the excreted products as fresh matter (kg FM d^{-1}), calculated according to Nennich et al. (2005), (ii) urine and its N content (kg d^{-1}), calculated according to Fox et al. (2004), (iii) the amount of faeces, calculated as difference between the total excreted products and urine (kg d^{-1}), (iv) the N faeces content and, v) the milk N content (kg d^{-1}).

The model developed for pigs estimate the excreted amount of N, P and K according to several studies (Pomar et al., 1991a; Pomar et al., 1991b; Pomar et al., 1991c; Le Bellego at al., 2001; van Milgen et al., 2003). In particular, the estimate is carried out for physiological stages of growth and production of the animal. The model quantifies the feed intake based on the animal growth (kg d^{-1}) and feed conversion efficiency for the considered growing phases and for number of farrows and litters size for the sow. The nitrogen, P and K intakes (kg d^{-1}) are estimated based on feed intake (kg d^{-1}) and diet contents, while excretions are determined from diet and protein digestibility and mineral absorption (%) for the considered physiological stages. The model allows to calculate the manure production (i.e. dry matter and volume) and the N, P and K excretion in faeces and urine. For other animal species such as poultry, sheep, goats and horses, the excretion is estimated as a fixed percentage of live weight, as recommended by existing legislation (Regione Lombardia, 2007).

2.3.2.2. **Housing, treatment and storage modules**

Slurry is subjected to chemical and physical modifications with relative gaseous losses to the atmosphere. For each stage of the storage and treatment process the module simulates the amount of slurry mass and its N, P and K content together with the investment and operating net costs of any joint production (energy, compost, fertilisers etc.). Moreover, it allows the assessment of the feasibility and suitability of alternative techniques in plant management.

The input data of the slurry storage and treatment module are: (i) the chemical and physical composition of the excreted products expressed as kg of dry matter, kg FM, faeces TKN (Total Kjeldhal nitrogen) content, urine TKN and P_2O_5 content in faeces and urine), (ii) the litter fraction of the manure, and (iii) the rainfall. The effect of the typology of livestock housing and the effect of different types of slurry storage are simulated according to IPCC (2006) and EEA (2009), considering also the experience of Amon et al. (2006) and Webb and Misselbrook (2004). A wide range of treatments is considered in the module: solid-liquid separation (Dinuccio, et al., 2008; Cocolo et al., 2012), anaerobic digestion with biogas and energy production (Amon et al., 2007; Biswas et al., 2007), ammonia stripping (Bonmatì and Flotats, 2003), nitrification and denitrification (Rousseau et al., 2008), aerobic stabilization (Loyon et al., 2006; Beline et al., 2007) and composting (Paillat et al., 2005; Szanto et al., 2007).

The slurry module calculates: (i) the final volume of the stored slurry, (ii) the final chemical and physical composition, (iii) the solid and liquid fraction, (iv) the gaseous losses to the atmosphere, and (v) the possible production of biogas for the anaerobic digestion plants and other joint products of treatments.

Economic aspects are involved in the estimation of the weight of manure management options on farm income, since it has been recognized the importance of cross compliance on the economy of agricultural sector (Bezlepkina et al., 2008; De Roest et al., 2011). For each phase of managing slurry and manure (housing type, treatments, storage, distribution), the module calculates investment and operating costs (Berglund and Börjesson, 2006; Gourmelen and Rieu, 2006). For the housing systems, while the investment cost is related to the cost of construction (e.g. raw material, facilities) the operating cost depends on bedding materials, energy consumption and cost of facilities maintenance and labour. In the case of manure storage and its cover and of plant for manure treatment the investment cost is mainly calculated as a function of specific technical parameters, namely the treated volume and the power required. For all treatment modules, the operating cost is related to energy consumption, raw materials, facilities maintenance and labour cost. The cost of manure distribution is a function of transported volumes and distance from farm to field. Operating costs are broken down into monetary costs and non cash charges, so that it is possible to draw cash flow and analyse the investment in term of net present value and internal interest rate. . The annual manure management cost considers the operating cost and amortization cost related to the economic life of facilities and structures (6, 8, 10 and 15 years).

2.3.2.3. **Agronomic module**

The agronomic module is based on the crop simulation model, ARMOSA (Perego et al., 2013a, b), but they do not exactly coincide because the efficacy of process-based models at large scale is questionable due to the long computational times and the parameterization constrains required. Therefore, a meta-model was developed, providing comparable results as the original model but a lower computational effort (Forsman et al., 2003), to ensure the quality of estimation while increasing the simulation speed.

The cropping system model ARMOSA

ARMOSA model simulates crop growth, water and N dynamics in arable land, under different climatic conditions, crops and management practices. It is a simulation model specifically developed on the basis of field data and it implements approaches largely validated in the scientific literature and used for practical applications. Crop growth model development is based on SUCROS – WOFOST (Supit et al., 1994; van Ittersum et al., 2003). Water dynamics are simulated using the cascading approach, or the Richards’ equation, solved as in the SWAP model (Van Dam et al., 2008); that model was previously calibrated under maize-based systems in Lombardy plain Bonfante et al.; 2010, Perego et al., 2012). Nitrogen dynamics is simulated according to the SOILN approach (Johnsson et al., 1987; Eckersten et al., 1996), but with some improvements. In SOILN only three pools of organic and mineral N are simulated: humus, litter, manure, while in ARMOSA each type of organic matter has been differentiated with reference to mineralisation rates, respiration losses and C/N ratio, allowing for separate calculations for the different types of organic fertilisers or crop residuals incorporated into the soil. Depth of incorporation is also taken in account and NH_4 and NO_3 pools are considered. NH_4 pool can be up taken by plants, oxidised to NO_3, fixed by the clay component of the soil, and immobilised in the organic matter; losses due to ammonia volatilisation are also simulated. NO_3 pool is subject to plant uptake, leaching and denitrification. Several options to use for medium-long time simulation are included: it is possible to define sowing and harvest date, crop rotation, automatic irrigation, set of fertilisation. The crop uptake is calculated on the basis of minimum, critical and maximum N dilution curves. Soil temperature is simulated considering the approach of Campbell (1985). ARMOSA model was calibrated and validated using a large dataset consisting of 3500 SWC daily data of soil profile (0.8-1.3 m depth), soil solution N concentrations, N leaching, N uptake and crop growth data (Perego et al., 2012).

The agronomic meta-model

The need to operate on a territorial scale involves the use of the meta-model, developed on the basis of the ARMOSA model. Such procedure represents an easy approach, quick in generating results of N losses and crop yields under different cropping systems, management and pedo-climatic conditions. The meta-model was developed on the basis of the examples provided by the literature (Forsman et al., 2003; Galelli et al., 2010). It was set up starting from the results of 70.000 simulation under different scenarios of cropping systems in the Lombardy. In particular, the agricultural management was defined as a function of the farm type and the pedoclimatic conditions of the region. Such different pedoclimatic conditions were identified using a cluster analysis as a function of median soil particles diameter, stone and organic carbon content along soil profile of 2 m depth. The meta-model development involved the sensitivity analysis (Morris, 1991; Saltelli et al., 2005) of the input variables on the ARMOSA output in order to finally reduce the input data. The output of the meta-model, which resulted by ARMOSA outputs, are: crop yield (t ha^{-1}), N leaching (kg ha^{-1} year^{-1}), crop N uptake and removal (kg ha^{-1} year^{-1}), water percolation (mm year^{-1}), N mineralization (kg ha^{-1} year^{-1}), ammonia N volatilization (kg ha^{-1} year^{-1}), denitrification (kg ha^{-1} year^{-1}), soil N fixation (kg ha^{-1} year^{-1}). For different crops, such as silage maize and grain maize (*Zea mayze* L.), winter wheat (*Triticum aestivum* L.), alfalfa (*Medicago sativa* L.), permanent meadow, foxtail millet (*Setaria italica* L.), and Italian ryegrass (*Lolium multiflorum* L.), a multiple linear regression was calculated applying the stepwise method in order to identify the significant factors in determining the model outputs with average R^2 of 0.82. In Figure 2.3.4 the development of the agronomic meta-model is displayed and the R^2 of the multiple linear regression for each variable are reported.

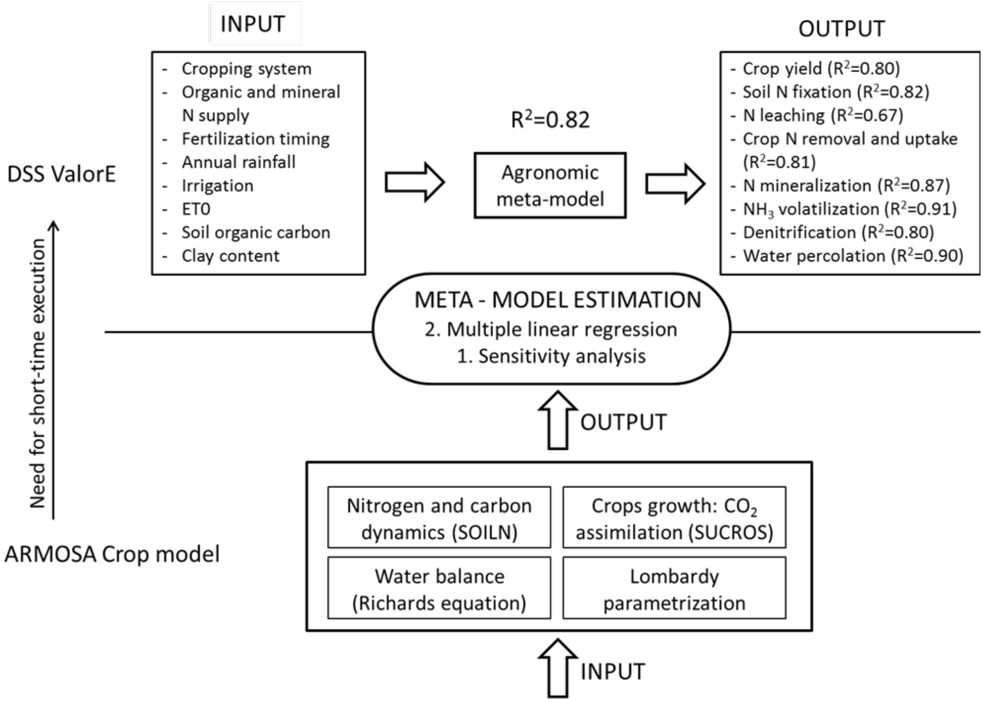


Figure 2.3.4. Schema showing the development of the agronomic meta-model from the biophysical model ARMOSA.

2.3.3.Farm and territorial simulations

The above model structure was implemented in a software module that manages the inputs provided by the external databases and by the user and consequently activates each model in cascade. It works at farm level so outputs can be used in the farm simulator or aggregated at different scale in the territorial simulator.

The farm simulator is aimed at farmers and their consultants and it allows to analyse in detail the management and technological alternatives available for the specific farm from the manure production as a function of animal diet, to its final distribution on field. The more sustainable farm management strategies are suggested to reduce environmental impact (mainly N feature) and to better use the livestock manure. The software is downloadable from the website of the Lombardy Region, which collects the data of the structure and management of farms in the regional database.

The territorial scale interface gives the possibility to investigate the current situation of the farms management practices in the whole Lombardy region by means of a set of default or custom queries. Then, the effects of the hypothetical implementation of alternative managements and the impact of any regulatory measure and/or incentive is analysed in a scenario simulator. The DSS considers different changes in the management of the investigated farms, such as updates of new technologies, new crops or agricultural practices or future scenarios of meteorological data. It compares scenarios through synthetic indicators that take into account environmental, economic, technical, multifunctional and normative aspects. The territorial simulator, available to regional and public authorities at request, works at a larger spatial scale and it is completely resident on web.

To improve the usability of the software, particular effort was devoted to enhance data retrieving performance from the databases and model calculation speed. Moreover, both interfaces were developed to be intuitive, requiring a short training time for learning main commands and sequences of actions.

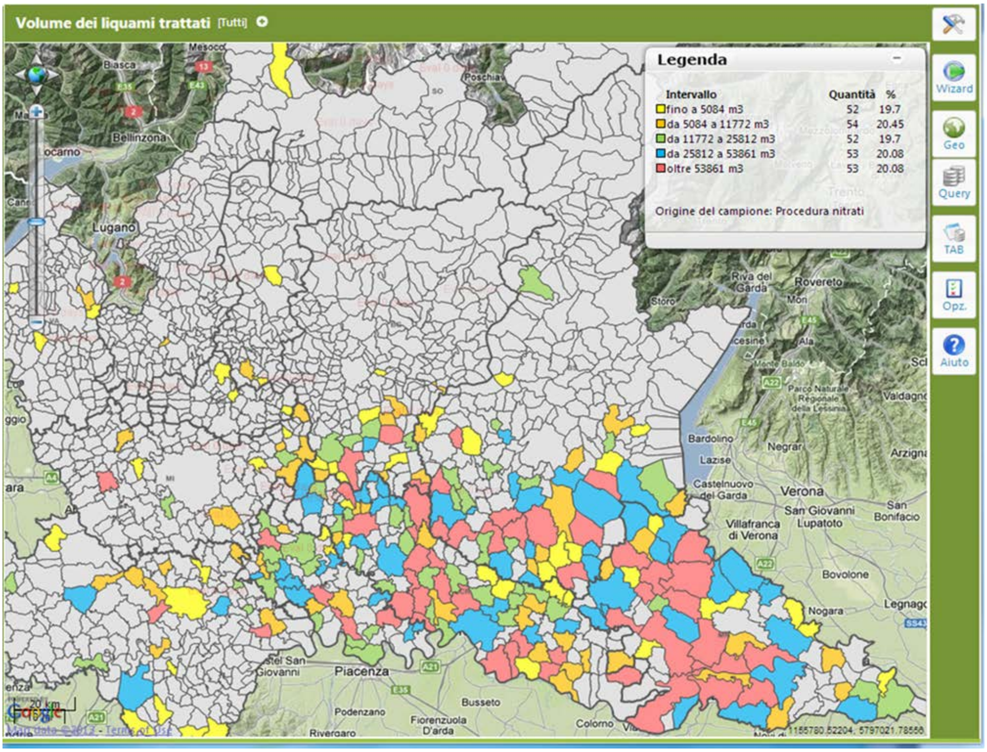
2.4. **Tasks of the DSS ValorE**

In order to carry out comparative analysis, the software offers the possibility to analyze the current perspective in terms of manure management system at farm or territorial scale by interrogating the available databases. Then, it is possible to modify the farm management by generating different alternative scenarios both at farm and territorial scale thanks to an extensive choice of options. Changes can be focused on manure management system and on cropping system features. Current and alternative scenarios sustainability can be evaluated and compared through indicators. Moreover a specific tool of the DSS allows the investigation of effects due to policy measures.

2.4.1. Query task

The territorial scale software can be used as a tool for easy interrogation of regional databases. Default and custom queries can be executed and the results are available in form of maps and exportable reports (Excel or PDF format).

The query system is based on a WebGis interface, to help users to obtain aggregated information for specific geographic areas (e.g. whole region, provinces, municipalities, farms etc..). The query procedure involves at first, the selection of the aggregation level (e.g. farm, municipality and province) and, secondly, the selection of the geographic area of interest (e.g. one or more municipalities). Default and custom queries are related to several domains: animals herd, animal housing, manure storage, manure treatments, cropping systems, economical and mechanisation aspects, policies aspects (e.g. normative compliance of slurry storages) and pedo-climatic characteristics. An example of a custom query is reported in Figure 2.4.1. The default query option provides a set of about 40 queries previously selected as relevant by a group of experts and stakeholders. Users can however change the parameterization of the query itself (e.g. selection criteria of several queries could be the agricultural utilisable area of the farm, the number of the livestock units, the typology of housing, the soil type etc.).



Legenda

Intervallo	Quantità	%
🟨 fino a 5084 m3	52	19.7
🟧 da 5084 a 11772 m3	54	20.45
🟩 da 11772 a 25812 m3	52	19.7
🟦 da 25812 a 53861 m3	53	20.08
🟥 oltre 53861 m3	53	20.08

Origine del campione: Procedura nitrati

Figure 2.4.1. Example of custom query operated on regional database using ValorE software: annual volume (m^3) of treated liquid manure (volume dei liquidi trattati) on the farms of each municipality. Results are aggregated at municipality scale (in the legend: Quantità: quantity; fino=up to; da= from; a= to; oltre= more than; origine del campione: procedura nitrati = sample origin: nitrate procedure directive). Municipalities without manure treatment plants are not marked with color.

2.4.2.Alternative scenarios generator

The user can also quickly generate many different alternative scenarios by choosing options related to animal housing systems, storage facilities, manure treatment and land application methods and by modifying crop rotations..

The farm simulator allows creating management options at farm scale by modifying several inputs, such as i) number of LSU (Livestock Standard Units), protein content in animal ration and daily weight gain (kg d^{-1}), ii) livestock housing (e.g. straw based or slurry based tying stalls), iii) slurry treatment (solid-liquid separation, anaerobic digestion with biogas and energy production, ammonia stripping, nitro-denitro process, aerobic stabilization and composting), iv) manure storage features (i.e. storage and covering types), v) type and timing of manure application, vi) cropping systems (e.g. changes in the crops rotation by introducing new crops and cover crops) and vii) fertiliser management on the basis of calculated fertilisation plan. To assist the choice of the users all the manure treatment options are detailed through predefined flowcharts.

New scenarios at territorial scale can be generated with the WebGIS interface by introducing alternative agricultural management for a sample of farms into a selected area. The territorial simulator allows defining alternative management only relative to four domains such as animal housing, manure treatment, storage facilities and cropping systems. In the case of cropping system and manure treatment domains users can select the management options such as, the method of manure distribution, the introduction of a cover crop and several manure treatments (e.g. solid-liquid separation, biogas production etc..). To simplify the stakeholders analysis, in the case of animal housing and manure storage domains, users can firstly choose the aim (i.e. the reduction of the manure amount or the ammonia emission) getting from the DSS different management options proposal. Scenarios evaluation at selected scale is obtained by aggregation of farms sample results. The ways in which users can operate about the different components of the manure management and the cropping systems at farm and regional scales, are summarized in Table 2.4.1. The software control ensures that adopted management is in agreement with current regulation and farm characteristics. For example, a particular type of treatment requires a minimum volume of manure to be considered functional or the crude protein content of the diet has to be included in a default range of values.

Table 2.4.1. Summary of how the users could generate alternative scenarios.

	Farm simulator	Regional simulator
	User opportunity	
Manure management component		
Livestock excretion	Change of the LSU, change of the protein content of the animal ration, change of the milk or meat yield and change of the live weight daily increase	
Livestock housing	Choice of the bedding and stable types for each animal age category	Choice of the aim: to reduce manure amount or ammonia emission
Treatment	Choice of the predefined alternative as a composition of manure treatments with a specific objective or design of the new alternative	Choice of the predefined alternative as a composition of manure treatments with a specific objective
Storage	Add new storage, choice of the covering type, choice to buy or sell manure	Choice of the aim: to reduce manure amount or ammonia emission
Land application	Change of the type and timing of application	Change of the type of application
Cropping system	Introduction of a new crop or cover crop and adoption of NMP	Introduction of a cover crop

LSU: livestock standard units; NMP: nitrogen management plan

2.4.3.Indicators

The evaluation of current and alternative scenarios and their comparison are computed through different indicators. They can be considered as a synthetic representation of the consequences on technical, agronomic, environmental, energetic, social and economic aspects brought by the adoption of a particular management. The major part of these indicators is quantitative, however, some of them, are expressed in a qualitative scale as bad, fair, good, excellent. The complete list of indicators is reported in Table 2.4.2.

Several indicators are related to agro-environmental aspects such as (i) CO_2, CH_4, NH_3, N_2O gaseous emissions to the atmosphere, (ii) crop prevalence at farm or regional scale (Crop Diversity Indicator, CDI, Bockstaller, 2000), which estimates cropping systems impact on biodiversity and landscape in terms of crops allocation and field size, (iii) soil surface N balance (Oenema et al., 2003), that compares the difference between in-going and out-going N fluxes through the soil surface, and (iv) agricultural nitrate hazard index (IPNOA, Capri et al., 2009) which summarizes the results of N supply, soil nitrogen content, meteorological condition, agricultural practices and irrigation adopted.

Each manure management plant is described by technical indicators, such as power required and energetic consumption and by economic indicators, which describe the operating costs. For new plants the investment costs and, in case of biogas production, the economic revenues are also estimated. The economic performance of the farm at cropping system level is defined via the variable costs sustained for the crop production and the relative value of production.

Regulatory indicators assess the compliance of a farm and/or a sample of farms to mandatory standards related to N and manure management to prevent the risk of N pollution.

To complete the assessment of the scenarios, multi-functional indicators are used to estimate the value of the human perception related to the impact of the manure management techniques on the area outside the farms. In addition, possible changes in crop rotation can influence the value of the indicator that qualitatively classifies the landscape based on crop types cultivated.

All indicators describing the current scenario (at farm scale) are already calculated for the entire regional area and stored in a database to reduce the computational time in what-if analysis.

Table 2.4.2. Indicators calculated and used for the evaluation of sustainability of the manure management options.

Agro-ecological indicators	Units	Reference
NH_3-N volatilization	kg N year^{-1}	EEA (2009)
N_2O-N emission	kg N year^{-1}	EEA (2009)
CO_2 emission	kg N year^{-1}	EEA (2009)
CH_4 emission	kg N year^{-1}	EEA (2009)
NO_3-N leaching	kg N year^{-1}	EEC (1991)
P_2O_5 erosion	kg P year^{-1}	Renard et al. (1997)
Soil surface N balance	kg N year^{-1}	Oenema et al. (2003)
IPNOA	Score from 1 (low risk) to 6 (high risk)	Capri et al. (2009)
Crop diversity indicator	Score from 0 (worst case) to 10 (best case)	Bockstaller and Girardin (2000)
Technical indicators		
Power installed	kW	EEA, Renewable gross final energy consumption (ENER 028) - Assessment published Jan 2011
Energy requirement	kWh year^{-1}	
Multi-functional indicators		
Landscape quality	Score from -5 (worst case) to +5 (best case)	Tempesta and Thiene (2006)
Odour emission		ERM (1998)
Visual impact		
Territorial accessibility		
Citizenship feedback		
Regulatory indicators		
Compliance of slurry storage	kg N year^{-1}	Regione Lombardia (2007)
Compliance of N-manure applied	kg N year^{-1}	EEC (1991)
Calculated N balance	kg N year^{-1}	Regione Lombardia (2007)
Economic indicators		
Variable costs	€	Fumagalli et al. (2012)
Value of production	€	Fumagalli et al. (2012)
Investment costs	€	Berglund and Börjesson (2006)
Operating costs	€ year^{-1}	Gourmelen and Rieu (2006)
Revenues from biogas	€ year^{-1}	De Reost et al. (2011)

2.4.4. Multi-criteria analysis

To identify the optimal or compromise solutions, which have to take into account the farming system characteristics, the agronomical, social, environmental and economic objectives as well as the expectations of the stakeholders involved, a subsequent multi-criteria analysis has to be performed on the basis of weighted sum of a subset of indicators. Relevant indicators and their weights are set in a configuration file on the base of a work of a panel of experts. Indicators and weights can be easily modified keeping the software up to date. An on-going work is the implementation of a multi-criteria analysis module based on the MEACROS software (Mazzetto et al., 2003). This software performs concordance analysis providing preference rankings for the alternatives based on computed indices and allowing sensitivity analysis of weighted values as well as displaying the results in a graphic form.

2.5. A case study using the DSS ValorE

The DSS was applied to a selected area with the main objective to evaluate options for reducing the reactive N losses through air and water. The simulation was done using input data from the regional databases updated at 2011 and from reference information obtained from literature and regional regulations. The data sample for the case study were obtained through a custom query. The studied area is represented by nine neighboring municipality localized in the south part of the province of Bergamo. It was chosen because is a nitrates vulnerable area with high organic N load. Within the area, were selected only livestock farms with over 50 ha of utilizable agricultural area (UAA) and that do not respect the limit of 170 kg per year/hectare of N from organic fertilizers. The final sample was composed by 23 farms (20 dairy farms, one swine farm and two with both animals) where maize was the main crop cultivated covering, on average, the 70% of the farms UAA. The UAA of the selected farms represented on average the 32% of that of the own municipality.

None of the farms had a manure treatment plant and covered manure storages. The actual configuration was labeled as "actual scenario" (ACT) while the two hypothetical configurations were labeled as "alternative scenarios" (ALT1) and (ALT2). The scenarios results are present in Table 2.5.1. For ACT, the farms organic N load (Figure 2.5.1) aggregated at municipality level was very high and ranged from 249 to 929 kg ha^{-1} of farms UAA. The first alternative scenario (ALT1) hypothesized involved the implementation on farms of the nitro-denitro treatment plant with removal of nitrogen while the second option considered the construction of a rigid cover for all of the stores available on farm (ALT2). The ALT1 involves that the liquid manure is first separated in a liquid and solid fraction. The liquid fraction enters in the nitro-denitro plant and successively stored in a tank for the final agronomic use. The remaining part is moved to a belt press and stored in covered facility together with the solid fraction obtained from the first separation. This final product could be applied on fields or sold outside farm.

The first positive effect of ALT1 was the strong reduction of the organic N available to be distributed on fields. As reported in Figure 2.5.1 the reduction ranged from 26% to 61% demonstrating that nitro-denitro process is a reliable solution to get compliancy with nitrate directive under derogation limits of 250 kg N ha^{-1} (EC, 2011). Moreover as reported, relevant advantages from an environmental point of view can be obtained: N lost through leaching and volatilization were reduced from 38% to 75% and from 24% to 34%, respectively (Figure 2.5.2). Emissions of CH_4 were strongly reduced as well as the liquid manure volume available to be distributed: this implies lower demands for manure storage capacity, a better control and management of the application of manure as fertilizer and lower odour emissions. The negative consequence is that the fertilization value of manure was halved because of the 50% of N is lost as N_2 to the atmosphere. This implies to review the N fertilization plans for a more N use efficiency. From an economic point of view the expected costs simulated by the software were increased considerably: the investment costs were remarkable varying from 200,000 to 1,6000,000 Euro and the operating costs have grown by almost three times mainly due to the energy requirement by the plant. Overall, the adoption of ALT1 could require a higher organization as it grows the complexity of farm management..

The effectiveness of covering of manure stores was indicated by the reduction of N lost through volatilization process (from - 18% to -36%) and of methane emission (Figure 2.5.3). At the same time a mean reduction of the total liquid manure volume by 7% occurred due to the exclusion of rainfall water from the system. However, since ALT2 involved a mean increase of available N to be applied on field by 9%, compared to ACT, a more accurate nitrogen management at field scale to contain volatilization and N leaching is needed. In fact, the N leaching was expected to increase by 10%. As reported, the necessary investment were lower compared to ALT1 and ranged from 36,000 to 227,000 Euro while operating costs were similar to ACT.

Outcomes obtained from this application suggest that both alternatives could be viable solution to reduce environmental impacts caused by manure management (e.g. N losses), even though investment and operating costs were significant. However, the aids provided by the measure 121 of the current RDP applied in the Lombardy region, could offset the economic investment by 35-40%. The application on an area intensively managed, demonstrated how an intervention planned at territorial level could be a useful solution for the manure management issue. However, this requires a strong collaboration between farmers and industry, with the monitoring and coordination of the institutions which should provide regulations and economic helps.

Table 2.5.1. Indicators result municipality level under the current scenario (ACT) and after the implementation of nitro-denitro plants (ALT1) and the covering of all manure storages (ALT2).

Municipality	Scenario	Organic N load	SSB	N Leaching	N-NH$_3$ Volatilisation	N-N$_2$O emission	CH$_4$ emission	CO$_2$ emission	Phosporous loss	Liquid manure volume	Operating costs	Investment costs	Power requirement
					kg /ha					m^3	€		kwh/ha
Antegnate (BG)	ACT	438.99	299.23	203.32	155.98	2.10	132.70	0.00	44.80	8,734	153,099		982
	ALT1	203.31	116.82	93.67	120.19	4.16	11.11	14.41	41.04	5,951	471,696	759,446	
	ALT2	484.11	345.41	227.32	112.93	2.10	46.69	0.00	45.11	8,191	148,876	87,585	
Barbata (BG)	ACT	521.46	548.76	280.45	214.20	1.73	231.16	0.00	79.61	20,131	255,633		1,387
	ALT1	226.52	368.24	137.58	162.67	4.13	13.08	20.18	71.28	16,053	926,997	1,640,131	
	ALT2	575.71	648.79	311.96	158.44	1.73	113.37	0.00	79.77	18,863	244,816	163,248	
Calcio (BG)	ACT	483.25	369.69	189.27	183.99	0.87	204.08	0.00	71.96	29,640	274,434		1,432
	ALT1	189.13	112.24	79.82	139.74	3.00	9.27	18.81	68.91	18,615	1,161,216	2,410,975	
	ALT2	541.56	416.14	212.97	123.66	0.87	68.45	0.00	72.51	28,527	266,082	227,035	
Covo (BG)	ACT	412.15	269.61	218.43	151.54	1.89	122.05	0.00	53.46	7,442	134,746		1,096
	ALT1	216.13	128.84	107.14	114.28	2.64	6.69	13.19	48.99	5,066	426,545	753,842	
	ALT2	451.75	303.56	242.86	110.15	1.89	42.82	0.00	53.96	7,015	131,377	80,773	
Fontanella (BG)	ACT	376.33	410.63	198.86	131.38	3.21	98.18	0.00	124.83	10,157	200,380		1,212
	ALT1	204.79	232.47	124.35	111.68	4.90	10.70	10.74	119.57	6,068	573,648	837,556	
	ALT2	409.38	442.66	215.38	95.12	3.21	36.14	0.00	125.40	10,080	198,861	91,532	
Isso (BG)	ACT	602.34	378.65	268.94	202.25	3.92	178.97	0.00	64.84	10,272	180,912		2,456
	ALT1	314.81	259.39	82.65	152.11	6.59	16.20	19.06	67.73	7,169	571,016	915,431	
	ALT2	657.76	573.44	315.47	147.79	3.92	63.88	0.00	63.49	9,748	176,509	106,807	
Pumenengo (BG)	ACT	249.20	226.26	138.56	65.88	3.44	27.84	0.00	100.40	1,652	54,618		265
	ALT1	185.65	172.91	137.23	60.40	3.98	7.85	4.88	100.32	1,385	138,709	226,260	
	ALT2	260.92	247.30	138.81	54.29	3.44	13.59	0.00	100.41	1,446	52,890	28,189	
Romano di Lombardia (BG)	ACT	928.92	774.61	173.11	267.68	3.78	282.30	0.00	52.55	7,485	104,253		4,048
	ALT1	408.10	275.50	77.63	209.78	8.21	23.47	26.11	53.45	4,143	311,326	400,624	
	ALT2	1027.11	857.29	192.58	171.98	3.78	98.95	0.00	54.54	7,171	101,756	36,240	
Torre Pallavicina (BG)	ACT	423.32	863.05	179.20	150.97	3.05	9.16	0.00	81.99	5,592	87,603		483
	ALT1	220.04	778.36	97.70	116.17	4.92	2.86	15.53	75.39	3,824	292,674	435,596	
	ALT2	463.45	979.73	196.53	111.61	3.05	4.62	0.00	83.01	4,610	79,355	50,425	

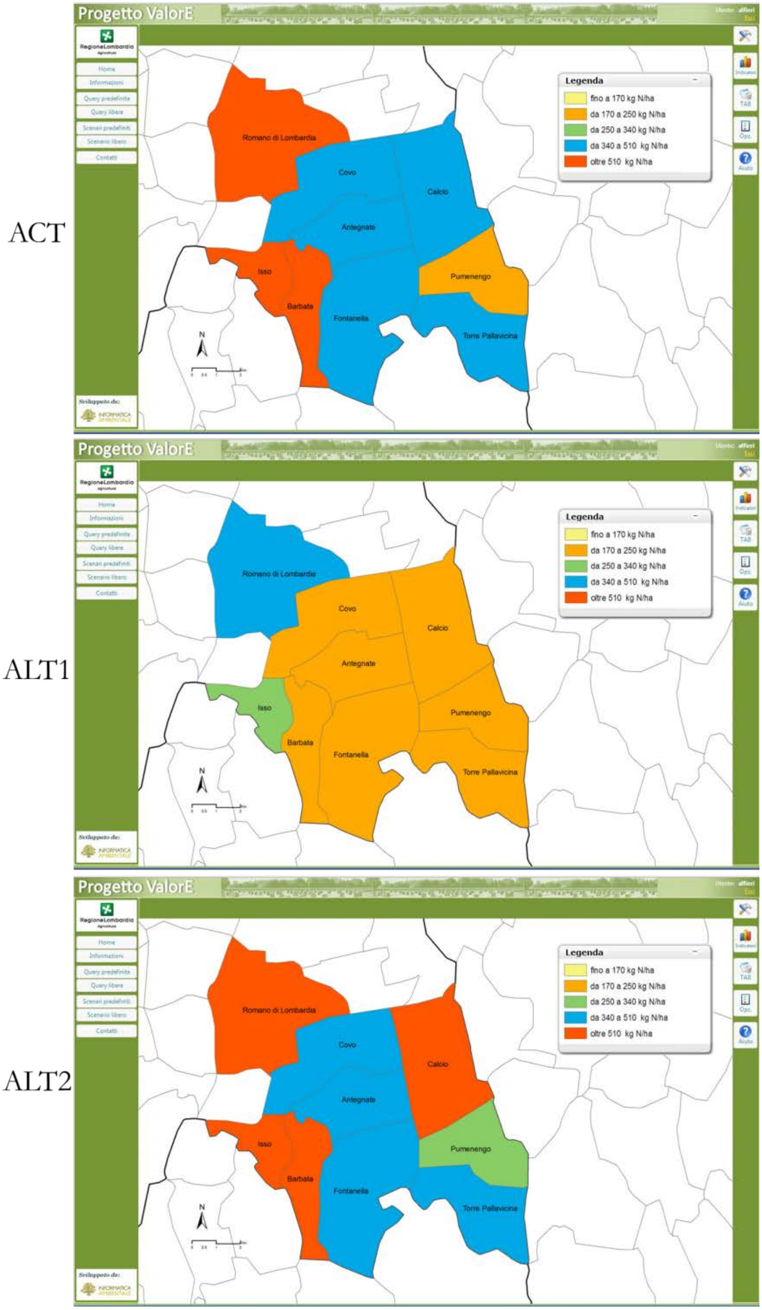


Figure 2.5.1. Mean organic N load (kg ha^{-1}) aggregated at municipality level under the current scenario (ACT) and after the implementation of nitro-denitro plants (ALT1) and the covering of all manure storages (ALT2).

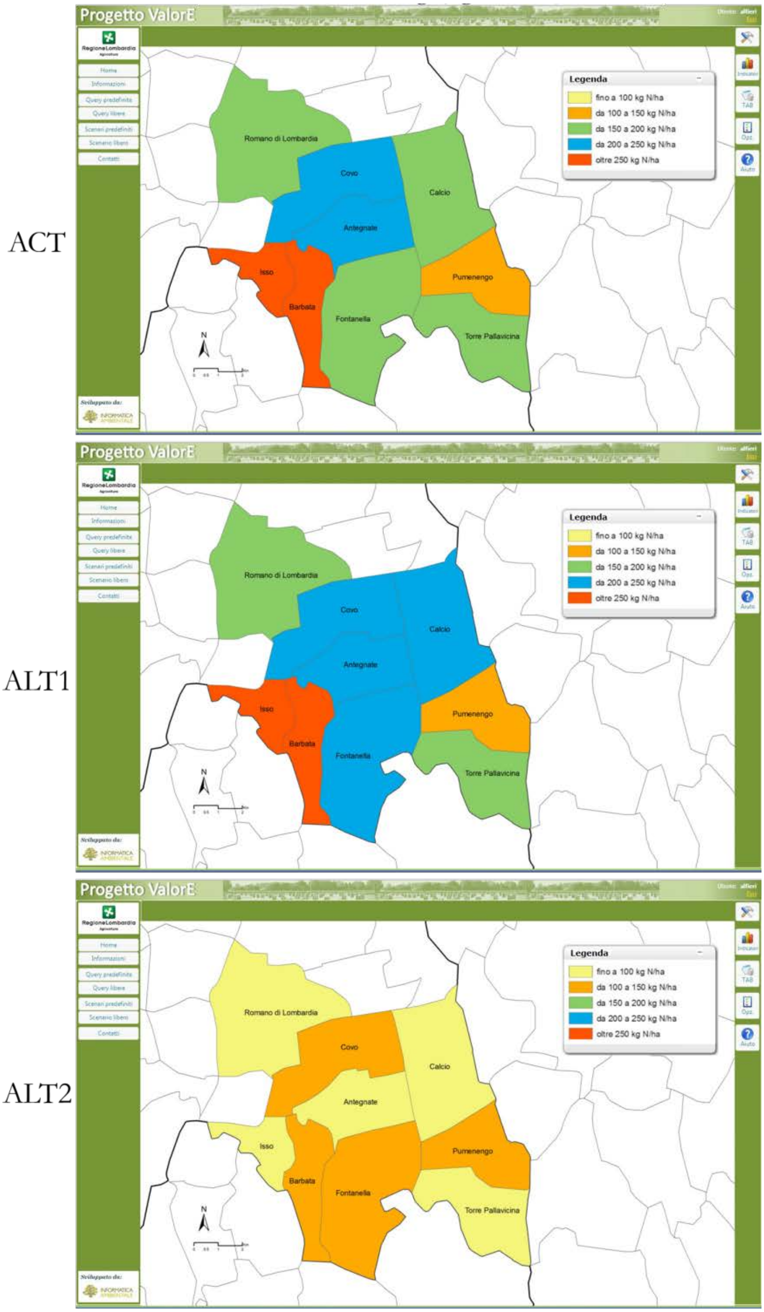


Figure 2.5.2. N leaching (kg ha^{-1}) aggregated at municipality level under the current scenario (ACT) and after the implementation of nitro-denitro plants (ALT1) and the covering of all manure storages (ALT2).

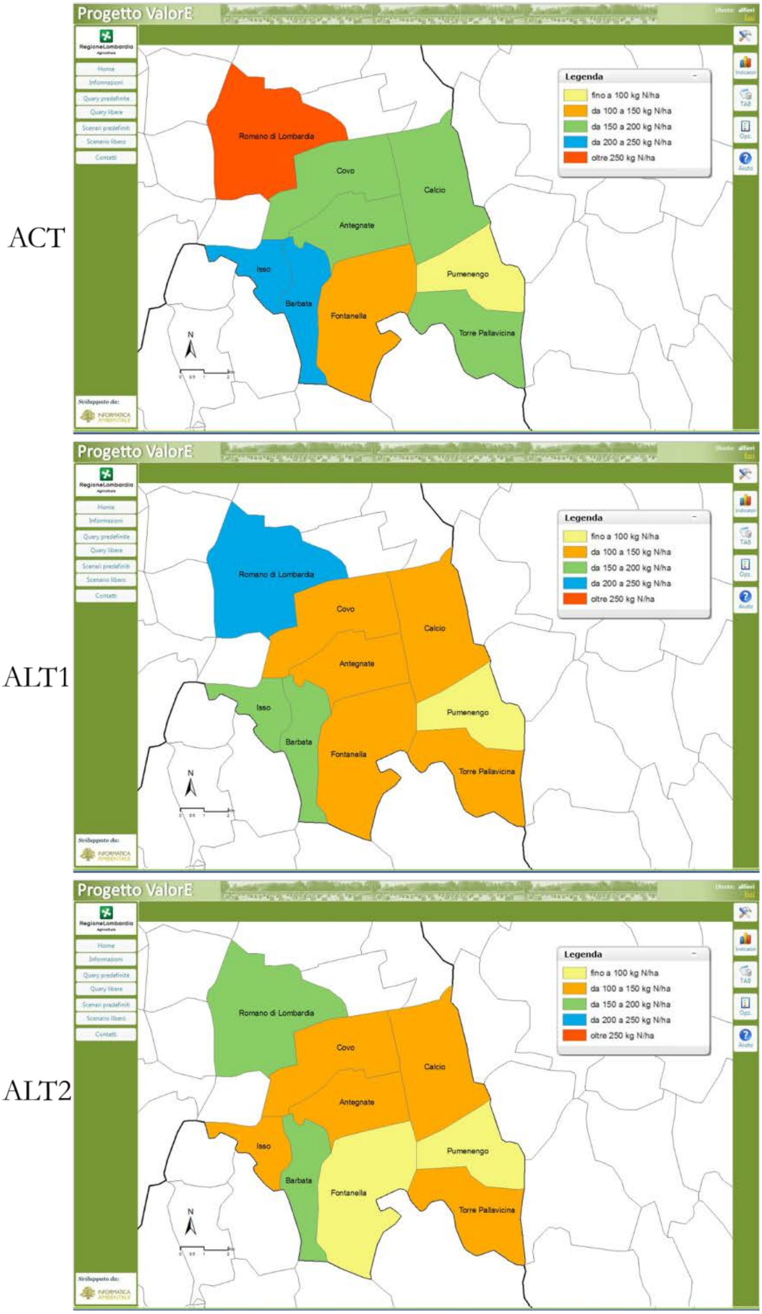


Figure 2.5.3. N volatilization (kg ha^{-1}) aggregated at municipality level under the current scenario (ACT) and after the implementation of nitro-denitro plants (ALT1) and the covering of all manure storages (ALT2).

2.6. Model validation, updating procedures and stakeholders interaction

The model validation step is an on-going procedure carried out by a group of potential users such as agronomists and Italian farmers organizations. Twenty farms have been identified as representative of the entire regional area by applying selection criteria (e.g. farm belonging to the nitrate vulnerable area, minimum agricultural area equal to 40 ha, number of animals over 150 and 2000 for cattle and swine, respectively) to get real data through farmer's interviews. This lets us to estimate the reliability of the model, to detect weaknesses of the system and to do a general improvement of the applicative usability.

Databases are updated to acquire the latest reference data available. The SIARL database is annually updated with the new information provided by the farmers and at the same time meteorological and soil databases could be refreshed if new information is available. The knowledge base could be modified with changes in regulations and/or new scientific achievements (e.g. parameters for crop modelling). Variations of the raw materials price such as energy, fertilisers and crop products are also taken into account.

Following the indications provided by the literature that reports the importance of the participatory processes on DSS' success (Van Meensel et al., 2012) we are currently involving stakeholders that actively collaborate to test it on real cases, to debug and propose new software features and improvement.

2.7. Conclusions

The DSS developed in the ValorE Project, funded by Regione Lombardy for 1,100,000 € (about 1,500,000 USD) is an attempt to create an instrument for environmental protection in a very intensive agricultural area with one of the highest livestock density in the World. Through the ValorE software a detailed analysis can be carried out for all farms in the region, and alternative management scenarios and hypothesis of policies can be tested. The spatial and integrated approach grants the possibility to deal with conflicting objectives, interests and expectation of stakeholders involved and offers to decision-makers a comprehensive tool for improving strategy and decision making. The advantage of the DSS ValorE over other similar systems is that it was designed to manage different livestock manure and types and not to be region-specific bound, being coupled to a GIS. The linking of DSS to a GIS tool is a strategy to deal with spatial decision problems, environmental planning and land allocation (Geneletti, 2004; Bottero et al., 2013).

From the software structure point of view, several benefits can be highlighted. The OOP targeting at modularity and reusability allows a more intuitive and stronger separation among data, models and interfaces. The architecture of the software and the OOP offer an easy and automatic updating of the application and of the model algorithms as well as the possibility to maximise the ease of maintenance. The software is adaptable to work with different databases, provided that they contain the same information. This feature could offer a possibility to further share and synchronise different databases of the other Regions of northern Italy, such as Emilia Romagna, Piemonte and Veneto to get an unique evaluation and decision making tool for similar agricultural areas. This opportunity is emphasized by the fact that the four Regions for which it was granted the nitrate derogation (EC, 2011), account for more than 70 % of livestock in Italy: in particular, 67.1% of dairy cattle, 60.6 % of other cattle, 81% of pigs and 79.4 % of poultry.

The first prototype of ValorE was appreciated by public bodies, producers organizations and farmer's consultants. Since it was first released the number of users has reached more than 200 and the 60% of them are agronomists, entailing about 4000 farms.

Based on the results of this study, we deem that further research should focus on the following objectives:

1- continuous interaction with stakeholders in the debug activities;
2- improvement of the software to satisfy the further request of the users;
3- implementation of the software in order to simulate the rules, constraints and limits of the nitrate derogation;
4- to make the software able to assists farmers in the preparation and submission of the Agronomic Utilisation Plans for livestock manure to obtain the authorisation by the regional government for spreading manure.

2.8. **Acknowledgements**

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CROP ROTATION, FERTILIZER TYPES AND APPLICATION TIMING AFFECTING NITROGEN LEACHING IN NITRATE VULNERABLE ZONES IN PO VALLEY

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Keywords

Nitrogen fertilization, crop simulation model, nitrate leaching, crop rotation.

3.1. **Abstract**

A critical analysis was performed to evaluate the potential risk of nitrate leaching towards groundwater in three Nitrate Vulnerable Zones (NVZs) of the Lombardy plain by applying the ARMOSA crop simulation model over a 20 years period (1988-2007). Each studied area was characterized by (i) two representative soil types, (ii) a meteorological data set, (iii) four crop rotations according to the regional land use, (iv) organic N load, calculated on the basis of livestock density. We simulated 3 scenarios defined by different fertilization time and amount of mineral and organic fertilizers. The A scenario involved no limitation in organic N application, while under the B and C scenarios the N organic amount was 170 and 250 kg N ha^{-1}y^{-1}, respectively. The C scenario was compliant with the requirement of the 2012 Italian derogation, allowing only the use of organic manure with an efficiency greater than 65%. The model results highlighted that nitrate leaching was significantly reduced passing from the A scenario to the B and C ones ($p<0.01$); on average nitrogen losses decreased by up to 53% from A to B and up to 75% from A to C.

3.2. **Introduction**

Agricultural activities are the primary source of no-point pollution due to nitrogen (NO_3-N) losses towards groundwater (Kersebaum et al., 2006). The vulnerability of crop land to nitrate leaching is evaluable by taking into account pedoclimatic condition such as soil permeability, skeleton content, mean annual rainfall (Thorup-Kristensen, 2006) and the local amount of nitrogen from animal waste which can be potentially applied.

The designation of Nitrates Vulnerable Zones (NVZ) in Italy falls under the competence of Region Government. Designation, which took place in the late nineties, has been enlarged between 2006 and 2008; it is based on the criteria set out in article 3 and Annex 1 of nitrates directive, on the basis of the results of monitoring programmes assessing nitrate concentration in surface and groundwater and trophic status of surface waters. In Lombardy NVZs represent approximately 67% of the Utilized Agricultural Area (UAA) in Northern Italy. In detail the percentage of NVZs over the UAA exceeds 80% in Lombardy, whereas NVZs represent 56% of the regional plain areas (Regione Lombardia, 2006a). In plain area of Lombardy (from 44°50'N to 45°50'N and from 8°40'E to 11°80'E), UAA is about 790,000 ha and the main cropping systems are maize-based (Zea mays L., Fumagalli, 2011). Such crops have a relative high N requirement and a potential N uptake which allows for elevated N input up to 300 kg ha^{-1}. Farming systems in the plain of the region are strictly linked to livestock type and account for the 36% and 64% of the national cattle and pigs respectively (Carozzi et al., 2013a). The average nitrogen load from livestock is about 172 kg N ha^{-1}. In the western area, where cereal farms are predominant, the mean annual nitrogen load from livestock is low (from 30 to 90 kg N ha^{-1}y^{-1}) whereas in the central and eastern parts the presence of livestock farms (mainly dairy, cattle and swine) determines high organic nitrogen loads (from 190 to 350 kg N ha^{-1}y^{-1}, Regione Lombardia, 2006b). Such high livestock density involves high availability of N manure but also serious problems related to manure stock and disposal. In Lombardy the percentage of soils in NVZs per texture classes are (i) 4% for soil with sand > 60%, (ii) 93% for soils with sand < 60% and clay < 35%, (iii) 3% for soils characterized by a clay content > 35% (Calzolari et al., 2001).

Over the last decade, results in measurements carried on Lombardy watertable showed a slightly reduction in nitrate concentration (mg NO_3 L^{-1}). Regional Environmental Agency (ARPA) monitored nitrate in groundwater in 335 wells. Well depth ranges from 2 to 40 m, while the depth to the bottom of the screen level from 12 to 25 m; all wells are within the unconfined aquifer. Average of measured concentrations of the whole regional area was 18.3 over the period from 2002 to 2005, and 17.4 mg NO_3 L^{-1} from 2006 to 2008. Over such two periods NO_3 concentration (mg NO_3 L^{-1}) was 21.4 in 2002-2005 and 20.9 in

2006-2008 in NVZs, whereas was 14.6 and 13.3 mg NO_3 L^{-1} in the zones not designated as vulnerable to nitrate.

In such contest alternative cropping systems and agricultural management could represent an opportunity to reduce nitrate leaching, avoiding any economic decrease in crop yield. The aim of this work was to evaluate nitrate leaching under three alternative scenarios of cropping systems by applying ARMOSA simulation model (Acutis et al., 2007) in three areas of Lombardy plain. One of the studied scenarios was defined according to the outline of the obtained request for derogation from Italian Government (2011/721/UE). In particular, we tested the leaching risk in relation with the amount of mineral and organic N fertilizers. In fact, several experimental findings (Borin et al., 1997; Morari and Giupponi, 1997; Acutis et al., 2000) confirmed high losses via leaching when elevated mineral N amount was applied. The introduction of a double cropping system is promoted because the autumn-winter crops are able to uptake the residual soil mineral N (Thorup-Kristensen, 2001; Kramberger et al., 2008; Trindade et al., 2008), to reduce potential nitrate leaching. In fact, one of the main factors determining the amount of leached N into ground water is the presence of a plant cover (Di and Cameron, 2002) which depletes the soil of mineral N by taking it up and consequently decreasing its leaching (Kramberger et al., 2009). Moreover, the double cropping system provides additional feedstock for livestock utilization (Fumagalli, 2012).

3.3. Materials and Methods

3.3.1. The studied area

We firstly identified three areas of the Lombardy plain that are characterized by different pedo-climatic conditions (Figure 3.3.1); the three areas are currently classified as NVZs by the Italian legislation, in compliance with the European

Union Nitrate Directive 91/676/EEC. The climate and soil related variables of the three areas are reported in Table 3.3.1.

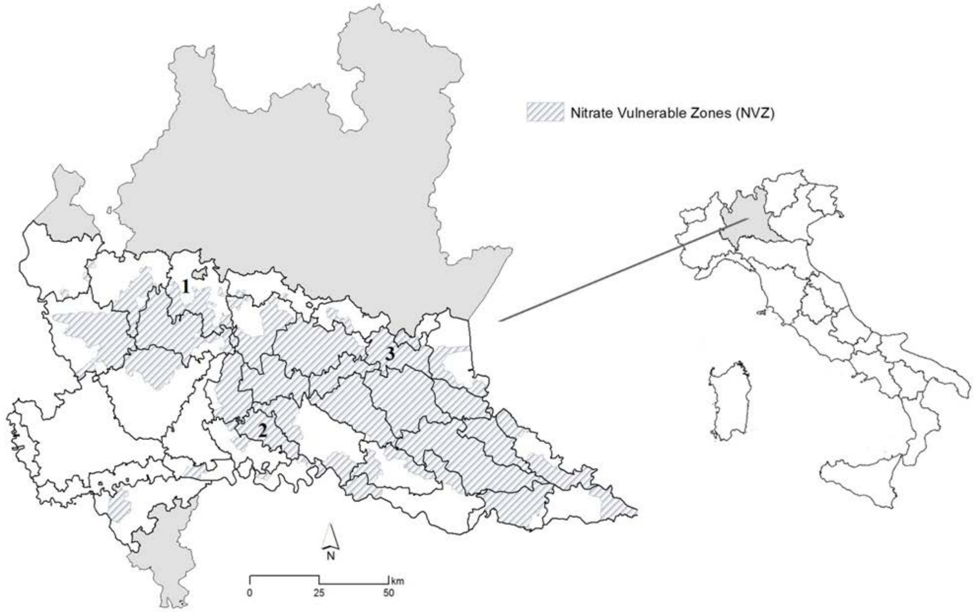

Figure 3.3.1. The designated Nitrate Vulnerable Zones (NVZs) in the Lombardy plain. The three studied areas are marked by "1", "2", "3". The grey area is the mountain region of Lombardy.

Table 3.3.1. Main climate (1988-2007 period) and soil related variables of the three studied areas. The soil variables are expressed as percentage on weight basis considering a profile depth of 1 m

Area	mean annual rainfall (mm)	mean annual rainy days	ET$_{ref}$ (mm)	max T(°C)	min T(°C)		Sand (%)	Silt (%)	Clay (%)	Organic carbon (%)
1	766-1553	64-111	896-947	17-20	8-10	soil 1	24	58	18	0.5
						soil 2	70	22	8	1.2
2	523-959	59-90	975-1056	17-19	6-10	soil 1	55	40	5	0.6
						soil 2	32	48	20	1
3	708-1240	62-103	1030-1085	18-20	8-10	soil 1	39	40	21	0.6
						soil 2	35	43	22	0.7

Since the modelling analysis was performed at local scale, then municipality borders were taken into account in defining the three studied areas to assess the local risk of N leaching. In terms of modelling application, each individuated area represented a simulation unit.

The ARMOSA model run over a period of 20 year using a set of daily meteorological data (1988 - 2007) observed by three weather stations set in each area. Such meteorological stations belong to the Regional Network Service. Meteorological variables, daily observed over the period of 1988-2007, were maximum and minimum value of temperature (°C), and rainfall (mm). Solar radiation was estimated by using the Hargreaves equation (Hargreaves and Samani, 1985), which was previously calibrated using observed data from reference weather stations. For each area two soils were individuated from the Regional Pedolological Map (Regione Lombardia, 2009), being the most representative in terms of UAA (%).

3.3.2.Scenarios definition

The modeling analysis performed by ARMOSA model consisted primarily of the scenario definition. In order to test different agriculture management three scenarios were defined: (i) the A scenario, with no limitation in organic N application (A), (ii) the B scenario, in which the threshold of N fertilization from manure is set on 170 kg N $ha^{-1}y^{-1}$, (iii) the C scenario, defined according to the outline of the obtained derogation of, in which the N input is enhanced from 170 to 250 kg N $ha^{-1}y^{-1}$, and mineral N fertilizers amount decreases according to crop N requirement. B differs from A in terms of N organic fertilization. Main differences from A to C consist of (i) higher N organic, (ii) avoiding manure application on bare soil, (iii) crop rotations including catch crops. Particularly, C was defined: (i) by introducing new crops in the rotation with the aim of further reducing N losses maintaining economic profitability, (ii) reducing the N applied from chemical fertilizers.

Crop rotations were individuated according to the Regional land use (Regional data base SIARL, 2003-2007). We took into account in the analysis crop rotations adopted at least in the 5% of the UAA; four crop rotations were then identified being characterized by a large area of cultivation in the three studied areas. Within any area, the relative area devoted to maize crop included both grain and silage maize (M rotation). The Me rotation consisted in permanent meadows. In A and B scenarios the MW rotation included grain maize and winter wheat (*Triticum aestivum* L.), while in C scenario it was modified by introducing a summer herbage of foxtail millet (*Setaria italica* L.) after winter wheat harvest to ensure crop N up take in summer. Only in the case of C scenario, the MR rotation, as double crop rotation of silage maize of FAO class 500 and Italian ryegrass (*Lolium multiflorum* Lam.), was introduced to simulate the effectiveness of a cover crop to reduce nitrate leaching over the autumn-winter period.

In order to simulate the identified rotations, we used previously calibrated values of crop parameters of maize, wheat and Italian ryegrass (Perego, 2010). In particular, for maize was used a parameterization for a FAO 600 hybrid which generally reaches physiological maturity over a period of 150 days. Meadows were parameterized starting from values reported by van Heemst (1988); then parameters were adapted according to existing studied carried out in Po plain (Sacco et al., 2003; Grignani et al. 2003). Foxtail millet parameters were calibrated in agreement with observed data of northern Italy (Onofri et al., 1990). Sowing, harvest and cutting dates were chosen according to ordinary management of farmers. Typically maize and meadows were sown at the beginning of spring, while foxtail millet was planted in summer and winter wheat and Italian ryegrass in autumn. Four cuttings of meadows were simulated. The nitrogen parameters of the ARMOSA model (Acutis et al., 2007, Perego et al., 2010) was calibrated on more than 2000 measures of soil nitrate contents observed in Lombardy plain according to Perego et al. (2012)

The amount of organic N fertilizer was derived from the regional database and was calculated on the basis of the livestock breeding of the three studied areas

(Regione Lombardia, 2008). In the A and B scenario the organic N fertilization was split in autumn (50%) and spring (50%) for maize and meadows. In the case of maize crops, once calculated the organic N input, the amount of mineral N fertilization was then calculated, in order to guarantee at least 350 kg N ha^{-1}y^{-1}, as farmers usually do (Grignani and Zavattaro, 2000; Mantovi et al., 2006; Perego et al., 2011). The mineral fertilization was simulated at V6-V8 stage of maize development. Winter wheat was fertilized with 200 kg N ha^{-1}y^{-1} as mineral N at 2 distributions. In B and C scenarios thresholds of organic N fertilization were set on 170 and 250 kg N ha^{-1}y^{-1}, respectively. Particularly, in C scenario manure N was applied only in spring or summer, avoiding any spreading in autumn if no crop is sown during such period (two thirds of the amount shall be applied before 30 June, according to the limits of the law). Table 3.3.2 summarizes the N amount applied to crops under the three scenarios in the three studied areas.

Table 3.3.2. Mean annual N fertilizer amount (N kg ha^{-1}y^{-1}) applied to crops under A, B and C scenarios. Org. and Min. stand respectively for organic and mineral N fertilizers.

Rotation	Crop	Area	Scenario					
			A		B		C	
			Org	Min	Org	Min	Org	Min
M	Maize	1	246	104	170	180	250	100
		2	320	100	170	180	250	100
		3	330	100	170	180	250	100
Me	Meadows	1	0	150	0	150	250	100
		2	132	0	170	0	250	100
		3	132	0	170	0	250	100
MW	Maize	1	176	174	170	180	176	149
	W. Wheat		0	200	120	60	0	165
	F.millet*		n.s.	n.s.	n.s.	n.s.	0	100
		2	320	0	170	180	250	100
			0	200	170	30	0	100
			n.s.	n.s.	n.s.	n.s.	250	0
		3	330	0	170	180	250	100
			0	200	170	30	0	100
			n.s.	n.s.	n.s.	n.s.	250	0
MR	Maize		n.s.	n.s.	n.s.	n.s.	250	130
	It. ryegrass		n.s.	n.s.	n.s.	n.s.	0	0

*Italian ryegrass and foxtail millet, manured in summer after wheat harvest at the end of June, were not simulated (n.s.) under the A and B scenarios

In the area 1, irrigation was not simulated in agreement with the ordinary agricultural practices of the area. In the area 2, we simulated four border irrigation treatments of 80 mm each from June to August to maize crop, whereas foxtail millet was irrigated three times. In area 3, 5 irrigations were simulated with 50 mm for maize and 3 for foxtail millet, being an area in which sprinkler irrigation is adopted.

3.3.3.The ARMOSA model overview

In order to assess the effectiveness of the management in agreement with the derogation on water quality, nitrogen losses to water from the main agricultural systems under the specific conditions of Lombardy plain were estimated through a dynamic soil-crop model. ARMOSA (Acutis et al., 2007, Perego et al., 2010) is a simulation model specifically developed on the basis of field trial data observed over years in the ARMOSA project monitoring sites. ARMOSA implements several alternatives for each process, using approaches already well known and largely validated in the scientific literature and used for practical application. In detail, reference evapotranspiration can be computed using Hargreaves, Priestley-Taylor or Penman-Monteith approach. Crop growth model development was based on SUCROS–WOFOST (used, among others application, at European scale for the Bulletin of yield prediction for wheat, maize and other important crops, Supit et al., 1994). Water dynamics can be simulated using the cascading approach, or the Richards' equation, solved as in the SWAP (Van Dam et al., 1997; Van Dam and Feddes, 2000) model. Such Richard equation solution has showed to be the best performing one with very detailed soil moisture data set (Bonfante et al., 2010). Nitrogen dynamics is simulated according to the SOILN approach (Johnsson et al., 1987, Eckersten et al., 1996), but with some improvements. In ARMOSA each type of organic matter has own mineralisation rates, respiration losses and C/N ratio, allowing for separate calculations for the different types of organic fertilisers or crop residuals incorporated into the soil. Distinct pools of NH_4-N and NO_3-N simulated; NH_4-N pool can be up taken by plants, oxidised to NO_3-N, fixed by the clay component of the soil, and immobilised in the organic matter; losses due to ammonia volatilization are also simulated. NO_3-N pool is subject to plant uptake, leaching and denitrification. It is possible to define sowing and harvest DOY (day of the year), crop rotation, automatic irrigation, set of fertilization management, LAI forcing. Results concerning the model calibration and validation, which were carried out using a large set of data observed from representative arable land in Lombardy plain, are detailed described by Perego (2010), who reported mean values of the Nash–Sutcliffe efficiency index of 0.94, 0.69, 0.52, 0.88 for crop biomass, crop N uptake, soil water content, N leaching, respectively.

3.3.4.Statistical analysis

A statistical analysis was carried out in order to test the significance of scenario and crop rotation in affecting N losses via leaching. The statistically significance was calculated by using SPSS 20.0 statistics package. We performed a rank transformation of the simulated data set due to not homogeneity of the variances, according to Conover and Iman (1981) and Acutis et al. (2012); a two-way ANOVA was then executed ($\alpha=0.05$) for N leaching and crop yield, as dependent variables, alternatively. A multiple pair-wise comparison was performed using the Dunn-Sidak's test (Sokal and Rohlf, 1981), obtaining a full control of type I error.

In order to find and rank for importance the correlations between N leaching and independent variables involved in the studied continuum crop-soil, a step-wise linear regression was carried out for each crop rotation. This type of regression analyses tries to obtain the optimal subset of the independent variables, getting to a regression model including only significant variables. Within any rotation, the standard coefficient *beta* was calculated for each independent variable.

3.4. **Results**

3.4.1.N leaching under the different scenarios and crop rotations

The mean annual N leaching were calculated under each scenario and crop rotation. Testing the effect of interaction between scenario and rotation on N leaching, a Dunn-Sidak's test was executed (Table 3.4.1). In such way it was possible to identify which was the most sustainable rotation in terms of N leaching. The Me rotation resulted to be the best rotation in every scenario, while M rotation (monoculture of maize) determined the highest leaching losses. The MW and MR rotations had the intermediate position in every scenario. Figure 3.4.1 shows the mean annual N leaching simulated under the different combinations of scenario x rotations. The outstanding result was the strongly decrease by up to 50% of N leaching passing from A to C scenario. Moreover, under the C scenario the MR crop rotation involved a decrease by 50% of the leaching associated to the M rotation.

Table 3.4.1. Mean annual N leaching (kg N ha^{-1}y^{-1}) for each simulated Scenario X Rotation. Numbers followed by different letter within a row are significantly different ($p<0.05$) according to Dunn-Sidak's test, where a was the best value being associated to lowest value of leaching.

		Rotation			
Scenario	**Area**	**M**	**Me**	**MW**	**MR**
A	1	65c	3a	16b	n.s.
	2	59c	1a	19b	n.s.
	3	75c	1a	41b	n.s.
B	1	64c	3a	48b	n.s.
	2	31b	1a	23b	n.s.
	3	36b	4a	21a	n.s.
C	1	26b	3a	21b	14ab
	2	26b	5a	18b	11ab
	3	28b	1a	22b	15ab

M=maize; Me=meadows; MW=maize, wheat (and f.millet under the C scenario); MR=maize and It.ryegrass.

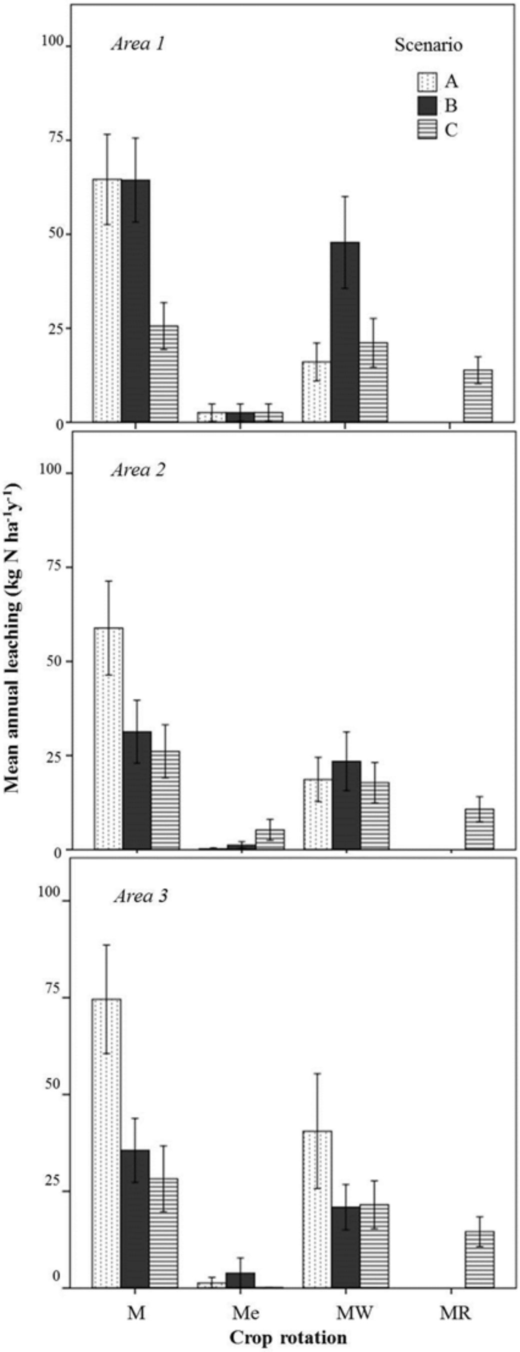

Figure 3.4.1. Mean annual N leaching (kg ha^{-1} y^{-1}) in the three studied areas under the A, B, C scenarios and the simulated crop rotations. The error bars are the 95%

C.I. M=maize; Me=meadows; MW=maize, wheat (and f. millet under the C scenario); MR=maize and It. ryegrass.

Although the N leaching varied substantially under the different combinations of scenario and rotation, significant difference in crop yield resulted just in the case of the M rotation. In fact, the interaction between the two independent factors resulted to be highly significant ($p<0.01$) because maize grain yield in the area 1 was higher under the C scenario (13000 kg ha^{-1}) compared to the mean value in A and B scenarios (9100 kg ha^{-1} on average). On the contrary, maize grain yield was significantly lower ($p<0.01$) under C scenario in comparison with the production under A and B.

The wheat crop yield did not change substantially under the three scenarios as much as the Italian ryegrass, maize 500 FAO and foxtail millet biomass ($p>0.05$). Meadows yield increased significantly from A and B to C scenario only in the area 3 ($p<0.01$), passing from 7800 kg of dry matter ha^{-1} to 10500 kg ha^{-1}. Such production was the highest because the mean annual production was 6100 and 9200 kg ha^{-1} respectively area1 and 2. Figure 3.4.2 shows the mean crop yield under the three scenarios.

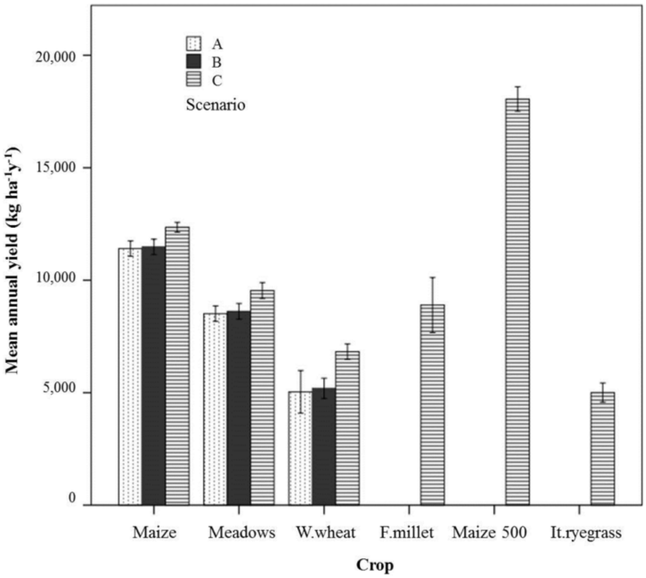

Figure 3.4.2. Mean annual yield (kg ha^{-1}y^{-1}) of each crop under the three scenarios. The yield is expressed as dry matter of above ground biomass, except for maize and wheat, and is the average of the crop production simulated in the three studied areas. Error bars: 95% C.I.

Stepwise regressions for N leaching (dependent variable) were executed within any crop rotation. The independent variables which were taken into account in this analysis were: (i) organic N and (ii) mineral N fertilization, (iii) soil mineralization rate, (iv) annual rainfall + irrigation, (v) percolation water, (vi) soil water content at the saturation point , (vii) soil organic carbon, (viii) crop yield and N uptake (xi), and (x) crop evapotranspiration (ETc). Within each rotation the linear regression had good value of R^2 (0.78 to 0.95) and statistically significant (Table 3.4.2). The beta standard coefficients gave a measure of the weight of each factor: on average, the mineral N fertilization appeared to be mostly relevant within any rotation. The percolation and the organic N fertilization resulted relevant variables in affecting N leaching, together with the mineralization rate under the M and MW crop rotations.

Table 3.4.2. Beta standardized coefficients of the multiple step-wise linear regression calculated for N leaching under the simulated crop rotations. The beta coefficient was reported only for the three most relevant variables in determining N leaching losses.

	Rotation			
	M	**Me**	**MW**	**MR**
R^2	0.91	0.78	0.77	0.95
sig.	< 0.01	< 0.01	< 0.01	< 0.01
Beta Standardized Coefficients				
organic N fertilization	0.96			1.48
mineral N fertilization	1.33	1.07		-1.17
mineralization rate	0.71		0.68	
rainfall + irrigation				
percolation		1.47	1.97	
crop ET				
soil organic carbon %				
soil water content at saturation %				
crop yield		-0.66		
crop N uptake			-0.33	-0.62

M=maize; Me=meadows; MW=maize, wheat (and f. millet under the C scenario); MR=maize and It. ryegrass.

3.4.2.N leaching in the three studied area

The total amount of N leaching in each studied area was calculated under the three scenarios as weighted mean on the basis of the relative area (UAA%) devoted to each crop rotation as indicated by the Regional database. In the three areas a comparison between the effect of the A with the B and C scenarios showed a net decrease of N leaching amount (Table 3.4.3). In fact, the mean annual N leaching were 32, 24 and 11 kg N $ha^{-1}y^{-1}$ under A, B and C, respectively. ANOVA test confirmed the statistically significance of the scenario factor in determining N leaching ($p<0.01$). The Dunn-Sidak post-hoc test confirmed that each scenario effect changed substantially to the others ($p<0.05$). On average, N leaching decreased by 62% passing from A to C, and by 48% from A to B with the exception of the area1 where higher leaching resulted. That was probably due to the mineral fertilization simulated for the wheat crop together with the seasonal high rainfall of that area.

Evaluating the N leaching within any area, the C scenario resulted to be the best combination of cropping systems and agricultural management.

Table 3.4.3. Mean annual N leaching (kg N $ha^{-1}y^{-1}$) calculated on the basis of the UAA (%) devoted to the simulated crop rotations within the three studied areas. The decrease (%) in N leaching from A to B and to C scenario is reported.

	Scenario				
Area	A	B	*B to A*	C	*C to A*
1	19	32	*-68%*	10	*47%*
2	37	21	*43%*	14	*62%*
3	40	19	*53%*	10	*75%*

3.5. **Discussion**

ARMOSA model application allowed to analyze all the interactive factors determining N leaching from arable land, evaluating different cropping systems and management.

With regard to crop production, the model simulated in agreement with existing studies carried out under similar conditions in Po plain. Considering grain maize production, Grignani et al. (2007) reported experimental results of trials in Piemonte (2003-2005) where grain yield was 12,000 kg ha^{-1} with an average crop N uptake of 200 to 300 kg N ha^{-1}. Such results are consistent with our simulated mean grain maize yield of 11,700 kg ha^{-1} and a mean crop N uptake of 279 kg N ha^{-1}. With regard to winter wheat grain production and crop N uptake, simulated values (5,400 kg ha^{-1}, 160 kg ha^{-1}) are in fully agreement with regional average data (5,900 kg ha^{-1}, ISTAT, 2010) and experimental studies of Grignani et al. 2003, reporting a grain yield of 6000 kg ha^{-1} and an average N uptake of 175 kg N ha^{-1}. The model underestimated silage maize and Italian ryegrass dry matter production if compared to field experiments (Onofri et al., 1993; Grignani et al., 2003) although regional data confirmed an average dry matter production of Italian ryegrass of 4,200 kg ha^{-1} (ISTAT, 2010). Moreover, the simulated average of N up take of the double cropping systems was 279 kg N ha^{-1}, which not differs from the range of 248-293 reported by Grignani et al., 2003.

The simulated meadows production (8,900 kg ha^{-1}) was slightly higher than regional data (ISTAT, 2010), whereas simulated foxtail millet production (8,800 kg ha^{-1}) and N uptake (101 kg N ha^{-1}) were consistent with results reported by Onofri et al. (1990) from field trials in Po plain were ranges of production and N uptake were from 4,000 to 7,000 kg ha^{-1} and 96 to 176 kg N ha^{-1}, respectively.

The ARMOSA model calculated all the items of the soil surface N balance and they are reported in Table 3.5.1. The N losses via leaching were in agreement with results reported in Po valley by Morari and Giupponi (1997) and Mantovi et al. (2006). The mean annual volatilization of 11 kg N ha^{-1}y^{-1} was consistent with results reported by Carozzi et al. (2012 and 2013b) under slurry spreading in Po Valley. The simulated denitrification losses were 1.5 kg N ha^{-1}y^{-1}, which are slightly lower than results reported by Ventura et al. (2008).

Table 3.5.1. Mean annual nitrogen balance simulated under the three scenarios. The items of the balance are reported as kg N ha^{-1}y^{-1} and as percentage of the mean annual N input.

	N Balance								
	Input			Output					
Scenario	Fer.	Cr. Res.	Atm. Dep.	Cr.Up.	Lea.	Min.	Vol.	Den.	Imm.
A	281	29	22	164	31	106	9	2.1	21
				49%	9%	32%	3%	0.60%	6%
B	277	28	22	176	26	94	10	1.2	20
				54%	8%	29%	3%	0.40%	6%
C	239	41	22	156	15	87	8	1.1	35
				52%	5%	29%	3%	0.40%	12%

Fer.=fertilization, Cr. Res.=crop residues, Atm.Dep.=atmosferical deposition, Cr.Up.=crop uptake, Lea=leaching, Min.=mineralization, Vol.=volatilization, Den.=denitrification, Imm.=immobilization.

The overall N efficiency increased from 49 to 52% passing from the A to the C scenario. Although the efficiency under the B scenario (54%) was higher than the C one, the B outline would be difficult to be adopted by farmers because of high livestock density. Particularly, under the C scenario the N leaching represented the 5% of N input, volatilization losses 3% and denitrification 1%. Therefore, 12% of N surplus was incorporated into soil organic matter through immobilization process. The C management could contribute more than the B one in enhancing soil organic matter representing a proper management to prevent the soil degradation (Bernardoni et al., 2012).

With regard to N leaching, the Me rotation resulted to be the best rotations in every scenario, while M rotation (monoculture of maize) was associated to the highest leaching losses. The MW and MR crop rotations, which include maize as prevalent crop, were a good compromise between productivity and environmental sustainability.

The outstanding result of scenarios comparison was the significantly decrease of N leaching when the C scenario was adopted maintaining crops yield at standard level and contributing to reduce N leaching losses to groundwater.

3.6. **Conclusions**

The ARMOSA simulation results highlighted that the C scenario can be considered as an interesting solution in order to face the current concern of N leaching in Lombardy plain. In fact, grain maize crops, as well as silage maize in a double-cropping systems with Italian ryegrass had an high N uptake and it involved a certain decrease of the N losses. Moreover, the length of biological cycle of FAO 600 maize hybrids generally reached 150 days, so that crop N uptake corresponded to the period in which soil mineralization rate is particularly high, determining a large mineral N availability useful for crop growth. The increase of organic N supply with the consequent low mineral fertilization, allowed for obtaining high Nitrogen use efficiency (N uptake/N input). Under C scenario, the replacement of mineral-N fertilizer with manure-N involved a significant decrease of mineralization rate in the three areas included in this study.

ARMOSA results show that winter wheat followed by summer herbage allowed for high N uptakes as much as the adoption of the double cropping system of forage maize and Italian ryegrass. Moreover, management adopted under the C scenario can help to enhance the efficiency of farmyard manure use and to increase the soil content of organic matter thanks to an higher amount of organic fertilizer and crop residues incorporated into the soil.

3.7. **Acknowledgements**

This study was carried out in the project ARMOSA, where soil water and nitrate dynamics are measured and analyzed under different cropping systems at monitoring sites in arable farms. The project is currently on-going and co-ordinated by the Department of Agricultural and Environmental Science of the University of Milan, the Regional Agency for Agricultural and Forestry Development of Lombardy Region, and the Institute for Mediterranean Agricultural and Forestry Systems - National Research Council of Ercolano, Naples.

Chapter 4

CONSERVATION AGRICULTURE AS A DRIVING FORCE TO CARBON SEQUESTRATION IN SOILS: AN ANALYSIS OF LOMBARDY PLAIN

Keywords

Soil organic carbon, carbon sequestration, crop simulation model, conservation agriculture.

4.1. Abstract

CO_2 emission credits and carbon (C) sequestration are measures which are largely applied to limit the rising concentration of CO_2 in earth atmosphere. In this context an increasing role is played by conservation agriculture (CA).

The present study aims to estimate the amount of C stored in soil of Lombardy plain following the change from tillage agriculture (TA) to CA by using crop ARMOSA crop model, assess the amount of funding needed to achieve predetermined objectives of storage under current (agro-environmental measure 214-M funded through European Rural Development Program) and alternative scenarios. The territorial analysis is performed at agrarian region scale after identification of the representative crops rotation and soil types.

The results show that the C sequestration in soils by CA can contribute to achieve Kyoto targets, but it needs a significant economic effort.

4.2. Introduction

Agriculture and forestry play a key role in producing public goods, notably environmental such as landscapes, farmland biodiversity, climate stability and greater resilience to flooding, drought and fire. At the same time, many farming practices have the potential to put pressure on the environment, causing soil depletion, water shortages and pollution, loss of wildlife habitats and biodiversity (COM(2010) 672/5). Moreover, the increase in global atmospheric concentration of carbon dioxide (CO_2) and in CO_2 equivalent emissions are nowadays considered a worldwide concern and an expression of the ongoing global warming.

The CO_2 emissions to the atmosphere started to increase in Holocene and according to Ruddiman (2003) the impact of human activity became relevant a long time before industrial era. In that study the rate of CO_2 emission from terrestrial ecosystems in pre-industrial era (the last 7800 years) was estimated to be about 0.04 gigatons (Gt) C year^{-1} average, for a total of 320 Gt C cumulative

(Figure 4.2.1b). During the industrial era (last 200 years), the rates of estimated carbon (C) emissions from land-use changes were only 0.3–0.4 Gt C year^{-1} in the middle 1800s, when CO_2 levels began to rise noticeably (Figure 4.2.1a). By contrast in recent years they have exceeded 1.5 Gt C year^{-1}.

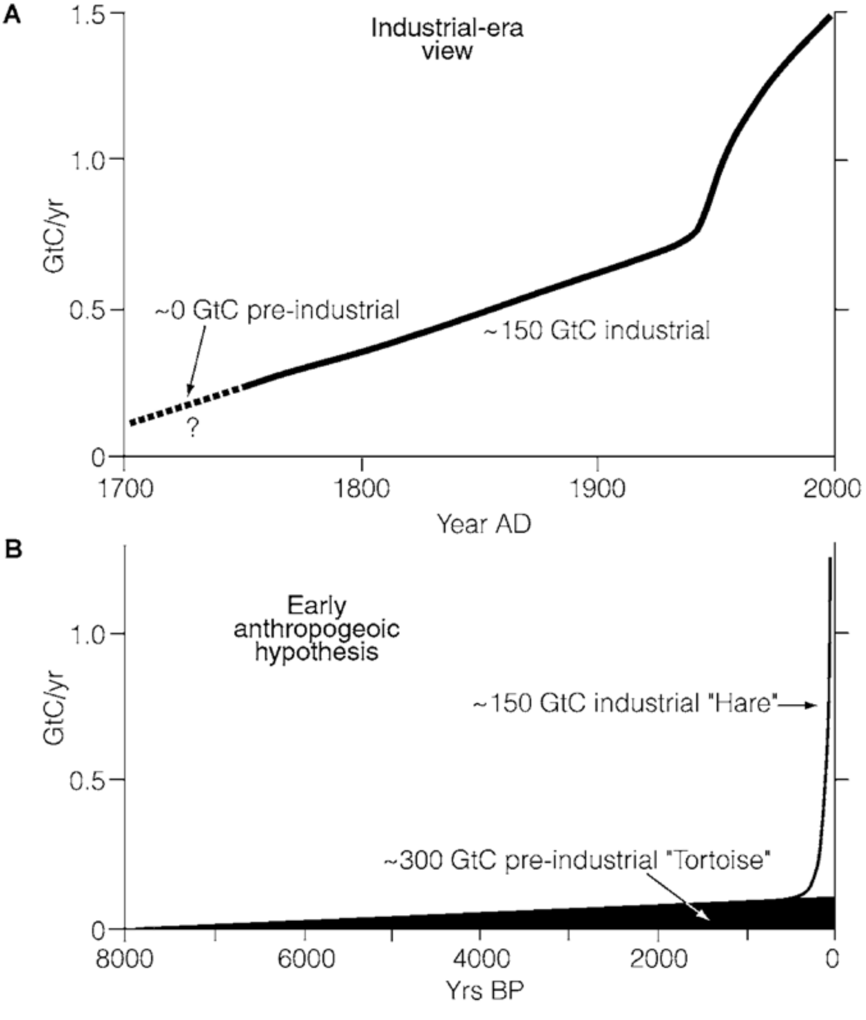

Figure 4.2.1. (a) Industrial-era perspective suggests that most land clearance occurred in the last 200 years. (b) Early-anthropogenic perspective suggests that much slower but longer-operating pre-industrial land clearance cumulatively exceeded clearance during the industrial era (from Ruddiman, 2003).

From 1850 to 1998, the emission from fossil fuel combustion into the atmosphere was 270 ± 30 Gt C, while the emission of terrestrial source was estimated to be about 136 ± 55 Gt C, considering the effects of land-use changing on carbon stocks, predominantly from forest ecosystem (Watson et al., 2000). Lal (2004) reported that the emission from soil cultivation was 78±12 Gt (28% of total emission), about one-third of which was attributed to soil degradation and accelerated erosion and the remaining part was related to the mineralization process.

The current global soil carbon pool of 2500 Gt includes about 1550 Gt of soil organic carbon (SOC) and 950 Gt of soil inorganic carbon. The SOC is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (Lal, 2004). Other estimates (Tarnocai et al., 2009; Schlesinger, 2000) indicate that SOC in terrain ecosystem accounts for roughly 1500 Gt of C, double the amount contained in plant biomass or atmosphere. Soil represents the largest C sink and a severe depletion of the SOC pool degrades soil quality, reduces biomass productivity and improves the CO_2 emissions. The rate of C losses from terrestrial ecosystems is an order of magnitude faster than that due to C sequestration (Korner, 2003). SOC results from a dynamic equilibrium and it is continuously affected by environmental changes (Janssens et al., 2010) and soil management practices (Lal, 2004). Since the control of SOC or its increase may have positive effects, namely the reduction of CO_2 emission to purposes of global warming mitigation (Six et al., 2004), the protection of already existing C stocks can be considered as an important strategy.

Lal (2004) listed some the main issues related to C sequestration, as follows:

1- Agricultural chemicals. Most recommended management practices involve C-based input; including crop protection products, fertilizer and fossil fuel.
2- Nutrients required. Carbon is only one of the elemental constituents of humus and the sequestration of 1 Gt of C in world soils is estimated to

require 80 Mt of N, 20 Mt of P, and 15 Mt of K. There are several natural sources of nutrients for C sequestration. Crop residue is a potential source to sequester C and improve soil quality, if not used for energy, by direct combustion, or for biofuel production.

3- Soil erosion and deposition. The SOC is preferentially removed by wind- and water-borne sediments, through erosional processes. The erosion in word involves 1.1 billion ha, with an average of 0.4 to 0.6 Gt C/year. The control of this processes is essential to suitable agriculture.

4- Extractive farming practices. Low input/subsistence farming causes a depletion rate of soil nutrients, soil C and soil fertility.

5- Societal value and hidden benefits. Commodification of soil C is important for trading C credits, as part of the solution to mitigate climate change. Carbon trading markets have existed since 2002, especially in European Union (EU) countries.

6- Hydrologic and carbon cycles. Because renewable freshwater is scarce, a projected increase in cereal production must occur on the same or smaller land area and with the same or less water. Thus, linking water and carbon cycles through conservation of water resources is crucial for improving agronomic yields and soil C sequestration in dry land.

7- Soil C sequestration and global warming. Global warming is a "century-scale" problem and a "global common" issue. Soil C sequestration is a bridge across global issues: climate change, desertification, and biodiversity.

8- Other greenhouse gases. Enhancing SOC stock increases the soil ability to oxidize CH_4, but it may also exacerbate emission of N_2O.

9- Soils of the tropics. Because of its severe depletion and degradation, the C sink capacity of soils of the tropics may be high, but the rate of sequestration can be low; this leads to the need of enhancing soil quality to also improve the crop yield.

Permanence. Soil carbon sequestration is a natural, cost-effective, and environment friendly process. Once sequestered, C remains in the soil, if sustainable agriculture practices are followed.

4.2.1. Conservation agriculture

Conservation Agricultural (CA) is defined by FAO as: "*a resource-saving agricultural production system that aims to achieve production intensification and high yields while enhancing the natural resource base through compliance with three interrelated principles, along with other good production practices of plant nutrition and pest management. These are: minimum mechanical soil disturbance with direct seeding; permanent soil organic cover with crop residues and/or cover crops to the extent allowed by water availability; and species diversification through varied crop associations and/or rotations (involving annual and/or perennial crops including trees)*". CA follows three main principles:

1- minimal or no soil disturbance by mechanical tillage, seeding or planting directly into untilled soil (for maintaining soil organic matter, soil structure and overall soil health);

2- permanent land cover and maintaining of organic matter cover on the soil surface, use of crops, cover crops or crop residues (for protecting soil surface, saving water and nutrients, promoting soil biological activity and contributing to integrated weed and pest management);

3- crop diversity, both annuals and perennials, in associations, sequences and rotations, including pastures and crops(for enhancing crop nutrition and improving system resilience).

Farmers can play a significant role on soil carbon sink because variations on management practices can reduce losses and increase the absorption of carbon. CA allows higher rates of carbon sequestration in the soil comparing with traditional agriculture, provided that it is properly adopted. It is well known that when carbon loss or no carbon sequestration are associated with non-traditional farming practices, they can be due to: i) soil disturbance, ii) monocropping, iii) specific crop rotations, iv) poor management of crop residues, or v) soil sampling extended deeper than 30 cm (Corsi et al., 2012).

CA strongly affects C sequestration, because maintaining the cover on the soil surface and avoiding (or limiting) soil perturbation of soil structure limits the kinetic of oxidative processes, improving the fertilizer effect in soil surface layers. (Lal, 2004; Daraghmeh et al., 2009). CA is also characterized by lower fuel consumptions, since lower power tractors are needed, tractors themselves have a longer lifetime and labour time is shorter. Smith et al (1998) compared fossil fuel-carbon consumption per unit area between CA and tillage agriculture (TA), estimating 29 kg C ha^{-1} y^{-1} and 52.8 kg C ha^{-1} y^{-1}, respectively. Moreover, they show that the complete conversion to CA could offset all direct fossil fuel-carbon emissions from agriculture in Europe. Other authors report that the adoption of rotational cropping systems, which include the integration of catch crops (e.g. leguminous) before maize, is able to decrease the quantities of N-fertilizer required (Christopher and Lal, 2007; Boddey et al., 2009).

The crop residue promotes the fast recycling of nutrients (Lafond et al., 2011), the residual nitrogen immobilization in the soil and the slowing down of the SOC mineralization process. By contrast, TA may results in a rapid mineralization of SOC, due to high oxidation rates, in releasing soluble organic compounds and in increasing soil microbial activity (Ball et al., 1999). Crop residues also allow lower losses of soil, reducing the impact of rain drops and the erosive action of wind and eventually determining a higher aggregation and stability of soil structure (Hernanz et al., 2002). Since the runoff is one of the primary causes of herbicides pollution of surface water (Krutz et al. 2005), the limited soil erosion can consequently reduce the contamination. On the other hand, the crop residues on soil surface can enhance water retention and soil moisture, decreasing the temperature leap in soil. Several studies report that soil temperature under CA is lower when compared to ploughed soil (Lal and Kimble, 1997; Ball et al., 1999; Curtin et al., 2000; Al Kaisi and Yin, 2005).

Moreover, the adoption of CA can lead to a lower reliance on pesticides and herbicides, since the natural soil biodiversity, together with crop rotations, creates natural competition among crops (Dumanski et al., 2006).

The main advantages FAO (FAO, 2013) attributes to CA are: reduction of soil losses, decreasing of pollutants in water and limitation of atmospheric emissions of CO_2, CH4 and N_2O. It is worth to underline that literature findings about N_2O emission are often conflicting. Some authors affirm that the optimization of crop rotation, the diffusion of cover crops and the restrained use of fertilizer can determine a reduction in N_2O emissions (Elmi et al., 2003, Eagle et al. 2010, Delgado et al. 2011). On the opposite, Baggs et al. (2003), Guzha (2004) and Bhatia et al. (2010) pointed out an increase of N_2O emission corresponding to both a greater soil bulk density and a higher soil water content, since these factors can reduce the oxygen diffusion and promote the anaerobic processes, enhancing the N_2O production, particularly on fine-textured soils (MacKenzie et al., 1998).

In general, CA enables the reduction of production costs (fuel, fertilizer and pesticide), as well as the operating and maintenance costs for farm machinery. Conversely, the disadvantages are mostly related to the transition period from a conventionally tilled system, requiring an initial investment for buying specialized machinery and the use of appropriate/improved seeds, already adapted to local conditions. Corsi et al. (2012) showed that some crop residues may be an additional source of income and farmers could find more convenient selling them in a short-term period, and paying higher costs in a medium to long-term period.

In any case, a successful CA needs of technical support and training to farmers, comparing with conventional till farming, and this can be achieved only through a radical change in approaching and managing, with particular regard to the control of weeds.

4.2.2.Legislative framework

In compliance with Kyoto Protocol (UN, 1998), the EU has developed policies to support greenhouse gases emissions reduction. Directive 2003/87/EC established a scheme for greenhouse gas emission allowance trading within the Community (ETS - Emissions Trading Scheme), in order to promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner (Article 1), and it relates mainly to the energy and industrial sectors. The climate and energy package (20-20-20) in 2008 and Decision No. 406/2009/EC of the European Parliament and of the Council of 23 April 2009 provide for the evaluation and implementation of a more rigorous commitment of the Community in the field of emission reductions, aiming to ensure the EU meets its ambitious climate and energy targets for 2020. Other European Community policies have been prepared for the containment of greenhouse gases, such as energy efficiency and use of renewable sources. The so-called "Effort Sharing Decision" (406/2009/EC) sets binding annual targets in terms of emissions of greenhouse gases for every Member States for the period 2013-2020, related to areas not included in the EU ETS (Emissions EU-ETS) such as transport, buildings, agriculture and waste. The total share fixed at European level of abatement of emissions from these sectors for 2020 is equal to 10% compared to 2005. This reduction in emissions added to the dimension reduction coming from the sectors of the ETS should allow to achieve the objectives of 20-20-20 (EU Climate and Energy, 2007).

European, national and regional policies support directly or indirectly the agricultural and forestry practices for GHG emissions reduction: agricultural and forestry practices that affect carbon sequestration are described in introduction, but include conversions from land or abandoned land to forest and energy crops and the adoption of organic farming techniques (Freibauer et al., 2004). The importance of soils in climate change mitigation is emphasized both in the implementation of the commitments of the Kyoto Protocol and in the priority areas of the EU Common Agricultural Policy (CAP), as well as in the document that directs the choices for the future CAP (2014 -2020). Indeed, it is known that ' ... *is important to further unlock the agricultural sector's potential to mitigate, adapt and make a positive contribution through GHG emission reduction, production efficiency measures including improvements in energy efficiency, biomass and renewable energy production, carbon sequestration and protection of carbon in soils based on innovation.*' (COM (2010) 672/5). The EU has reported (EU-comm, 2009) that European soils of the cropland could sequester between 50 and 100 million tons of carbon annually, by adopting agricultural practices to reduce the loss of organic carbon from the soil and from the use of machinery.

The requirement for agricultural sector to intensify efforts to reduce GHG emissions in the framework of EU strategy on climate change is also mentioned in the Regulations 74/2009/CE on support for rural development (Health Check), which require the adoption of specific measures to the reduction of GHG emission addressed from 2010.

The advantages and disadvantages reveal the divergence between the social desirability of conservation agriculture and its potential attractiveness to individual farmers. While many of the costs associated with the exchange of till technics fall at farm level, most of the benefits relate to the production of public goods and environmental (Knowler et al., 2007). Without policies and fundings to farmers, the adoption of conservation techniques will be a function of perceived profitability at farm scale.

European Rural Development Program (RDP) aims to protect and enhance rural environment and contributes to the development of a competitive and sustainable farm. It is also focused on improving quality of life of rural communities and it is split into three main areas, linked to Farming and Food (Also known as Axis 1), Environment and Countryside (Also known as Axis 2) and Rural Life (Also known as Axis 3). Lombardy Region supports conservative agriculture, through a specific measure of the RDP.

The present study aims to (i) estimate the amount of carbon stored in soil following the change from TA to CA, by using crop modelling; (ii) assess the amount of funding needed to achieve predetermined objectives of storage; (iii) compare the effects of similar policies at international level. It is part of "AgriCO$_2$ltura project", a research project funded by the Direzione Generale Agricultura ed Ambiente of the Lombardy Region, whose purposes are (i) to evaluate the carbon accumulation in soils, the reduction of CO_2 emissions into the atmosphere and the enhancement of the conservation of soil biodiversity, and (ii) to compare results from CA and TA techniques, under different soil and climatic conditions. AgriCO$_2$ltura is focused on the following issues: the study of storage and emission of carbon in cultivated soils, as a function of the different farming techniques and soil and climatic conditions; the identification of regional deposits of carbon in agricultural soils; the assessment of methodologies or techniques to elaborate a reliable carbon balance of Lombard agricultural systems. AgriCO$_2$ltura eventually aims to compare the analysis outcome with the impact of EU and regional policies, related to carbon storage in soils.

4.3. **Materials and methods**

The work carried out to estimate the organic C sequestration in arable soil of the Lombardy region can be summarized in the following phases:

1. Identification of the representative cropping systems (crops rotation) and soil types for each Agrarian Region analyzing the regional databases;
2. Investigation on the diffusion of CA practices from the analysis of the measure 214-M of the Rural Development Programme (current scenario);
3. Application of the ARMOSA cropping systems simulation model to compare conservative and conventional agricultural;
4. Estimation of the carbon balance for each agrarian region based on the simulation results;

5. Territorial analysis of the current and alternative scenarios with regards to CA implementation.

4.3.1. Sites description

The study area is the agricultural plain area of the Lombardy region (northern Italy – between 44°50'N and 45°50'N and 8°40'E and 11°80'E) that represents the 47% of the total area. Hills and mountains accounted for 13 and 40%, respectively. The predominant land uses are: agriculture (40.0%), forest (25.4%) and urban and residential areas (12.6%) (DUSAF, 2007).

Lombardy Region is characterized by an intensively managed agriculture with high livestock density accounting for a big part of the Italian livestock, in particular more than 27% of cattle and 51% of pigs. More than 72% of utilized agricultural area (UAA) is arable land, which cereals are the main cultivated crops (ISTAT, 2013). However the spatial distribution of crops is not equable, in particular there is a high difference between Lombardy plain and mountain area. The percentage of UAA used as grassland and arable land vary considerably in region. In mountain area, grasslands are especially more than 40% of UAA, while in the plain, grassland covers just 3% of the UAA. In convers the arable land of Lombardy plain represent more than 70% of total Lombardy UAA (DUSAF, 2007). For this reason the analysis was made only in Lombardy plain.

4.3.2. Cropping system

The land use information are data available at cadastral scale and referred to 5 years (from 2007 to 2011). Cadastral unit is an area of original municipality delimited by its boundaries and represented in cadastral map. Information are included in a regional database SIARL (Agricultural Information System of the Lombardy Region) that collects structural information of agricultural farm periodically updated by farmers that have to provide details about the regulatory compliance on the matter of N management also to get subsidies by the CAP and RDP.

For each year it was possible to identify from one to five different soil uses. In this study was taken into account only first and second soil use to year because more year soil use represented a greenhouse or open filed vegetable. Data were then aggregated at agrarian region (AR) level which is meant as territorial subdivision consisting in a few number of neighboring municipalities being homogeneous in terms of land use and pedoclimatic conditions defined by ISTAT. In Lombardy plain have been identified 56 AR (Figure 4.3.1).

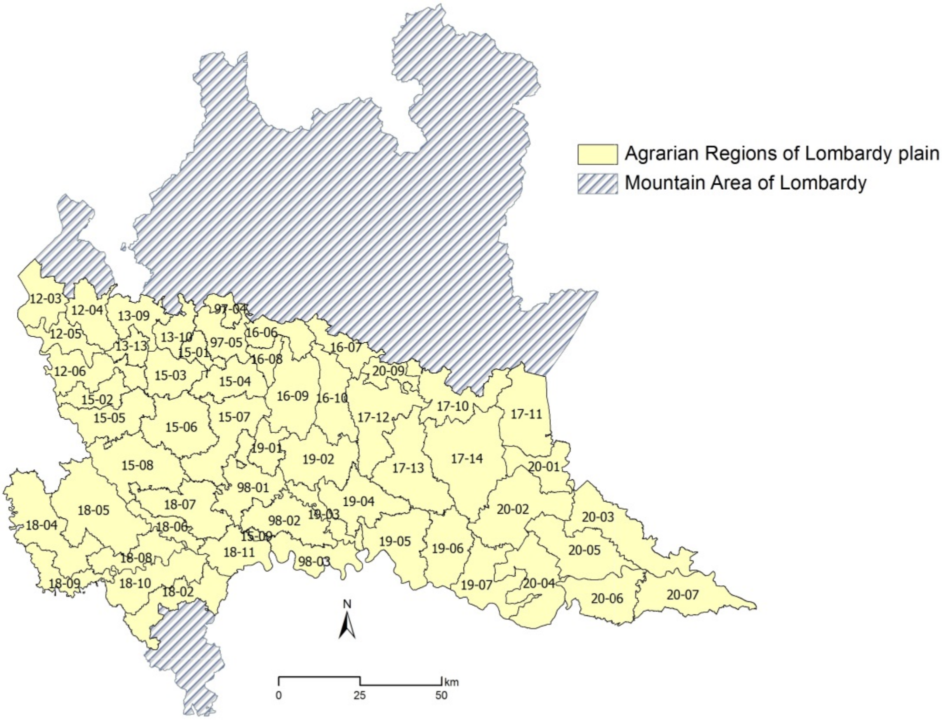

Figure 4.3.1. Maps of the 56 Agrarian Regions (AR) in Lombardy plain. The grey area is the mountain area of Lombardy.

For the identification of the cropping system, on the basis of land use were first individuated groups of crops having similar characteristics in term of growth period, final use of product and tillage techniques. 214 types of land use successively aggregated into 17 groups were identified, taking into account a maximum of double crops for year. Such information was used to derive the type of the rotation system adopted in studied area.

Based on the land use (17 crop groups) of the single cadastral unit over the years a crops rotation of 5 years was created. In general, to define the rotation the following procedure was adopted:

1- elimination of any land use different from arable land or meadows grass, namely tree crops, rice, permanent meadows and open field vegetables. Rice was not taken account into because ARMOSA model is not able to simulate the paddy field system. The UAA considered in this study represent of the 79% of the total UAA of Lombardy plain.
2- connection of single cadastral unit over the five years considering the identification code that consist of: i) municipality national code; ii) sheet of cadastral maps code; iii) parcel code (included “subalterno”); iv) utilizable surface (in m2); v) “condotta” surface. If “condotta” surface if >0 means that the single unit is divided in 2 or more different crop. The cadastral units available only in the last years (2011) were assumed to be characterized by monoculture as a function of crop type. In the case of different combination of missing data information was processed as explained in scheme available in Table 4.3.1;

Table 4.3.1. Logical schema to define crop rotation when data were missing.

Years						Years				
2011	2010	2009	2008	2007		2011	2010	2009	2008	2007
a	NULL	b			-->	a	a	b		
a	NULL	NULL	b		-->	a	a	a	b	
a	b	NULL	NULL	c	-->	a	b	a	b	c
a	NULL	NULL	NULL	b	-->	a	a	a	a	b

a,b,c are crops

3- to aggregate crop rotation at AR was used the following criterion. The first step of the analysis consisted in coupling each crop rotation to the area, it is currently applied to. Then, those crop rotations were selected, whose area is greater than 5% of the UAA. These rotations were considered as representative and their area were added up to determine the percentage of UAA covered ($\mathrm{CR\_Rep\_Perc} = \sum_{i=1}^{n} cr\_rep\_perc_i$, where n is the number of representative crop rotations and $cr\_rep\_perc_i$ is the percentage of UAA covered by the i^{th} representative crop rotation). Afterwards, the remaining part (i.e. $100 - \mathrm{CR\_Rep\_Perc}$, the percentage of UAA covered by not representative crop rotations) was divided in n sub-areas, by assigning to each of them the corresponding representative crop rotation. The assignment was done, applying the same proportion, as described above. Remaining part as:

$100 - \mathrm{CR\_Rep\_Perc} = \sum_{i=1}^{n} new\_cr\_rep\_perc_i$,

where $new\_cr\_rep\_perc_i = \frac{cr\_rep\_perc_i \cdot 100}{\mathrm{CR\_Rep\_Perc}}$ and the i^{th} representative crop rotation was assigned to the i^{th} sub-area. This procedure was repeated for each AR. The representative crop rotation represent 81% of the total UAA considered.

For each AR a number of 1 to 6 representative crop rotations were therefore obtained. In Table 4.3.2 is shown the UAA of crop rotations and the soil use which not considered in this work.

Table 4.3.2. UAA of the representative crop rotations of the AR in Lombardy plain.

Cropping rotations	ID	Map ID	UAA (ha)
Wheat	F	F	26,048
Maize – Wheat (1 year + 1 year)	M_F	MF	92,134
Alfalfa - Grain maize (3 years + 2 years)	Alfa_MG	Alfa	39,483
Alfalfa - Maize - Wheat (3 years + 1 year + 1 year)	Alfa_F_MG	Alfa	31,165
Silage maize	MF	MF	55,286
Grain maize	MG	MG	185,513
Grain maize + cover crop	MG_cover	MG_L	21,570
Meadows - Grain maize (4 years + 1 year)	PVMG	PVM	35,255
Meadows - Forage maize (4 years + 1 year)	PVMF	PVM	22,653
Permanent meadows (not simulated)	PP	PP	5,232
Rice (not simulated)	R	R	102,656
Crops trees (not simulated)	A	A	16,193
Open-field vegetables (not simulated)	O	O	7,880
Total UAA			641,068
Total UAA related to the simulated systems			509,106

In Figure 4.3.2 is visualized the spatial distribution of each crop rotation in AR. To help the reader similar crop rotations were aggregated under a specific Map ID as reported in Table 4.3.2.

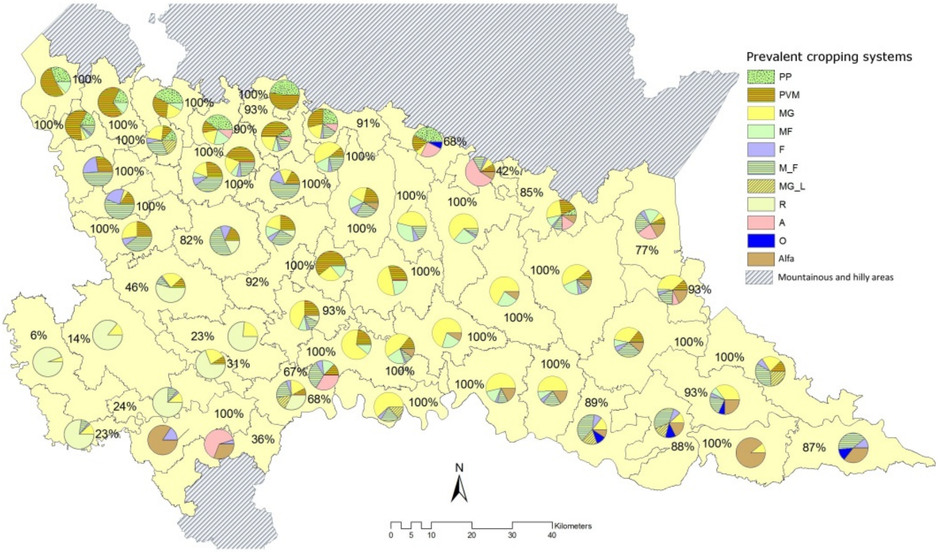

Figure 4.3.2. Representative crop rotations in the AR in Lombardy plain. The current UAA % related to the simulated systems is displayed in each AR.

4.3.3.Pedoclimatic characteristics

To define for each agrarian region the predominant soil types as different sources of information were used:

1- A land use map, derived from the 1:10,000 scale map of DUSAF (2007), produced by the Lombardy Region using digital orthophotos of 2007. The information mapped as polygonal component refer to 5 macroareas, 12 class and 8 subclass only for agricultural area (Table 4.3.3).

Table 4.3.3. The territorial area subdivision in DUSAF 2007.

Macro areas	Level I	Level II (reported only agricultural areas)
Antropizate areas	Urbanized areas	
	Industry areas, transport infrastructure	
	Quarry, landfill, derelict land	
	green urban area	
Agricultural areas	Arable land	Non-irrigated arable land
		Irrigated arable land
		paddy field
	Perennial crops	Crops trees
		Vineyard
		Olive groves
		Arboriculture
	meadows grass	meadows grass
Wooded and semi natural environments	Wooded	
	Shrubland, moorland	
	Open area without or less vegetation	
Humid areas	Wetland, mire	
Water bodies	Lake, watercourse	

2- A soil map a 1:250,000 scale the Lombardy Region (. The geographic component of the soil map is organized in four nested levels: 5 Soil Regions (Alps, Prealps, Po plain, Apenines hills and Apennines), 18 Soil Sub Regions (8 in the plain area), 65 Great Soilscapes (GS) and 1038 Soilscapes (that represent the Soil Mapping Units). The Soil Typological

Units (STU) have been classified according to the WRB (FAO, 1998) and to the Soil Taxonomy (USDA, 1998) and can be found in several GS. For this study 29 GS, namely 156 STU were used as representative of the plain area.

4.3.3.1. **Soil type selection**

The selection of the representative soil type of each AR was carried out following 4 steps.

1- Overlaying of agricultural land use (Figure 4.3.3a) and AR maps (Figure 4.3.3b) to obtain the spatial distribution of UAA of each AR (Figure 4.3.3c).
2- Overlaying of spatial distribution UAA (Figure 4.3.3c) and the soil maps (Figure 4.3.3d) to individuate the GS types more widespread across the agricultural land (Figure 4.3.3e).
3- Selection of the most representative GS for each AR considering only those that alone or together covered more than 80% of the UAA.
4- Selection of a maximum of 2 STU for GS: to reduce the number of STU and the number of simulations it was decided to select the most representative STU according to expert opinion. In particular the expert analysis focused on soil texture characteristics and SOC content. In Table 4.3.4 are present for each AR the relative representative area of GS and STU.

Figure 4.3.3. Synthesis of overlay map used to select representative soil types. "a" is the land use map, "b" is the Agrarian Region (AR) map, "c" is the map of spatial distribution of UAA for each AR, "d" is the soil map (Great Soilscapes - GS) and "e" is the map of GS types more widespread across the agricultural land

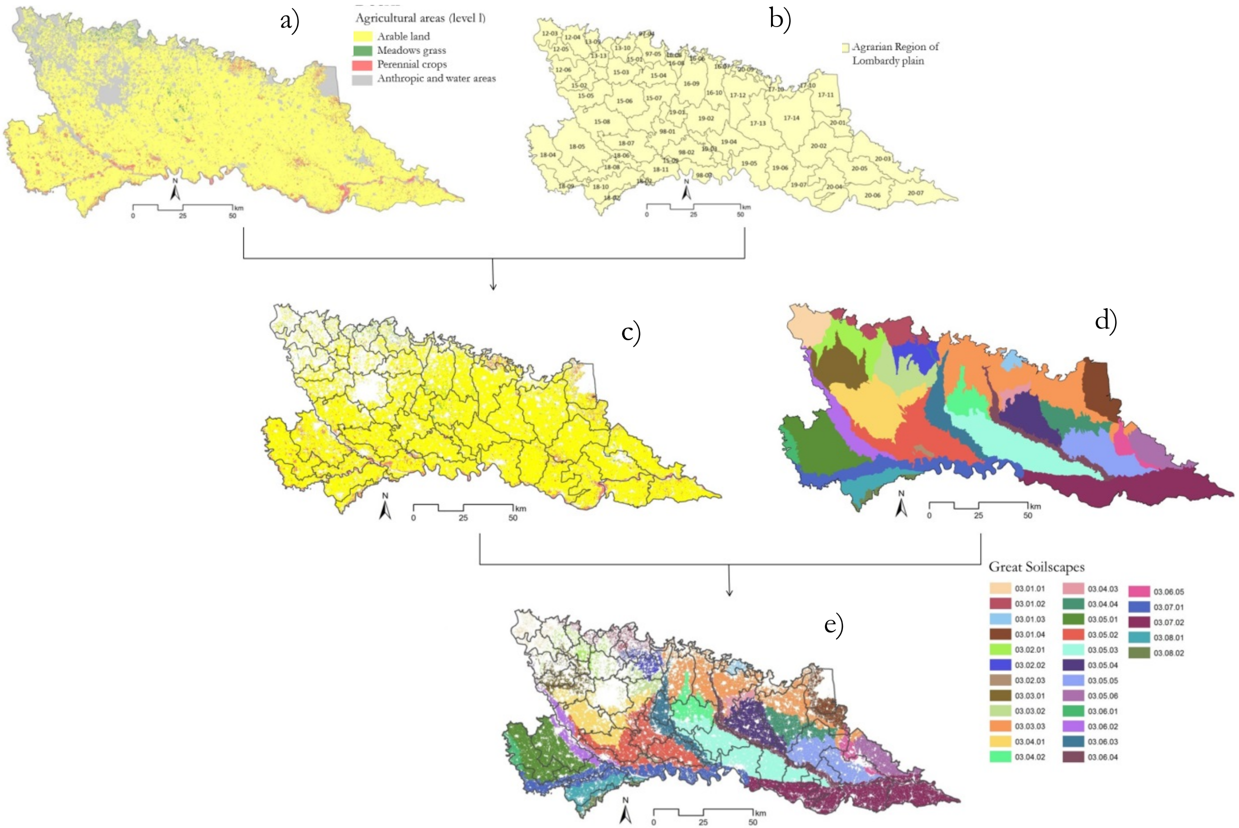

Table 4.3.4. AR an relative percentage of area of GS and STU

AR	GS	STU	% rapresentative GS on UUA of AR	% STU on GS	% STU on UUA of AR
12-03	03.01.01	236	100.0%	100.0%	100.0%
12-04	03.01.01	236	33.8%	100.0%	33.8%
12-04	03.01.02	353	11.2%	100.0%	11.2%
12-04	03.02.01	548	55.1%	100.0%	55.1%
12-05	03.01.01	236	73.7%	100.0%	73.7%
12-05	03.02.01	548	26.3%	100.0%	26.3%
12-06	03.03.01	208	84.5%	21.0%	17.7%
12-06	03.03.01	475	84.5%	79.0%	66.7%
12-06	03.02.01	548	15.5%	100.0%	15.5%
13-09	03.01.02	353	49.9%	100.0%	49.9%
13-09	03.02.01	548	50.1%	100.0%	50.1%
13-10	03.01.02	353	60.3%	100.0%	60.3%
13-10	03.02.01	548	39.7%	100.0%	39.7%
13-13	03.02.01	548	100.0%	100.0%	100.0%
15-01	03.01.02	353	46.5%	100.0%	46.5%
15-01	03.02.02	400	53.5%	100.0%	53.5%
15-02	03.03.01	208	100.0%	21.0%	21.0%
15-02	03.03.01	475	100.0%	79.0%	79.0%
15-03	03.03.02	334	52.7%	100.0%	52.7%
15-03	03.02.01	548	47.3%	100.0%	47.3%
15-04	03.03.02	334	47.9%	100.0%	47.9%
15-04	03.02.02	400	52.1%	100.0%	52.1%
15-05	03.06.02	77	14.4%	65.0%	9.4%
15-05	03.03.01	208	48.4%	21.0%	10.2%
15-05	03.04.01	350	37.2%	36.0%	13.4%
15-05	03.03.01	475	48.4%	79.0%	38.2%
15-05	03.06.02	586	14.4%	35.0%	5.0%
15-05	03.04.01	612	37.2%	64.0%	23.8%
15-06	03.03.02	334	33.2%	100.0%	33.2%
15-06	03.04.01	350	66.8%	36.0%	24.0%
15-06	03.04.01	612	66.8%	64.0%	42.7%
15-07	03.05.02	286	21.7%	60.0%	13.0%
15-07	03.03.02	334	38.1%	100.0%	38.1%
15-07	03.04.01	350	40.2%	36.0%	14.5%
15-07	03.05.02	565	21.7%	40.0%	8.7%
15-07	03.04.01	612	40.2%	64.0%	25.7%
15-08	03.06.02	77	89.7%	65.0%	58.3%
15-08	03.04.01	350	10.3%	36.0%	3.7%
15-08	03.06.02	586	89.7%	35.0%	31.4%
15-08	03.04.01	612	10.3%	64.0%	6.6%
15-09	03.02.03	102	45.6%	100.0%	45.6%
15-09	03.05.02	286	54.4%	60.0%	32.7%
15-09	03.05.02	565	54.4%	40.0%	21.8%
16-06	03.03.03	87	84.4%	74.0%	62.4%
16-06	03.03.03	271	84.4%	26.0%	21.9%
16-06	03.01.02	353	15.6%	100.0%	15.6%
16-07	03.03.03	87	100.0%	74.0%	74.0%
16-07	03.03.03	271	100.0%	26.0%	26.0%
16-08	03.03.03	87	56.9%	74.0%	42.1%
16-08	03.03.03	271	56.9%	26.0%	14.8%
16-08	03.02.02	400	43.1%	100.0%	43.1%
16-09	03.03.03	87	82.5%	74.0%	61.1%
16-09	03.04.02	112	17.5%	54.0%	9.4%
16-09	03.04.02	262	17.5%	46.0%	8.0%
16-09	03.03.03	271	82.5%	26.0%	21.5%
16-10	03.03.03	87	100.0%	74.0%	74.0%
16-10	03.03.03	271	100.0%	26.0%	26.0%
17-10	03.03.03	87	100.0%	74.0%	74.0%
17-10	03.03.03	271	100.0%	26.0%	26.0%

17-11	03.01.04	238	100.0%	79.0%	79.0%
17-11	03.01.04	456	100.0%	21.0%	21.0%
17-12	03.06.04	16	14.4%	44.0%	6.3%
17-12	03.03.03	87	72.9%	74.0%	53.9%
17-12	03.04.03	96	12.7%	100.0%	12.7%
17-12	03.06.04	219	14.4%	56.0%	8.1%
17-12	03.03.03	271	72.9%	26.0%	18.9%
17-13	03.04.03	96	11.4%	100.0%	11.4%
17-13	03.05.04	105	88.6%	22.0%	19.5%
17-13	03.05.04	577	88.6%	78.0%	69.1%
17-14	03.03.03	87	56.2%	74.0%	41.6%
17-14	03.04.04	184	43.8%	43.0%	18.8%
17-14	03.04.04	185	43.8%	57.0%	25.0%
17-14	03.03.03	271	56.2%	26.0%	14.6%
18-02	03.08.01	247	53.1%	35.0%	18.6%
18-02	03.08.02	462	46.9%	100.0%	46.9%
18-02	03.08.01	524	53.1%	65.0%	34.5%
18-04	03.06.01	484	19.7%	100.0%	19.7%
18-04	03.05.01	535	80.3%	47.0%	37.7%
18-04	03.05.01	574	80.3%	53.0%	42.6%
18-05	03.06.02	77	28.1%	65.0%	18.3%
18-05	03.05.01	535	71.9%	47.0%	33.8%
18-05	03.05.01	574	71.9%	53.0%	38.1%
18-05	03.06.02	586	28.1%	35.0%	9.8%
18-06	03.06.02	77	40.8%	65.0%	26.5%
18-06	03.05.02	286	59.2%	60.0%	35.5%
18-06	03.05.02	565	59.2%	40.0%	23.7%
18-06	03.06.02	586	40.8%	35.0%	14.3%
18-07	03.05.02	286	63.8%	60.0%	38.3%
18-07	03.04.01	350	36.2%	36.0%	13.0%
18-07	03.05.02	565	63.8%	40.0%	25.5%
18-07	03.04.01	612	36.2%	64.0%	23.2%
18-08	03.07.01	466	57.0%	43.0%	24.5%
18-08	03.05.01	535	43.0%	47.0%	20.2%
18-08	03.05.01	574	43.0%	53.0%	22.8%
18-08	03.07.01	601	57.0%	57.0%	32.5%
18-09	03.07.01	466	76.8%	43.0%	33.0%
18-09	03.05.01	535	23.2%	47.0%	10.9%
18-09	03.05.01	574	23.2%	53.0%	12.3%
18-09	03.07.01	601	76.8%	57.0%	43.8%
18-10	03.08.01	247	67.3%	35.0%	23.6%
18-10	03.07.01	466	32.7%	43.0%	14.1%
18-10	03.08.01	524	67.3%	65.0%	43.7%
18-10	03.07.01	601	32.7%	57.0%	18.6%
18-11	03.05.02	286	33.5%	60.0%	20.1%
18-11	03.07.01	466	66.5%	43.0%	28.6%
18-11	03.05.02	565	33.5%	40.0%	13.4%
18-11	03.07.01	601	66.5%	57.0%	37.9%
19-01	03.06.03	34	100.0%	54.0%	54.0%
19-01	03.06.03	195	100.0%	46.0%	46.0%
19-02	03.05.03	91	35.3%	70.0%	24.7%
19-02	03.04.02	112	64.7%	54.0%	34.9%
19-02	03.04.02	262	64.7%	46.0%	29.8%
19-02	03.05.03	384	35.3%	30.0%	10.6%
19-03	03.06.03	34	51.0%	54.0%	27.5%
19-03	03.05.03	91	49.0%	70.0%	34.3%
19-03	03.06.03	195	51.0%	46.0%	23.5%
19-03	03.05.03	384	49.0%	30.0%	14.7%
19-04	03.06.04	16	10.9%	44.0%	4.8%
19-04	03.05.03	91	89.1%	70.0%	62.4%
19-04	03.06.04	219	10.9%	56.0%	6.1%
19-04	03.05.03	384	89.1%	30.0%	26.7%

19-05	03.05.03	91	81.0%	70.0%	56.7%
19-05	03.05.03	384	81.0%	30.0%	24.3%
19-05	03.07.01	466	19.0%	43.0%	8.2%
19-05	03.07.01	601	19.0%	57.0%	10.9%
19-06	03.06.04	16	13.6%	44.0%	6.0%
19-06	03.05.03	91	68.4%	70.0%	47.8%
19-06	03.06.04	219	13.6%	56.0%	7.6%
19-06	03.05.03	384	68.4%	30.0%	20.5%
19-06	03.07.02	478	18.1%	50.0%	9.0%
19-06	03.07.02	504	18.1%	50.0%	9.0%
19-07	03.05.03	91	30.9%	70.0%	21.7%
19-07	03.05.03	384	30.9%	30.0%	9.3%
19-07	03.07.02	478	69.1%	50.0%	34.5%
19-07	03.07.02	504	69.1%	50.0%	34.5%
20-01	03.03.03	87	32.8%	74.0%	24.3%
20-01	03.01.04	238	67.2%	79.0%	53.1%
20-01	03.03.03	271	32.8%	26.0%	8.5%
20-01	03.01.04	456	67.2%	21.0%	14.1%
20-02	03.03.03	87	11.2%	74.0%	8.3%
20-02	03.05.05	100	66.0%	88.0%	58.1%
20-02	03.05.05	144	66.0%	12.0%	7.9%
20-02	03.04.04	184	22.8%	43.0%	9.8%
20-02	03.04.04	185	22.8%	57.0%	13.0%
20-02	03.03.03	271	11.2%	26.0%	2.9%
20-03	03.06.05	33	13.5%	15.0%	2.0%
20-03	03.06.05	220	13.5%	85.0%	11.5%
20-03	03.07.02	478	16.3%	50.0%	8.2%
20-03	03.07.02	504	16.3%	50.0%	8.2%
20-03	03.05.06	523	70.1%	100.0%	70.1%
20-04	03.06.04	16	17.2%	44.0%	7.6%
20-04	03.05.05	100	21.3%	88.0%	18.8%
20-04	03.05.05	144	21.3%	12.0%	2.6%
20-04	03.06.04	219	17.2%	56.0%	9.6%
20-04	03.07.02	478	61.5%	50.0%	30.7%
20-04	03.07.02	504	61.5%	50.0%	30.7%
20-05	03.06.05	33	17.6%	15.0%	2.6%
20-05	03.05.05	100	82.4%	88.0%	72.5%
20-05	03.05.05	144	82.4%	12.0%	9.9%
20-05	03.06.05	220	17.6%	85.0%	14.9%
20-06	03.07.02	478	100.0%	50.0%	50.0%
20-06	03.07.02	504	100.0%	50.0%	50.0%
20-07	03.07.02	478	100.0%	50.0%	50.0%
20-07	03.07.02	504	100.0%	50.0%	50.0%
20-09	03.01.03	72	65.5%	60.0%	39.3%
20-09	03.03.03	87	34.5%	74.0%	25.5%
20-09	03.03.03	271	34.5%	26.0%	9.0%
20-09	03.01.03	425	65.5%	40.0%	26.2%
97-04	03.01.02	353	100.0%	100.0%	100.0%
97-05	03.01.02	353	67.9%	100.0%	67.9%
97-05	03.02.02	400	32.1%	100.0%	32.1%
98-01	03.06.03	34	30.6%	54.0%	16.5%
98-01	03.06.03	195	30.6%	46.0%	14.1%
98-01	03.05.02	286	69.4%	60.0%	41.6%
98-01	03.05.02	565	69.4%	40.0%	27.8%
98-02	03.06.03	34	22.0%	54.0%	11.9%
98-02	03.06.03	195	22.0%	46.0%	10.1%
98-02	03.05.02	286	78.0%	60.0%	46.8%
98-02	03.05.02	565	78.0%	40.0%	31.2%
98-03	03.05.02	286	25.5%	60.0%	15.3%
98-03	03.07.01	466	74.5%	43.0%	32.0%
98-03	03.05.02	565	25.5%	40.0%	10.2%
98-03	03.07.01	601	74.5%	57.0%	42.5%

4.3.3.2. **Meteorological data**

The Lombardy Region has made available a twenty-three-year time series of daily meteorological data such as maximum and minimum temperature (°C) and precipitation (mm). The provided data were measured at 14 monitoring stations from 1989 to 2011. The solar radiation (MJ m^2 d^{-1}) was estimated using the model proposed by Bristow and Campbell (1994). To assign the climatic data to each AR a spatial interpolation method on the basis of the measured data to extend the meteorological information throughout the entire plain of the region by employing Thiessen polygon method was used. For each AR were assigned the meteorological data of the polygon the most representative in terms of surface (Figure 4.3.4.).

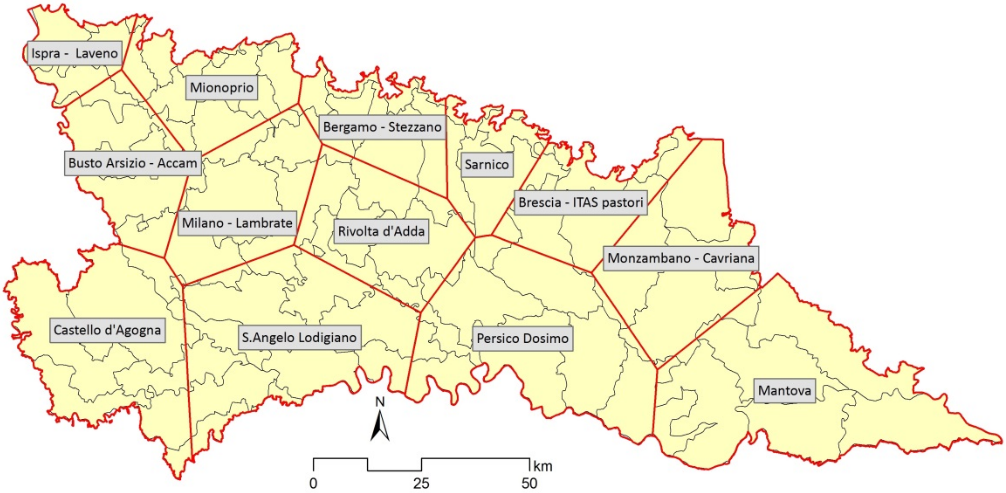

Figure 4.3.4. Meteorological station and relative Thiesse polygons.

4.3.4. Diffusion of CA practices in the region

From 2010 Lombardy Region introduced the agro-environmental measure 214-M funded through RDP that supports farmers who decide to introduce and manage all or part of their land through conservation agriculture. The main objective is to increase the amount of C in soils by counteracting the adverse side effects resulting from the simplification of cropping systems and the intensive management of the soil as deep plowing with inversion of the soil layers and repeated periods of bare soil. Such negative consequences are CO_2 emissions, high energy consumption, reduction of biodiversity and soil fertility (organic matter reduction, increased erosion in particular solid transposed in the plains, compaction or sealing). The policy regards only to arable land of the region. Farmers in order to get the subsidies must guarantee specific conservative techniques for at least 5 continuous years on a minimum area of 1 ha and in any case not less than 10% of the total area of the single farm. The contributions are disbursed according to the areas covered by conservation and are summarized in Table 4.3.5.

Table 4.3.5. The amount of subsidies paid to farmers for the use of CA of operating space is described.

Subsidies		Techniques
208	€ ha^{-1} y^{-1}	Direct seeding
290	€ ha^{-1} y^{-1}	Direct seeding + cover crop
278	€ ha^{-1} y^{-1}	Direct seeding + direct injection of sewage farming
360	€ ha^{-1} y^{-1}	Direct seeding + cover crop + direct injection of liquid manure
190	€ ha^{-1} y^{-1}	Minimum tillage
272	€ ha^{-1} y^{-1}	Minimum tillage + cover crop
260	€ ha^{-1} y^{-1}	Minimum tillage + direct injection of sewage farming
342	€ ha^{-1} y^{-1}	Minimum tillage + cover crop + direct injection of liquid manure

Data relative to the farmers request for CA subsidies in the Lombardy Region were collected from SIARL database and refer to 2011 and 2012. The cropland managed as CA was about 1% (8,306 ha) and 3% (24,492 ha) of the UAA, respectively in 2011 and in 2012 (SIARL, 2013). The amount of the loan was 2,039,522.25 € for the first year (2011) and of 5,721,607.44 € for the second

(2012). The Figure 4.3.5 displays the distribution of UAA managed as CA over the AR in Lombardy plain.

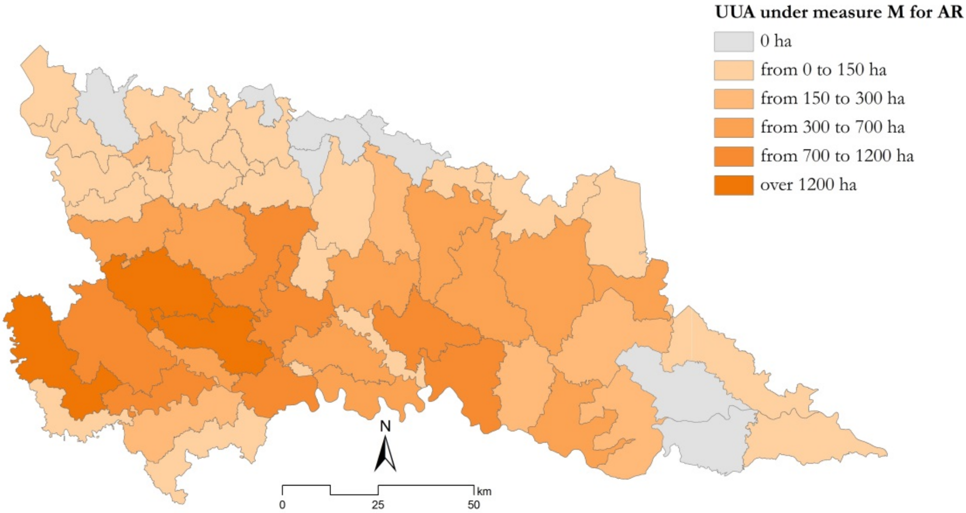

Figure 4.3.5. UAA for AR under measure M in 2012 in Lombardy plain

4.3.5.Description and application of the ARMOSA Model

The carbon balance in the soil was calculated on the basis of the output variables simulated by the ARMOSA crop simulation model (Acutis et al., 2008; Perego et al., 2013) applied under the cropping systems which were previously identified, comparing the two techniques agronomic management under examination, conventional and conservative tillage. ARMOSA was developed to define a methodology for the assessment of soil quality and nitrate vulnerability in arable systems in Lombardy plain and it was calibrated and validated by a large set of data observed in six monitoring sites (Perego *at al.*, 2013).

ARMOSA is a dynamic model that simulates the cropping systems at a daily time-step. The software was written using the Unified Modelling Language (UML, Rumbaugh et al., 2005) to have an explicit definition of its structure. The model simulates agro-meteorological variables, the water balance, the N balance, and the crop development and growth. It consists in four modules which are: i) a micro-meteorological model that simulates the energy balance, allowing the evapotranspiration estimation, ii) a crop development and growth model that uses global radiation and temperature, iii) a model of soil water balance, and iv) a model of soil N and carbon balance.

The ARMOSA crop simulation model was developed after a literature review of available algorithmic frames to be implemented in the software code. Particularly, the crop module is based on gross assimilation of carbon dioxide (CO_2), and on maintenance and growth respiration to get the final net carbon assimilation as implemented in SUCROS (Van Keulen et al., 1982) and WOFOST models (Van Keulen and Wolf, 1986). The water dynamics can be simulated according to the physically based approach of the Richards' equation, as implemented in the SWAP model (Van Dam et al., 1997; Van Dam and Feddes, 2000), or through the empirical cascading approach (Burns et al., 1974). The hydraulic parameters of the Richards' approach are internally estimated from the van Genuchten parameters provided in the soil data base.

The N dynamics module was developed on the basis of the SOILN model (Eckersten et al., 1996; Larsson et al.,1999) which was already implemented in other simulation models as WAVE (Vanclooster et al., 1994) and LEACHN (Hutson, 2003). In particular, the latter was applied in Po plain scenario (Acutis et al. 2000), showing a good performance in simulating the ordinary intensive cropping systems of the studied area. Pedological parameters, as input data, are included in data base where physical parameters as texture and bulk density, chemical, as organic carbon (kg kg^{-1} soil) and carbon in the stable fraction of organic matter (kg), are reported layer by layer.

The user can define (i) crop rotation, (i) sowing and harvest time, (ii) time, amount and type of N fertilizers (iv) time and amount of the irrigation events. Further, the user can choose the option of the automatic irrigation, defined by water availability threshold below whose value irrigation water is provided to ensure the field capacity content at a defined depth.

ARMOSA model also allows for selection of daily outputs for all growth and soil related variables and indicators derived from the simulation results e.g. the development stage and AGB of crops, soil water balance, as well as stress and efficiency indicators, organic carbon and N, mineral nitrogen, and water flux between layers.

4.3.5.1. **Carbon and Nitrogen module**

The C-N module simulates the transformations of carbon and nitrogen. A graphic description of C-N module is shown in Figure 4.3.6. It considers the decomposition of organic matter, mineralization, immobilization, nitrification, denitrification, fixation and humification. The C-N module was developed according to the approaches of the SOILN model (Eckersten et al., 1996; Larsson et al., 1999) with differences on attributes of the organic pools.

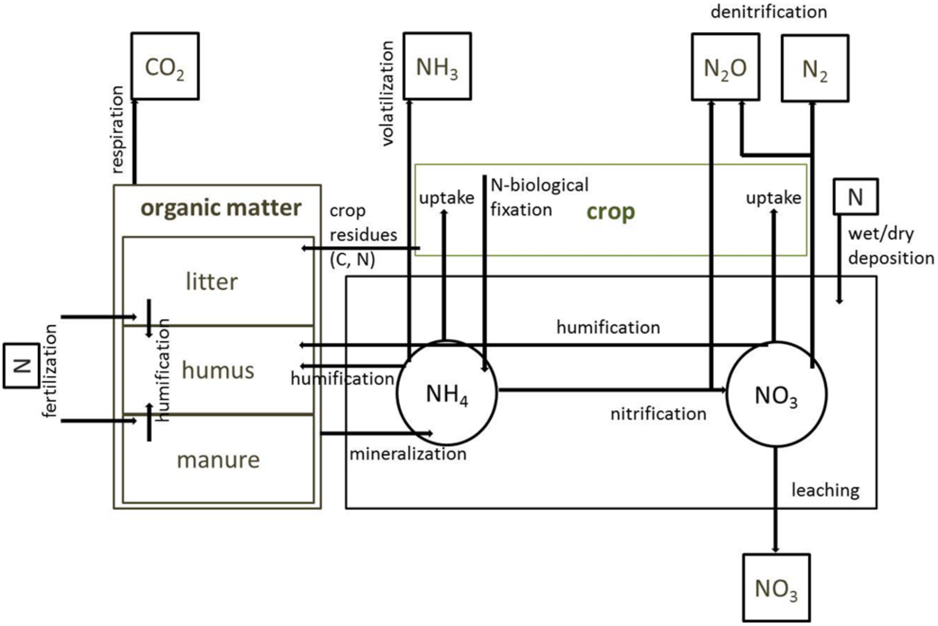

Figure 4.3.6. Logical structure of the nitrogen component of the ARMOSA model.

The model simulates different soil organic pools which may be defined as a compartment containing material that is chemically indistinguishable and equally accessible by plants or to the microbial population in the soil (Smith et al., 2002). The model implements three types of organic pool, two of which are characterized by a quicker rate of decomposition (30 up to 400 days), named litter (if C/N < 10) and manure (if C/N > 10) which represent the crop residues and the fertilizer contribution respectively and the other pool named “humus” which represent the stable organic matter with C/N equal to 10. In addition, each organic matter of any fertilizer application and crop residues incorporation is assigned to an independent sub-pool of the manure or litter type. In particular, the decomposition rates of the sub-pool both different kind of fertilizer and different crop residues are function of the crop type and organ plant (i.e. stem, leaves, root and storage) (Garnier et al., 2003). The third type of pool, humus, is the one characterized by the slower decomposition rate being the stable fraction of the organic matter in soil. The microbial biomass is implicit in all the pools.

The model represents two inorganic pool, namely ammonia and nitrate (NH_4-N and NO_3-N), each one characterized by its own rate of mineralization or transformation.

ARMOSA model allows to simulate in each soil layer the gross mineralization, gross immobilization and net mineralization. The gross mineralization is the production of inorganic N and CO_2 from the organic pool. The gross immobilization is the conversion of inorganic N into organic N and manure or litter pools in humus that is humification. The net mineralization is the difference between gross mineralization and immobilization. This processes depends on soil layer temperature and soil water contents.

The environmental factors, such as soil temperature and water content, are involved in every processes as correction factors and are calculated on the basis of reference value of the optimal condition for the microbial activity in the soil. The factors are calculated at daily time step in each soil layer. The temperature factor is expressed as a Q1O function so that it increases at temperature increasing of 10°C. Two different water factors are simulated: one for the mineralization and nitrification processes and a specific one for denitrification. Both water factors are function of the soil water content at saturation. Both the mineralization and humification processes are calculated as function of specific rates, C/N ratio and the N amount in the mineral pools. The crop uptake occurs along the soil profile investigated by roots. Crop preferentially uptakes NH_4-N, if it is not available then crop uptakes NO_3-N (Watson, 1986). If available NH_4-N and NO_3-N do not satisfy crop demand then N stress occurs. The NO_3-N leaching is simulated according to a convection and dispersion mechanisms as function of the soil water content and the N amount of the mineral pools. The nitrification process is calculated as function of the specific rate and the equilibrium NO_3-N / NH_4-N ratio. Denitrification is simulated on the basis of soil NO_3-N and water content. Volatilization occurs in the first layer as a function of soil NH_4-N and water content and its rate is maximum within the first 3 days after fertilization. Biological fixation is simulated under the leguminous cultivation and is calculated on the basis of crop N demand and NH_4-N and NO_3-N availability. Dry and wet atmosphere depositions of NH_4-N and NO_3-N occur in the first layer: dry deposition is constant while wet deposition is proportional to rain fall.

A model description of the main C-N related process is given in this paragraph.

Mineralization

Mineralization of the organic matter follows a different way. C and N rates are calculated separately.

Manure pool

Carbon rates form manure pool to CO2:

$$CM\ to\ CO_2 = -k \times (1 - feM) \times C \times fT \times fW$$

Implicit biomass of pool:

$$CM\ to\ CMimplicit = -k \times C \times (1 - fh) \times feM \times fT \times fW$$

Nitrogen rates from manure pool to NH4

$$NM\ to\ NH4 = -k \times \left[N - \left(feM \times \frac{C}{CNH}\right)\right] \times fT \times fW$$

Implicit biomass of pool

$$NM\ to\ NM = -k \times C \times feM \times (1 - fh) \times fT \times \frac{fW}{CNH}$$

Litter pool

Carbon rates form manure pool to CO2:

$$CL\ to\ CO_2 = -k \times C \times (1 - feL) \times fT \times fW$$

Implicit biomass of pool:

$$CL\ to\ CL\ implicit = -k \times C \times fT \times fW \times (1 - fh) \times feL$$

Nitrogen rates from litter pool to NH4:

$$NL\ to\ NH_4 = -k \times \left[N - \left(feL \times \frac{C}{CNH}\right)\right] \times fT \times fW$$

Implicit biomass of pool

$$NL\ to\ NL = -k \times C \times feL \times (1 - fh) \times fT \times \frac{fW}{CHN}$$

Humus pool

Carbon rates form manure pool to CO2:

$$CH\ to\ CO\ _2 = -k \times C \times fT \times fW$$

Nitrogen rates from litter pool to NH4:

$$NH\ to\ NH_4 = -k \times N \times fT \times fW$$

where fT and fW are temperature and soil water factors, k is the mineralization rate of each pool (input parameter, d^{-1}), CNH is the CN ratio of the humus pool, C is the carbon amount of the pool (kg ha^{-1}), N is the nitrogen amount of the pool kg N ha^{-1}, feM and feL are manure and litter microbial efficiency in carbon utilization, fh is humification fraction of litter/manure (input parameters).

The potential mineralization (kg NH_4^+ ha^{-1}) is the sum of mineralized NH_4 by litter and manure pools

$$Min\,pot\ =\ NM\ to\ NH4\ +\ NL\ to\ NH4$$

Humification

Humification of the organic matter follows a different way. C and N in manure and litter pool are transferred directly to the humus pool. Also inorganic N can be immobilized in the humus pool and it is carried out on ammonium and nitrate in the same proportion.

Inorganic nitrogen pools

Humification is occur only mineralization potential is > 0 and if the inorganic pools of N ($NO_{3\,pool}$, $NH_{4\,pool}$) are present in the soil layer.

NH_4 immobilized (kg N ha^{-1}) is calculate:

$$NH_4\ imm = \min\left\{\frac{Min\ Pot\ \times NH_{4\,pool}}{NO_{3\,pool}\ +\ NH_{4\,pool}}, fN \max \times\ NH_{4\,pool}\right\}$$

Manure pool

Carbon rate from manure pool to humus:

$$CM\ to\ CH\ =\ -k\ \times\ C\ \times\ fh\ \times\ feM\ \times\ fT\ \times\ fW$$

Nitrogen rate from manure pool to humus:

$$NM\ to\ NH\ =\ -k\ \times\ C\ \times\ feM\ \times\ fh\ \times\ fT\ \times\ \frac{fW}{CNH}$$

Litter pool

Carbon rate from litter pool to humus:

$$CL\ to\ CH\ =\ -k\ \times\ C\ \times\ feL\ \times\ fT\ \times\ fW\ \times\ fh$$

Nitrogen rate from manure pool to humus:

$$dNL\,dt\,NH = -k \times C \times feL \times fh \times fT \times \frac{fW}{CNH}$$

where fT and fW are temperature and soil water factors, k is the mineralization rate of each pool (input parameter, d^{-1}), CNH is the CN ratio of the humus pool, C is the carbon amount of the pool (kg ha^{-1}), N is the nitrogen amount of the pool kg N ha^{-1}, feM and feL are manure and litter microbial efficiency in carbon utilization, fh is humification fraction of litter/manure (input parameters), fNmax is maximum availability of mineral nitrogen for immobilization and plant uptake.

fT is the microbial temperature factor:

$$fT = Q^{(T-Tmicro/10)}$$

Q= input parameter related to pedological features; it is set to 2 [-].

T= it is the actual mean air temperature which is shortened by 2 °C (°C). T value does not exceed 28 °C.

Tmicro= input parameter below whose value denitrification does not occur (C°).

The microbial water factor (fW) is calculated in each soil layer with a daily timestep as follows:

$$\begin{cases} fW = 0 & if \quad SWC < b \\ fW = \left(\frac{SWC - b}{l - b}\right)^m & if \quad b \le SWC \le l \\ fW = fSAT + (1 - fSAT) \times \left(\frac{SWC\_SAT - SWC}{SWC\_SAT - h}\right)^m & if \quad l < SWC \le h \end{cases}$$

where:

fW = microbial water factor (-).

SWC = actual water content in the soil layer ($m^3\ m^{-3}$).

SWC_SAT = soil water content at saturation ($m^3\ m^{-3}$).

b = lower SWC limit of microbial activity ($m^3\ m^{-3}$); it is calculated as:

$$b = SWC\_base \times SWC\_SAT$$

l = lower *SWC* limit of optimum of microbial activity (m^3 m^{-3}); it is calculated as:

$$l = SWC\_low \times SWC\_SAT$$

h = higher *SWC* limit of optimum of microbial activity (m^3 m^{-3}); it is calculated as:

$$h = SWC\_high \times SWC\_SAT$$

SWC_base = input coefficient related to pedological features; it is set to 0.3(-)
SWC_low = input coefficient related to pedological features; it is set to 0.5 (-)
SWC_high = input coefficient related to pedological features; it is set to 0.6(-)
m = empirical water coefficient of microbial mineralization activity (-).
fSAT = microbial water factor at saturation (-).

Crop Residual simulation

As mentioned above the management of crop residual has a basic role in soil C processes, for this reason the ARMOSA model has been improved in this way. In general ARMOSA model requires input data which represent crop residue simulation, this input are variables, parameters, coefficients. The model user can define more that (i) crop rotation, (i) sowing and harvest time, (ii) time, amount and type of nitrogen fertilizers (iv) time and amount of water irrigation, can define the quantity (in percent of total) of single plant part biomass remain in soil and the tillage depth which represents the depth of incorporation. ARMOSA for simulation the growing of crop used a several parameters which included in database. In particular for (i) growth, using 74 parameters which lead the gross assimilation of CO_2, LAI (leaf area index) and SLA (specific leaf area), stem and root elongation, respiration loss, vernalization, nitrogen dilution curve; (ii) development based on GDD (Growing Degree Days); (iii) coefficients of dry matter partitioning between above and below ground parts of the crop; (iv) coefficients of dry matter partitioning between leaves, stem and storage; (v) coefficients for the evapotranspiration calculation (FAO56) and (vi) parameters related to crop residuals module.

Below are present the implementations made.

The user define for each crop the percentage of single crop part, leaves, stem and storage which remain on soil surface at harvest ; consequently the remaining part is define as yield. The roots remain all in the soil. For model of residuals ARMOSA needed to indicate the rate of mineralization (d^{-1}) of and the fraction of carbon of each part of the crop.

ARMOSA estimates the nitrogen demand and the nitrogen stress and according to nitrogen soil availability and dilution curve calculated nitrogen uptake. ARMOSA divided AGB uptake and roots uptake. For calculate the nitrogen in crop residual used the specific parameter which represent the percentage of nitrogen which is present in all part of crop at harvest, consequence it is possible calculate the organic nitrogen that remain in the soil (root + residuals). The parameters is described in Table 4.3.6.

Table 4.3.6. Parameters related to crop residuals module.

Parameter	Description
id_Crop	crop number
crop	Crop name
LeavesResidual	% of leaves that remains on the field after harvest
StemResidual	% of stem that remains on the field after harvest
StorageResidual	% of stem that remains on the field after harvest
kleaf	mineralization rate of leaves d^{-1}
kstem	mineralization rate of stem d^{-1}
kstorage	mineralization rate of storage d^{-1}
kroot	mineralization rate of roots d^{-1}
fCleaf	carbon fraction of leaves
fCstem	carbon fraction of stem
fCstorage	carbon fraction of storage
fCroot	carbon fraction of root
CNleaf	% Nitrogen in leaves at harvest
CNstem	% Nitrogen in stem at harvest
CNstorage	% Nitrogen in storage at harvest

The roots have an important factor to C soil processes (Wilts et al., 2004), for improve the estimate root residuals was introduced according to Van den Berg and Driessen (2002) the estimates root fractions and root length densities in each soil layer as a function of root biomass in the soil profile and root depth using the empirical model.

$$RootFraction_i = -0.8\left[\left(\frac{BottomDepth_i}{RootDepth}\right)^2 - \left(\frac{TopDepth_i}{RootDepth}\right)^2\right] + 1.8\left(\frac{BottomDepht_i - TopDepth_1}{RootDepth}\right)$$

where $RootFraction_i$ is the fraction of total roots at the layer i (0-1), $BottomDepth_i$ is the depth of the bottom of layer i (cm), $TopDepth_i$ is depth of the top of layer I (cm), RootDepth is the depth reached by roots (cm) and all coefficients are derived empirically.

The biomass fraction is computed as:

$$BiomassFraction_i = RootFranction_i i \times RootBiomass$$

where $RootFraction_i$ is the fraction of total roots at the layer i (0-1), RootBiomass is the total root biomass (kg ha^{-1}) and $BiomassFraction_i$ is the root biomass at soil layer i (kg ha^{-1}).

The calculation of root density is done according to the following equation:

$$RootLengthDensity_i = BiomassFraction_i \frac{10.5}{Thickness_i}$$

where $BiomassFraction_i$ is the root biomass at soil layer i (kg ha^{-1}), $Thickness_i$ is the layer i thickness, $RootLengthDensity_i$ is the root length density at layer i (m m^{-3})and 10.5 is the conversion factor from root biomass to root length (m kg^{-1}).

For many plants as much as 30–50% of the C fixed in photosynthesis is initially translocated below-ground. Some is used for structural growth of the root system, some for autotrophic respiration, and some is lost to the surrounding soil in organic form (rhizodeposition). Baker et al. (2006) reported that rhizodeposition by winter wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.) accounted for up to 15% of net C assimilation during the growing season.

From an analysis of literature (Amos and Walter, 2006) is reported the wide variation existing in the literature regarding reported root and shoot biomass and the roots/Above Ground Biomass (AGB) ratio and there are estimated a roots/AGB ratio at physiological maturity; approximately 20% of total biomass at maturity stays in the form of roots in the soil. Other authors (Buyanovsky and Wagner, 1997) has been suggested to range from 20 to 40% and Wilts et al. (2004) has measured a roots/AGB ratios almost 200% higher than most value shown ion the literature. According to ISTAT, 2013 the average yield of Lombady for maize is about 25 t ha^{-1} AGB the root biomass is about 5 to 10 t ha^{-1} of dry matter or more.

The improved model module allows to perform more realistic simulations on C sequestration in particular with regard the evolution of SOC under different management systems.

4.3.5.2. **Model parameterization**

ARMOSA was parameterized to simulate the two tillage systems. For CA scenario the depth of tillage was limited to 10 cm without crop residual incorporation mimicking the minimum tillage which determine a least soil disturbance leaving the maximum amount of crop residue on the soil surface. ARMOSA is not able at the time of modeling the effects of sod seeding; in the future will be extended whit mulch module to simulated no-tillage whit surface crop residual. The mulch module is needed to evaluated the changes in water evaporation dynamics, thermal exchanges and C and N transformations which the no-tillage condition created in soil surface (Oorts et al., 2007). In fact the mulch layer exerted a considerable influence on the water dynamics:

evaporation was reduced while water drainage increased. This effect has a largest influence on the difference in decomposition rate of crop (Al-Kaisi and Yin, 2005). However, since Alvarez (2005) shown that there were not differences in SOC between reduced till (i.e. chisel, disc, and sweep till) and no-till, the two systems were assumed to be equivalent as simulation depth as well as for the model parameters. For TA scenario the model was run assigning a plowing depth for each crop to optimize the incorporation of residuals: the tillage depth varied from 0 cm for meadows grass to 30 cm for maize.

Since the lack of experimental data the parameters describing the organic matter composition processes were taken from the literature. To simulate AT practices were used the parameters calibrated and validated by Perego et al., (2013) on a large dataset collected at six monitoring sites in Lombardy plain. To simulate the CA practices the parameters were selected according to Oorts et al. (2007). They found that the rate of C decomposition of humified organic C was smaller by 30% in no-tillage than in TA. Table 4.3.7 showed the parameter of mineralization rate of humus and Table 4.3.8 residuals parameters of simulated crops.

Table 4.3.7. Parameters of humification processes in the tillage agriculture (TA) and conservation agriculture (CA).

Symbol	Parameters	ID nitrogen*	TA	CA
k	Decomposition rate of humus (d^{-1})	1	0.000125	0.000145
		2	0.000108	0.000125
		3	0.0000905	0.000105
hf	Humification factor of litter/manure (d^{-1})	1	0.45	0.35
		2	0.45	0.35
		3	0.45	0.35

* id of nitrogen soil caracterization: 1 if send < 25%, 2 if 25% > sand < 40%, 3 if sand > 40%

Table 4.3.8. Residual parameters of simulated crops.

Parameters	Alfalfa	Cover crop	Grain maize	Meadows	Silage maize	Soybean	Wheat
LeavesResidual (%)	15	5	100	15	5	100	10
StemResidual (%)	10	5	100	10	10	100	10
StorageResidual (%)	1	1	1	1	1	1	1
kleaf (d^{-1})	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143
kstem (d^{-1})	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148
kstorage (d^{-1})	0.03	0.03	0.03	0.03	0.03	0.03	0.03
kroot (d^{-1})	0.000311	0.000311	0.000311	0.000311	0.000311	0.000311	0.000311
N_leaf_harvest (%)	0	0	0	0	0	0	0
N_storage_harvest (%)	0	0	0	0	0	0	0
N_stem_harvest (%)	0	0	0	0	0	0	0

4.3.5.3. **Model simulation**

The ARMOSA model was run over a period of 23 years using a daily meteorological data previously shown. The model input and output used under the simulation of CA and TA systems are shown in Table 4.3.9.

Table 4.3.9. The model input and output

Model input
Soil properties: SOC, bulk density, texture
Daily weather: precipitation, maximum and minimum air temperature, solar radiation
Crop: crop rotation (five years based)
Farming management: planting and harvest dates, tillage depht, crop residue management, organic and mineral N fertilization (date, amount, depht)
Model output
Crop productivity: grain, stem and root yield, N-uptake, N-fixation by legumes
Trace gas fluxes: CO_2, NH_3, N_2
Soil organic C and N pools
Soil inorganic N content (nitrate and ammonia)

For the simulation of the two systems was used a specific management for each crop rotation considering: fertilization and manure application (time and amount), planting and harvest dates, tillage depths for conventional tillage, and crop residue management.

The two systems were simulated for the same crop rotations and soil types previously individuated to assert their effects on C sequestration potential.

4.3.5.4. **Carbon balance**

The results of simulation, eexcluding the first three years of the simulation as model warm up, were used to estimate the carbon balance of two systems. The input data are: (i) the atmospheric CO_2-C fixed via photosynthesis, (ii) the addition of C through manure fertilization, (iii) the amount of C contained in the crop residues. The output data are: (i) the C content of the harvested biomass, (ii) the C mineralized by the microbial biomass. Moreover, the difference in C content of the M, L and H pools are items of the balance. The C balance allows for the estimation of the increasing or decrease of the soil C content over the years of simulation. C sequestration rates were estimated by calculating the mean difference between the final and initial SOC under alternative practices, using soil data to a depth of cm 40 from the latest year of simulations done by West and Post (2002), Freibauer et al. (2004) and Smith (2004). To obtain the C sequestration potential at AR level we considered the difference of carbon balance (ΔSOC) between CA and TA for each crop rotation and soil type combination as described below:

1- Calculation of the potential of C sequestration for each crop rotation ($\Delta SOCRot_i$) as weighted average for the ΔSOC in all AR soils, as:

$$\Delta SOCRot_i = \sum_{i=1}^{n\,rot} (\Delta SOC_i \times \%\, UUA\, UTS_1 + \Delta SOC_i \times \%\, UUA\, UTS_2 + \Delta SOC_i \times \%\, UUA\, UTS_n)$$

where i is the number of rotation, ΔSOC is the different between CA and TA and % UAA UTS is the percentage of the area covered by each soil type in AR.

2- Calculation of the potential of C sequestration for each AR ($\Delta SOCAR_i$) as:

$$\Delta SOCAR_i = \sum_{i=1}^{n\,rot} (\Delta SOC_i \times \%\, UUA)$$

where i is the number of rotation and % UAA is the percentage of the area covered by each rotation in AR.

4.3.6. Territorial analysis

The information about the potential C sequestration relative to each hectare of soil under conservative practices into each AR, was further used to carried out a territorial analysis under the current and alternative scenarios.

The current scenario was relative to the diffusion of the conservative techniques in the UAA currently adopted with the measure 214 M in 2012.

In the alternatives scenarios it was assumed an increasing in each AR of the UAA under conservative management, till a maximum of 50% of the simulated UAA, as follow:

Scenario1 : Conversion of the 5% of simulated UAA to CA
Scenario2 : Conversion of the 10% of simulated UAA to CA
Scenario3 : Conversion of the 20% of simulated UAA to CA
Scenario4 : Conversion of the 30% of simulated UAA to CA
Scenario5 : Conversion of the 50% of simulated UAA to CA

4.4. Result and discussion

4.4.1.1. Model results

The model results showed a significant improve of SOC ($p<0.01$) from TA to CA under all the crop rotations. In Table 4.4.1, it is shown the difference of SOC which is calculated as mean of AR results; all the crop rotations have a positive potential of carbon sequestration. The carbon sequestration potential ranged from 0.1 to 0.48 t C ha^{-1} y^{-1}. A lot of experimental outcomes confirm these result: in a review, Freibauer et al.(2004) showed a potential carbon sequestration of 0.1 to 0.5 t C^{-1} ha^{-1} for CA.

Table 4.4.1. Model results of soil C sequestration rates (t C ha^{-1} y^{-1}) by conversion from TA to CA in main crop rotations types in soil of Lombardy plain.

ID Rotation	SOC sequestration potential from TA to AC (t C^{-ha} year^{-1})	% difference from TA to AC	% difference per year from TA to AC
F	0.21	7.7%	0.4%
MG	0.48	12.6%	0.6%
MF	0.18	7.1%	0.4%
Med_F_MG	0.14	3.2%	0.2%
Med_MG	0.15	3.5%	0.2%
MG_cover	0.42	10.3%	0.5%
MG_F	0.33	10.7%	0.5%
PVMG	0.10	2.1%	0.1%
PVMF	0.10	2.0%	0.1%

The largest increases were estimated under MG and MG_cover rotations, which were respectively 0.48 and 0.49 t C^{-1} ha^{-1} y^{-1}; this result was probably due to the amount of crop residue left in the field: for MG were 5.88 t C ha^{-1} y^{-1} and for MG_cover 5.9 t C ha^{-1} y^{-1}. For continuous maize in long term trial (29 years) Wilts et al. (2004) reported an increases of 25% or more of δ13C which represented the relative contribution of C by plant organs when stover was returned into soil profile and not harvested. West and Post (2002) indicated the change to CA from TA for maize monoculture system: it sequestered 1.2% (±0.9) of SOC a year in the first 30 cm of soil. Freibauer et al.(2004) indicated the crop residue incorporation into soil as a measure for increasing soil carbon sequestration up to 0.7 t C ha^{-1} y^{-1}. Smith et al. (2000) indicated that increasing from 2 to 10 t ha^{-1} y^{-1} of cereal straw incorporated into soil involved a accumulation rate increase (% year^{-1}) of 0.42 to 1.31% in the first 30 cm of soil. The ARMOSA model results (Table 4.4.2 and Table 4.4.1) indicated similar value; in our case, we compare the rotation MG (harvest only grain) and MF (harvested grain and stover). For MG the crop residue and roots (in the first 40 cm of soil) was 5.8 t C ha^{-1} y^{-1} on average, which corresponded to 13.9 t ha^{-1} y^{-1} of dry matter (DM), while for MF was 1.08 t C ha^{-1} y^{-1} (2.57 t DM ha^{-1} y^{-1}. The carbon was assumed to be the 42% of the maize biomass in agreement with

Wilts at al., 2004. West and Post (2002) showed that no change in SOC content did not result in increased C sequestration from continuous corn to a corn–soybean rotation because corn generally produces to more residues, involving higher C input than a corn–soybean rotation system.

Table 4.4.2. Amount of residual incorporation on soil (t C ha^{-1}). The data were calculated as mean of two treatment for rotations.

ID Rotation	Residulas in soil (t C ha^{-1})
F	7.38
MG	13.99
MF	2.58
Med_F_MG	7.05
Med_MG	7.05
MG_cover	14.05
MG_F	11.23
PVMG	5.61
PVMF	5.97

Conversely, the lowest increase of SOC occurred under the maize-meadow grass (1 year of maize and 4 years of meadow grass) and the maize-alfalfa rotation (2 years maize and 3 years alfalfa or 1 year maize, 1 year wheat and 3 years alfalfa). In such a case the effect of CA was reduced because the management of grass fields was set equally in both treatments (Table 4.4.2).

The results are in agreement whit outcomes reported by Alvarez (2005) who calculated the mean of SOC evolution in cereals systems over 20-30 years under CA in first 30 cm of soil layer, reporting an increase of 14% of SOC.

The effect of the soil texture on SOC evolution was studied through the soil conditions of Lombardy plain. This analysis of carbon sequestration was conducted by aggregating the soil for texture class. The aggregation of soil was executed in agreement with the FAO textural classes (Alvarez, 2005 and FAO/Unesco, 1970-1980), which are: a) coarse textured: sands, loamy sands and sandy loams with less than 18% clay and more than 65% of sand; b) medium textured: sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams and clay loams with less than 35 % clay and less than 65 % sand; the sand fraction may be as high as 82% if a minimum of 18% of clay is present; c) fine textured: clays, silty clays, sandy clays, clay loams and silty clay loams with more than 35% of clay.

Texture has significant influence on the sequestration and depletion of SOC, especially clay concentration (Parton et al., 1987; Burke et al., 1989; Beker-Heidmann and Scharpenseel, 1992; Parton et al., 1994; Schimel et al., 1994; Lantz et al., 2002). Soil texture in C sequestration influences the formation rate of passive C (Parton et al., 1994); secondly, it affects crop production and decomposition by controlling the water budget through its effects on soil hydrologic properties (Schimel et al., 1994).

The model results showed a not significant improve of SOC ($p>0.05$) from TA to CA under different soil group (Table 4.4.3). This result are in according to Alvarez (2005) that reported the data of 137 experimental trials which were carried out to evaluate the impact of contrasting tillage systems practices (CA vs AT) on carbon sequestration. He showed that soil texture did not affect significantly the SOC sequestration process, whereas the soil tillage involved significant differences ($p<0.05$) in SOC storage between CA versus CT.

Table 4.4.3. Model results of soil C sequestration rates (t C ha^{-1} y^{-1}) by conversion from TA to CA in main crop rotations types in Lombardy plain aggregate for soil texture.

Texture class	SOC sequestration potential from TA to AC (t C^{-ha} year^{-1})	% difference from TA to AC	% difference per year from TA to AC
coarse	0.23	5.84%	0.29%
fine	0.29	7.14%	0.36%
medium	0.26	6.94%	0.35%

In the Table 4.4.4 is shown the SOC sequestration potential for each AR calculated when the procedure descripted in chapter 4.3.5.4 after 20 year of model simulations.

Table 4.4.4. Soil C sequestration potential from AT to CA in AR of Lombardy plain according to rotations and soil types after 20 years of simulation data.

Agrarian Region	SOC sequestration potential from TA to AC (t C^{-ha} year^{-1})	% difference from TA to AC	% difference per year from TA to AC
12-03	0.65	11.14%	0.56%
12-04	0.65	13.85%	0.69%
12-05	0.69	13.09%	0.65%
12-06	0.45	10.74%	0.54%
13-09	0.45	8.87%	0.44%
13-10	0.38	7.05%	0.35%
13-13	0.38	10.43%	0.52%
15-01	0.65	14.33%	0.72%
15-02	0.44	10.11%	0.51%
15-03	0.50	12.52%	0.63%
15-04	0.39	10.98%	0.55%
15-05	0.47	11.91%	0.60%
15-06	0.39	10.37%	0.52%
15-07	0.40	10.73%	0.54%
15-08	0.47	13.04%	0.65%
15-09	0.41	16.16%	0.81%
16-06	0.39	10.37%	0.52%
16-07	0.16	5.06%	0.25%
16-08	0.42	13.87%	0.69%
16-09	0.37	10.60%	0.53%
16-10	0.34	10.73%	0.54%
17-10	0.46	14.31%	0.72%
17-11	0.30	9.54%	0.48%
17-12	0.39	11.80%	0.59%
17-13	0.51	21.46%	1.07%
17-14	0.49	14.69%	0.73%
18-02	0.20	7.82%	0.39%
18-04	0.61	19.80%	0.99%
18-05	0.35	10.84%	0.54%
18-06	0.33	10.54%	0.53%
18-07	0.44	14.41%	0.72%
18-08	0.41	15.01%	0.75%
18-09	0.40	15.52%	0.78%
18-10	0.31	11.24%	0.56%
18-11	0.56	21.82%	1.09%
19-01	0.51	11.54%	0.58%
19-02	0.90	20.99%	1.05%
19-03	0.81	20.41%	1.02%
19-04	0.78	21.91%	1.10%
19-05	0.71	21.41%	1.07%
19-06	0.77	21.86%	1.09%
19-07	0.40	12.34%	0.62%
20-01	0.72	23.10%	1.15%
20-02	0.48	13.80%	0.69%
20-03	0.87	21.39%	1.07%
20-04	0.40	11.90%	0.59%
20-05	0.83	21.31%	1.07%
20-06	0.40	12.75%	0.64%
20-07	0.32	10.23%	0.51%
20-09	0.54	19.96%	1.00%
97-04	0.58	8.81%	0.44%
97-05	0.73	13.62%	0.68%
98-01	0.40	12.01%	0.60%
98-02	0.75	23.44%	1.17%
98-03	0.61	23.98%	1.20%

4.4.2.Current scenario

The current scenario was defined on the basis of the data available in the official Regional database (SIATL), which reports the percentage of UAA in which the M measure is currently applied (Figure 4.3.5). These data were useful to estimate the actual SOC sequestration in the UAA of Lombardy plain. In such an area, the simulations were performed only in crop land. To calculate the SOC in the crop land of the Lombardy UAA, we assumed that in the UAA were the CA is not adopted the SOC has the same value reported in the SIATL database.

The calculated SOC sequestration potential under the current scenario is reported in Table 4.4.5; it is 252,201 t, over an area of 24,492 ha, which means a rate of 0.65 t C ha^{-1} year^{-1}on average.

Table 4.4.5. The soil sequestration of carbon under the current scenario in each AR in Lombardy plain

AR	SOC T0 (t)	UAA total (ha)	UAA (ha) representative crop rotations	% UAA under CA	UAA under CA (ha)	SOC sequestration potential from TA to AC (t C^{-ha} year^{-1})	SOC stored (t)	SOC T20 (t)
12-03	123,922	1,058	738	0.04%	0.4	0.65	5	123,927
12-04	165,097	1,758	1,447	0.00%	0.0	0.00	0	165,097
12-05	144,702	1,374	1,133	3.45%	47.4	0.69	654	145,356
12-06	214,859	2,541	2,541	2.65%	67.4	0.45	612	215,471
13-09	256,801	2,532	1,448	5.75%	145.5	0.45	1,308	258,110
13-10	197,790	1,840	911	0.23%	4.2	0.38	32	197,822
13-13	201,830	2,794	2,448	9.07%	253.4	0.38	1,908	203,738
15-01	143,700	1,587	1,587	1.27%	20.1	0.65	261	143,961
15-02	254,114	2,927	2,927	2.85%	83.5	0.44	733	254,847
15-03	194,634	2,421	2,421	2.48%	60.1	0.50	605	195,240
15-04	408,792	5,757	5,757	2.30%	132.4	0.39	1,033	409,824
15-05	583,591	7,444	7,444	6.92%	514.8	0.47	4,806	588,397
15-06	323,641	4,268	3,516	12.98%	554.1	0.39	4,358	327,999
15-07	1,238,592	16,786	15,442	6.03%	1,011.5	0.40	8,009	1,246,601
15-08	1,503,093	20,924	9,526	14.13%	2,957.4	0.47	27,706	1,530,800
15-09	32,387	645	430	2.64%	17.0	0.41	138	32,525
16-06	121,968	1,639	1,088	0.00%	0.0	0.00	0	121,968
16-07	127,627	1,995	499	0.00%	0.0	0.00	0	127,627
16-08	131,464	2,178	2,178	0.00%	0.0	0.00	0	131,464
16-09	1,135,193	16,415	16,415	0.70%	115.5	0.37	847	1,136,040
16-10	786,552	12,297	12,297	1.63%	201.0	0.34	1,379	787,931
17-10	370,483	5,792	4,526	2.24%	129.9	0.46	1,190	371,672
17-11	689,550	11,121	8,535	1.05%	116.5	0.30	689	690,239
17-12	1,472,483	22,063	22,063	3.25%	717.3	0.39	5,652	1,478,134
17-13	1,244,576	26,215	26,215	2.51%	659.1	0.51	6,716	1,251,291
17-14	2,342,099	35,315	35,315	1.39%	491.6	0.49	4,789	2,346,888
18-02	699,017	13,568	4,858	0.33%	44.9	0.20	181	699,198
18-04	1,822,935	29,773	1,699	7.43%	2,213.3	0.61	26,834	1,849,768
18-05	1,827,228	28,231	3,907	3.91%	1,105.0	0.35	7,755	1,834,983
18-06	279,852	4,454	1,385	12.62%	562.0	0.33	3,722	283,574
18-07	1,121,274	18,276	4,248	16.08%	2,939.4	0.44	25,994	1,147,268
18-08	586,973	10,733	2,622	8.30%	890.4	0.41	7,309	594,282
18-09	478,657	9,172	2,072	0.59%	54.3	0.40	440	479,097
18-10	859,037	15,337	15,337	2.14%	328.6	0.31	2,069	861,107
18-11	518,741	10,036	6,800	9.25%	928.4	0.56	10,471	529,212
19-01	727,184	8,191	8,191	1.68%	137.9	0.51	1,412	728,597
19-02	1,787,874	20,931	20,931	3.33%	697.3	0.90	12,502	1,800,375
19-03	610,568	7,658	7,658	2.08%	159.1	0.81	2,589	613,157
19-04	1,357,731	18,987	18,987	5.97%	1,133.7	0.78	17,765	1,375,496
19-05	1,324,991	19,985	19,985	4.30%	859.4	0.71	12,198	1,337,189
19-06	1,308,115	18,573	18,573	1.67%	310.3	0.77	4,777	1,312,892
19-07	1,133,306	17,418	15,554	2.55%	443.3	0.40	3,560	1,136,866
20-01	631,377	10,079	9,328	4.28%	431.8	0.72	6,248	637,626
20-02	1,774,844	25,408	25,408	0.81%	205.4	0.48	1,980	1,776,824
20-03	1,646,870	20,272	20,272	0.66%	134.5	0.87	2,337	1,649,208
20-04	1,277,636	18,873	16,700	1.02%	192.4	0.40	1,549	1,279,185
20-05	1,442,397	18,467	17,161	0.00%	0.0	0.00	0	1,442,397
20-06	990,034	15,786	15,786	0.00%	0.0	0.00	0	990,034
20-07	1,145,615	18,266	15,877	0.04%	6.6	0.32	43	1,145,657
20-09	186,127	3,420	1,437	3.20%	109.3	0.54	1,188	187,314
97-04	46,165	353	187	0.00%	0.0	0.00	0	46,165
97-05	403,330	3,783	3,168	0.05%	1.8	0.73	26	403,356
98-01	1,135,516	17,109	15,889	5.94%	1,015.9	0.40	8,096	1,143,612
98-02	1,039,880	16,354	16,354	4.51%	738.3	0.75	11,004	1,050,884
98-03	505,379	9,888	9,888	5.55%	548.6	0.61	6,722	512,101
Totale	**43,078,189**	**641,068**	**509,106**	**3.82%**	**24,492**	**0.65**	**252,201**	**43,330,390**

4.4.3.Alternative scenarios

We defined five alternative scenarios in which the UAA under M measure was assumed increasing. The resulting variation of SOC stock in such area are shown in Figure 4.4.1; the maps display the result of the five scenarios. The greater amount of SOC sequestration is in the province of Cremona, plain of Brescia and east of Mantova (in the center of plain), in fact in this AR the grain maize rotation represents the over 60% of simulated UAA, in view of higher rate of residues incorporated into the soil.

Conversely, in the AR (in north-east of plain) in which the permanent or annual meadow are the most cultivated the difference of SOC involved by the two treatments was not relevant (0.3 t ha^{-1} $year^{-1}$), whereas it was higher under maize rotations (0.38 t ha^{-1} $year^{-1}$). An exception is represented by the ARs of Lomellina (in south-east of plain) because the most UAA of crop land is cultivated with rice and, consequently, the low rate of carbon sequestration was not included in this study.

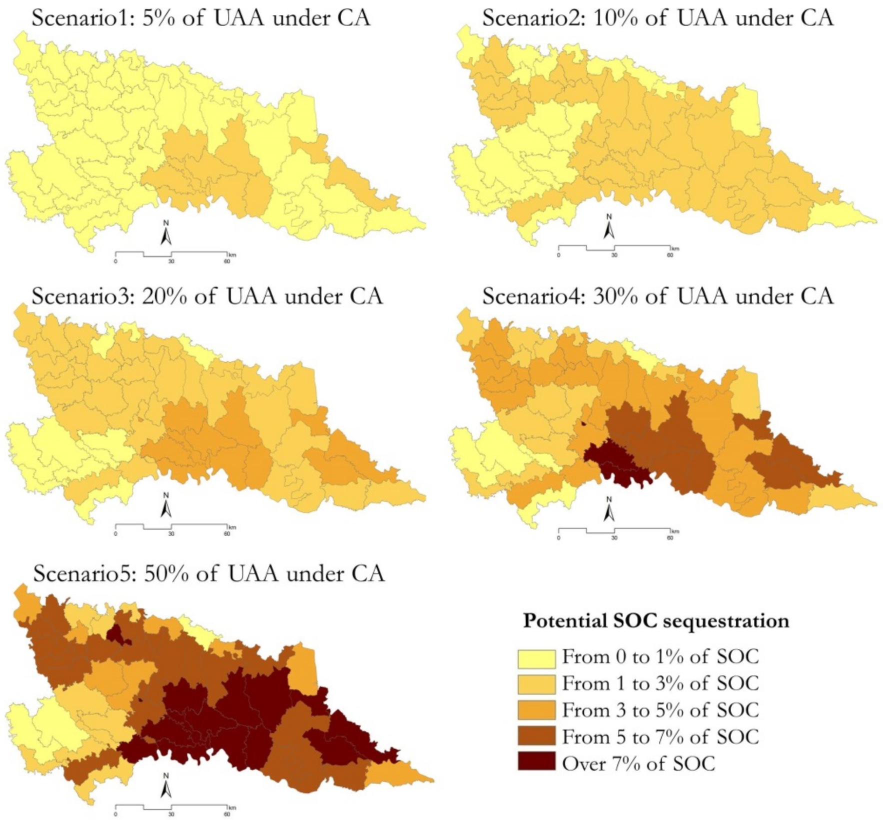

Figure 4.4.1. Maps of potential SOC sequestration in AR under five alternatives scenarios, (data in % of improves SOC).

4.4.4. The contribution from measure M

To determine the amount of funding for each simulated scenario, we considered the amount of annual compensation of the measure 214th, M action, assuming a contribution of 190 € ha^{-1} y^{-1} that is the current one for minimum tillage. For each scenario we estimated the contribution that farmers should receive after 20 years of conservative agriculture, assuming unchanged the value of financing equal to 190 € ha^{-1} y^{-1}.

Table 4.4.6 reports the AR involved in the action M, measure 214th, and shows the estimated value of the storage of C in the soil after 20 years under conservative techniques in the UAA under actual scenarios.

The carbon stored in soils can be put in relation with the CO_2 emission (rate of conversion from C to CO_2 equal to 3.67). The columns of Table 4.4.6 "€ t^{-1} C incorporated" and "€ t^{-1} CO_2 not emitted" were included to highlight the possible funding granted by the European policies for any unit of C stored per unit or per unit of CO_2 emission. The difference of € t^{-1} of C incorporated in the AR, which ranged between 211.96 and 943.08 € t^{-1} of C is due to the different crop rotations which are cropping in the AR (Table 4.4.6).

Table 4.4.6. Soil C sequestration and total payment (190 € ha^{-1} y^{-1}) by the actual M measure, action 214th after 20 years for AR under the current scenario (T0: initial time, T20: after 20 year).

Agrarian Region	UAA under CA (ha)	SOC stored (t)	CO_2 eq. (t)	payments T20 (190€ ha^{-1} y^{-1})	payments (€ y^{-1})	€ t^{-1} C stored	€ t^{-1} CO2 not emitted
12-03	0	5	20	1,584	79	291.19	79.34
12-04	0	0	0	0	0	0.00	0.00
12-05	47	654	2,399	180,263	9,013	275.75	75.14
12-06	67	612	2,246	255,988	12,799	418.30	113.98
13-09	145	1,308	4,801	552,723	27,636	422.49	115.12
13-10	4	32	117	15,951	798	501.51	136.65
13-13	253	1,908	7,003	962,988	48,149	504.67	137.51
15-01	20	261	956	76,324	3,816	292.90	79.81
15-02	83	733	2,690	317,277	15,864	432.79	117.93
15-03	60	605	2,222	228,550	11,428	377.49	102.86
15-04	132	1,033	3,790	503,240	25,162	487.32	132.79
15-05	515	4,806	17,639	1,956,325	97,816	407.03	110.91
15-06	554	4,358	15,993	2,105,545	105,277	483.18	131.66
15-07	1,012	8,009	29,394	3,843,840	192,192	479.92	130.77
15-08	2,957	27,706	101,682	11,238,094	561,905	405.61	110.52
15-09	17	138	506	64,614	3,231	468.60	127.69
16-06	0	0	0	0	0	0.00	0.00
16-07	0	0	0	0	0	0.00	0.00
16-08	0	0	0	0	0	0.00	0.00
16-09	116	847	3,110	439,088	21,954	518.14	141.18
16-10	201	1,379	5,062	763,798	38,190	553.80	150.90
17-10	130	1,190	4,366	493,793	24,690	415.07	113.10
17-11	116	689	2,529	442,616	22,131	642.38	175.03
17-12	717	5,652	20,741	2,725,879	136,294	482.33	131.42
17-13	659	6,716	24,647	2,504,500	125,225	372.92	101.61
17-14	492	4,789	17,575	1,867,912	93,396	390.05	106.28
18-02	45	181	664	170,529	8,526	943.08	256.97
18-04	2,213	26,834	98,480	8,410,429	420,521	313.43	85.40
18-05	1,105	7,755	28,462	4,198,955	209,948	541.43	147.53
18-06	562	3,722	13,659	2,135,685	106,784	573.82	156.35
18-07	2,939	25,994	95,397	11,169,650	558,483	429.70	117.09
18-08	890	7,309	26,826	3,383,634	169,182	462.91	126.13
18-09	54	440	1,614	206,432	10,322	469.31	127.88
18-10	329	2,069	7,594	1,248,671	62,434	603.45	164.43
18-11	928	10,471	38,428	3,528,005	176,400	336.93	91.81
19-01	138	1,412	5,183	523,897	26,195	370.96	101.08
19-02	697	12,502	45,882	2,649,897	132,495	211.96	57.75
19-03	159	2,589	9,501	604,720	30,236	233.58	63.65
19-04	1,134	17,765	65,197	4,308,122	215,406	242.51	66.08
19-05	859	12,198	44,765	3,265,685	163,284	267.73	72.95
19-06	310	4,777	17,532	1,179,265	58,963	246.86	67.26
19-07	443	3,560	13,065	1,684,688	84,234	473.25	128.95
20-01	432	6,248	22,931	1,640,897	82,045	262.61	71.56
20-02	205	1,980	7,266	780,599	39,030	394.27	107.43
20-03	135	2,337	8,578	511,179	25,559	218.71	59.60
20-04	192	1,549	5,685	730,953	36,548	471.83	128.57
20-05	0	0	0	0	0	0.00	0.00
20-06	0	0	0	0	0	0.00	0.00
20-07	7	43	156	25,193	1,260	592.06	161.32
20-09	109	1,188	4,358	415,361	20,768	349.76	95.30
97-04	0	0	0	0	0	0.00	0.00
97-05	2	26	95	6,773	339	261.77	71.33
98-01	1,016	8,096	29,713	3,860,587	193,029	476.84	129.93
98-02	738	11,004	40,385	2,805,447	140,272	254.95	69.47
98-03	549	6,722	24,670	2,084,562	104,228	310.11	84.50
Totale	**24,492**	**252,201**	**925,576**	**93,070,707**	**4,653,535**	**369.03**	**100.55**

Table 4.4.7 shows the model outcome under the first scenario (190 € ha^{-1}) considering increasing of UAA involved in the M measure, action 214th, which corresponds to a different amount of contribution. Table 4.4.7 also reports the analysis outcome under the five hypothetical scenarios up to a maximum of 50% of the UAA cultivated under CA. The analysis took into account only a minimum tillage with a loan of 190 € ha^{-1}.

Through the modeling analysis it was possible to estimate the amount of carbon stored in the soil for which the grant is meant to be constant. In particular funding of € 353.01 would be paid for one ton of C stored, which corresponds to 96.19 € for a ton of CO_2 not emitted. The last column shows the annual funding that should be provided for the amount of land concerned by conservative techniques.

Table 4.4.7. Total amount of payment of M measure for five alternative scenarios (190 € ha^{-1} y^{-1}).

Scenario	% simulated UAA under CA	UAA under CA (ha)	% total UAA	fundings € for 20 years	C stored (t)	% difference from T0 to T20	ton CO2 eq.	€ t^{-1} C stored	€ t^{-1} CO2 not emitted	€ y^{-1}
Scenario 1	5%	25,455	4%	96,730,196	274,016	0	1,005,637	353.01	96.19	4,836,510
Scenario 2	10%	50,911	8%	193,460,391	548,031	0	2,011,274	353.01	96.19	9,673,020
Scenario 3	20%	101,821	16%	386,920,782	1,096,062	0	4,022,548	353.01	96.19	19,346,039
Scenario 4	30%	152,732	24%	580,381,174	1,644,093	0	6,033,823	353.01	96.19	29,019,059
Scenario 5	50%	254,553	40%	967,301,956	2,740,156	0	10,056,371	353.01	96.19	48,365,098

The estimated subsidies appeared to be pretty high. If we take into account the public financial resources allocated to the Rural Development Program for the Lombardy Region for the whole period 2007-2013 which amounted to 1,025,193,491 € (Mid-term evaluation of the RDP, 2010). Such amount includes 503,958,147 € for axis 2 and € 273,797,954 to the M measure, action 214th. Considering that the funding program lasts seven years, it is reasonable to think that they can be allocated from 6 to 12 million euro to M measure.

If funding amount of the next rural development program (2013-2020) will remain similar to the current, as suggested by the press of the European

Commission, it is conceivable to allocate 5 to 10% of the Lombardy UAA land to conservative agriculture for minimum tillage (190 € ha^{-1} y^{-1}), or 5% of Lombardy UAA for minimum tillage coupled with the slurry injection (260 € ha^{-1} y^{-1}).

4.5. **Conclusion**

The model ARMOSA allowed to set the conditions for the accounting of organic C stored in soil subject to conservative techniques. The model results showed a significant improve of SOC ($p<0.01$) from TA to CA under all the crop rotations with a potential SOC sequestration ranged from 0.1 to 0.48 t C ha^{-1} y^{-1}. Conversely, ARMOSA showed a not significant improve of SOC ($p>0.05$) from TA to CA under different soil group. This result showed the great role of crop residue in C sequestration processes, in fact the largest increases were estimated under grain maize monoculture with or without cover crop, due to the abundant residues left on the soil; a lot of study confirm the positive role of crop residue (Wilts et al., 2004; West and Post 2002).

In a recent study of Lombardy soils (Brenna et al., 2010) it was estimated the SOC stored in the upper 40 cm of soils is about 124 million t. Analyzing the soil map and DUSAF it was possible showed the mean content of SOC in arable land; the mean is 54 t ha^{-1} with level below 30-40 t ha^{-1} especially in western and southern part. This analysis show a wide potential capacity to sequestration a large amount of C, if they are managed adopting conservative practices, so that SOC incorporation could in theory become a big challenge as well as a relevant opportunity for agriculture. Considering a prudential scenario, according to UAA under CA in Lombardy plain, converting a 10% of UAA able to conversion it would be possible improve the SOC to almost 1.6% after 20 years of time. Although considering a favorable scenario (50% of UAA able to conversion) the SOC sequestrating it would be almost 8% of actual level.

Under current scenario the impact of C sequestered by soils is quite limited (about 1%) if compared with the CO_2 annual emissions occurred in the Lombardy Region in 2010 (83 Mt CO_2 equivalent INEMAR, 2010). However, if compared to the total emissions related to the regional agricultural sector, the percentage becomes significant, representing the 12.1% of all emissions recorded in 2010 (7.8 Mt CO_2 equivalent).

A further comparison can be made with the objectives outlined in the Kyoto Protocol referring to the reduction of the quantities of domestic emissions. For Italy, it was required a reduction from 501.3 Mt CO_2 equivalent in 2010 to 485.7 MtCO_2 in 2012 (EEA, 2012). Considering the amount of equivalent CO_2 potentially not emitted with current scenario (Table 4.4.6), the Lombardy Region could contribute significantly by almost 6.1% with the cropping systems management. This result suggest that the carbon storage in the soil via conservative agriculture could be considered as indirect action for reducing CO_2 emission, then included in the inventory of LULUCF (Land Use, Land-Use Change and Forestry) to reach the standards set by the Kyoto and post-Kyoto.

The analysis indicated that payments to farmers referred to one ton of carbon stored (€ 353.01 t^{-1} C) turn out to be one of the largest in comparison to other programs or policies developed in international contexts.

The regional measure 214 action M allows to increase the SOC but payments for farmers are considerably greater than policies present at the international level. Considering the allocation of PSR funding and the amount paid in 2012 for the action M of the measure 214 it is conceivable to believe in an investment of 5% or 10% of the territory of the region of Lombardy with conservative agriculture.

For example, a pilot program introduced in Canada, Canada's Pilot Emission Removals, Reductions and Learning's (PERRL) enabled farmers to receive € 11.08 t^{-1} (1€ = 1,33 \$ Canada) of CO_2 stored which was. estimated through the coefficients of carbon sequestration. Farmers had to respect the conservative techniques such as no-till, and couldn't burn the stubble.

In Australia the ASCAS (Australian Soil Carbon Accreditation Scheme), a system of carbon credits, used to pay \$ 90 t^{-1} $year^{-1}$ (1€ = 1,33 \$ AUD). The increase of carbon in soil was assessed measuring the actual carbon yearly stored and compared with the initial stock (McKenzie et al. 2000). For each increase of 0.15% of carbon in soil sampled at 110 cm-depth the equivalent increase was 23.1 t ha^{-1} soil carbon stored.

CA has not only the purpose of incorporating soil C but also to reduce erosion and nutrient losses to water, to increase biodiversity and to reduce the emission of greenhouse gases from soils (Ball et al., 1999; Dumanski et al., 2006; Krutz et al. 2005).

It is however very high funding estimated in the scenarios proposed for the amount of carbon stored in soils and therefore can be expected in future years an increasing participation of farmers and the Lombardy plain.

Chapter 5

GENERAL CONCLUSIONS

As reported in Chapter 2, the ValorE DSS gives the possibility of carrying out a detailed analysis of manure management for all livestock farms in the Lombardy Region, contemporary assessing the effects of alternative scenarios and policies. The outcomes of running ValorE at regional scale highlighted its potentiality, as a tool supporting stakeholders on choosing and evaluating practical options, related to manure and cropping systems management. For example, the implementation of nitro-denitro plant (ALT 1) and the cover of all the available manure storage (ALT2), suggest both alternatives could be a viable solution to reduce environmental impacts, coming from manure management (e.g., N losses), even though investment and operating costs that could be significant.

On the other hand, the territorial scale application demonstrated the effectiveness, for the livestock manure management, of planning the interventions at territorial level, being referred to intensively managed areas. However, this result cannot be achieved, without (i) a strong collaboration between farmers and industry and (ii) the monitoring and coordination action of the Institutions, which should provide regulations and economic helps.

The effects of different nitrogen managements are presented in Chapter 3, as outlined by the current legislation on nitrate leaching. The territorial analysis, carried out by running the ARMOSA model under the nitrate derogation scenario (i.e., maximum N from manure = 250 kg ha-1 y-1 of which two thirds applied before 30 June cover crops introduction only when long growing season crops are not cultivated according to the limits of the law), pointed out that the potential risk of nitrate leaching in NVZ can be reduced, maintaining similar level of crop yields. In fact, simulation results showed N leaching decreasing by over half, comparing with actual scenario (no limitation in organic N application), and N efficiency globally improving. Moreover, management adopted under the derogation scenario can help increasing soil organic matter content, since an higher amount of organic fertilizer and crop residues are incorporated into the soil. Thus, from this preliminary application, the nitrate derogation can be considered as an interesting solution, for facing with the current concern of N leaching in Lombardy plain.

The positive effects of conservation agriculture on the potential carbon sequestration of the regional soils, are presented in Chapter 4. The territorial analysis, carried out again by using the ARMOSA model, detected a statistically significant difference after 20 years of simulation time ($p<0.01$) in SOC between conventional management and conservation agriculture, taking into account all typical crop rotations adopted in our region. Largest increases were estimated under grain maize monoculture (with or without cover crop), due to the abundant residues left on the soil. Since the C sequestration under the current scenario (i.e. current UAA under conservation agriculture, namely the area in which the agro-environmental measure 214-M, funded through RDP is currently applied), represents the 12.1% of the annual CO2 equivalent emitted by the agricultural sector in Lombardy Region, it would be interesting to extend the area to get further benefits. However, according to the actual amount of financial resources available in RDP for the measure M, it would be conceivable to allocate up to 10% of the Lombardy plain UAA to conservation agriculture.

Coming to conclusion, the territorial approach proposed in this thesis, was based on robust methodologies, extensive databases, stand-alone reliable models, more complex structures (ValorE DSS) reliable too, and GIS techniques. All these components led this approach to be an effective solution for investigating and supporting the regional agricultural management, as well as for assessing the potential impact of the regional policies.

Modelling and mapping agricultural and livestock production systems under improved scenarios can then effectively help producers and policy makers, always keeping in mind that agricultural sector plays a key role in the climate change mitigation and in the environmental protection from biodiversity loss and from N pollution.

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