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A MODEL BASED, DISTRICT SCALE DECISION SUPPORT SYSTEM FOR SWINE MANURE MANAGEMENT

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Sommario

ABSTRACT

Nitrates from slurries are one of the most important environmental issues regarding intensive livestock farming. Nitrate pollutes water bodies and high nitrates levels in water can also harm human and animal health. Farmers must face up with environmental laws, bureaucracy, manage their own decisions to respect them and to make profit. Farmers have to face these problems with limited tools.

In this framework an Individual approaches are extremely inefficient. The purpose of the Ager SEES PIG project, "Multi – regional Solutions to improve the Environmental and Economic Sustainability of Pig manure management in the Regions of the Po and Veneto basin", within which the present work has been carried out, is to support farmers, administrators and technicians to choose the best technological, environmental and economic solution to manage manure at farm and regional scale. Solutions should be valid through the Regions of the Po and Veneto basin (Piemonte, Lombardia, Veneto and Friuli Venezia Giulia) in the North of Italy.

The doctoral work focused its attention to cropping system simulation model in particular to the development of the agronomic module for the decision support system (DSS) with a user friendly interface.

One of the most important aspect related to cropping system simulation by models at the farm – district scale is the high number of simulations to be run.

This requires high computing power and, most important, it is time consuming. To overcome this issues, a number of methods aimed at reducing the computational complexity have been proposed. These methods regards technological data, crop rotations, second harvest and soil – climate combinations. Each method was tested and verified with statistical analysis. Simulations outputs, run with these strategies, have been manipulated to calculate a set of multiple linear regressions which are preloaded into the DSS so problems associated to cropping systems simulation model, database and inputs are avoided.

The developed DSS is based on a user friendly WebGIS interface and user is not obliged to download any software. With this approach user is not limited by operating system and processor.

The DSS allows users, whose farm is located in Regions of the Po and Veneto basin, to design alternative scenarios under different farming conditions (i.e.: irrigation, crops and their area, fertilization, cadastral unit property) and get an answer on the level of nitrogen (N) leached, percolated water and N volatilized from the farm using a minimal set of data.

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INTRODUCTION AND RELATED WORK

Intensive livestock farming has led to a progressive industrialization following the needs of adopting sophisticated technologies to build and manage livestock structures and equipment. Technological innovations regards buildings, air conditioning systems, feed processing and distribution, equipment for animal husbandry (e.g. milking devices for dairy cows), but also, more recently, manure removal, management, treatment systems and manure storage.

In particular, manure management has changed over time since the 1970s, with a transition from a solid form, (solid manure), to a fluid one, (slurries, liquid manure) (Sangiorgi et al., 1986). This evolution is mainly justified by the possibility of a livestock mechanization and automation associated to a significant decrease at labor demand. Slurries have now definitely established in most of livestock farms. Even if fluid management systems have reduced the problems related to the progressive reduction of labor force, new environmental issues have to be faced since the 1980s.

Intensive livestock are often unbound to agricultural activities, breaking the secular equilibrium between animal production, bearer nutrients, such as N, and the cultivation of crop. The progressive use of agricultural land with non – agricultural activities led to the disruption of the original production pattern. Furthermore, an increasingly restrictive legislation makes the situation even more problematic (Chiumenti et al., 1993).

Similarly to a factory, livestock, like other industrial activities, pollute atmosphere and groundwater by wastes, resulting in a potentially harming activities to environment, as well as human and animal health (European Commission, 2003).

Slurry collection, storage, treatment and spreading contribute, with different degrees of impact, to air pollution. In particular they contribute to the emission of greenhouse gases (GHG) (Gerber et al., 2013; Steinfeld et al., 2010) and acid rain phenomena (Steinfeld et al., 2006; Blake, 2005).

The Council Directive 96/61/EC of 24 September 1996, IPPC, is a framework directive aiming at a high level of protection for the environment. Regarding livestock production it classifies, as sources of pollution, livestock with more than 2,000 pigs (> 30 kg) or more than 750 sows, or more than 40,000 poultry. These livestock must adopt "best available techniques" (BAT) to operate.

Water pollution occurs mainly through slurry spreading as N is mainly lost as nitrate (NO_3^-). An exceeding of NO_3^- and phosphates (PO_4^{3-}) in water results in eutrophication phenomena which impact the environment making it unsuitable to aquatic life (Steinfeld et al., 2006; Gold and Sims, 2005). NO_3^- are also considered responsible of human diseases like cancer (Fan, 2011; Ward and Brendner, 2011; Santamaria, 2006; World Health Organization, 2007) and methemoglobinemia (MetHb) (Fan, 2011).

The Nitrates Directive (91/676/EEC) limits the amounts of nitrogen (N) from manure that can be applied to agriculture land, distinguishing them in nitrates vulnerable zones (NVZs) and ordinary zones (OZs). In NVZs it is allowed to spread up to 170 $kg * ha^{-1}$, while in OZs the upper limit is 340 $kg * ha^{-1}$of N from manure.

Farmers must respect environmental laws and bureaucracy, managing their own decisions to make profit. In most cases farmers have to face these problems with limited "tools" and in such a complex panorama an individual approach is extremely inefficient.

In this framework the Ager SEES PIG project "Multi – regional Solutions to improve the Environmental and Economic Sustainability of Pig manure management in the Regions of the Po and Veneto basin" has been developed to provide farmers, administrators and technicians, tools aimed at choosing the best technological, agronomic and economic solution for manure management both at farm and regional scales. The solutions should be valid through the Regions of the Po and Veneto basin, (Piemonte, Lombardia, Veneto and Friuli Venezia Giulia), in the North of Italy.

Even if the purpose of the doctoral work, carried out in this framework, is to design the agronomic module for the DSS, with a user friendly WebGIS interface, the cropping system simulation model and the strategies adopted to lower the computational complexity are the core of the work.

In Italy livestock activities have an important economic role. Pig production in the Po and Veneto basin regions is very important: in fact 74% of the Italian production is raised here (ISTAT 2010). The high density of pigs and the lack of available agricultural land, pushed farmers to rent land from other farmers for spreading the slurries they produce. This is an additional cost occurring at a time when the profitability margin of the sector is very low.

The thesis is organized in 3 sections:

Section 1, REVIEW, deals with:

- animal waste characteristics, their impact in human health, with particular attention to the concerns caused by NO_3^-;
- environmental pollution by N, in particular air and water pollution;
- European Community Legislation regarding NO_3^-, its evolution from the 70s to 2012;
- technological solutions applied to animal wastes, aimed at reducing N pollution;
- evolution of agronomic models and DSS.

Section 2, MATERIALS AND METHODS describes:

- identification of the study areas;
- swine and cattle data in the study area;
- data collection regarding soils, climate and treatments in the study area;
- CropSyst, the cropping system simulation model;

Section 3, RESULTS, deals with:

- simulation server;
- strategies applied to: treatments, crops and rotations, second harvest, soil – climate combinations, output manipulation;
- DSS modules: system architecture and data modelling.
- WebGIS user interface.

Section 4, DISCUSSION, discusses:

- methods to reduce computational complexity;
- improvement of DSS and WebGis user interface.

1 REVIEW

The doctoral work is mainly focused on designing the agronomic module for the DSS with a user friendly WebGIS interface, with the aim of a cropping system simulation model and to adopt strategies to reduce its computational complexity.
The purpose of the first section, review, is to provide a comprehensive view of the concerns related to N pollution from animal wastes, with particular attention to N leached as NO_3^-, environmental laws and technologies aimed to reduce livestock pollution and the modelling approach in agro – ecosystems.
This section deals with a brief description of animal wastes, their chemical and physical characteristics and their role as vectors of harmful pathogens to human and animal health. In particular there have been reported studies regarding the concerns of NO_3^- in waters for human consumption: methenoglobinemia and cancer.
The section subsequently deals with environmental pollution, air and water. The air pollution section describes the role of livestock in gaseous emissions, GHG, ammonia (NH_3) and particulate matter (PM). The water section is focused mainly on N pollution and its role in the eutrophication phenomena.
Environmental policies and laws set a series of standards, limits, practices and technologies to minimize environmental pollution and to protect human and animal health. The most important water, agriculture and livestock laws and regulations, from the 70s to present and their *ratio legis* are reported.
In order to minimize environmental pollution by N, several technologies have been proposed, based on physical, chemical and biological treatments. This section describes some of them and their main characteristics. A synthetic section is also dedicated to animal waste storage and spreading operations.
Section 1, due to the content of the thesis, is concluded with models and DSS in agro - ecosystem, in particular cropping system simulation models which simulate the N dynamics in the plant – soil system. It is reported their history and evolution towards modular systems and frameworks. The DSS sections is similarly structured: it is reported their history and evolution towards mobile devices.

1.1. ANIMAL WASTES

1.1.1. Chemical characteristics

Slurries have different physical and chemical characteristics depending on species and breeding, nutrition, farming systems, treatments, and storage. Each issue induces variability to waste composition, while solid manure is a mixture of urine, feces and litter, slurry has a low solids content due to the use of washing water (Sommer and Hutching, 2001). The following table presents the average characteristics of animal slurries according to species and type of housing (Tab. 1).

Table 1. Animal waste characteristics (from: Sommer and Hutching, 2001)

Manure ($g * kg^{-1}$)	Animal ($g * kg^{-1}$)	DM ($g * kg^{-1}$)	N-tot ($g * kg^{-1}$)	TAN ($g * kg^{-1}$)	Ureic acid–N ($g * kg^{-1}$)	P ($g * kg^{-1}$)	K ($g * kg^{-1}$)	pH
Slurry	Cattle	74.23	3.95	1.63	-	0.63	3.46	7.20
Slurry	Pig	34.50	9.35	3.66	-	0.74	3.62	6.72
Slurry	Poultry	218.00	12.00	5.93	-			7.23
Solid manure	Cattle	181.50	4.85	1.33	-	1.45	3.85	7.80
Solid manure	Pig	222.00	10.45	4.40	-	3.70	5.25	7.70
Solid manure	Poultry	574.60	29.60	5.49	6.0	5.98	6.53	8.50
Deep litter	Cattle	261.00	5.20	0.90	-	1.40	9.70	8.60
Deep litter	Pig	412.00	11.20	2.80	-			
Deep litter	Poultry	570.00	27.10	6.48	7.54	9.25	15.50	9.1

DM: dry matter; N – tot: total nitrogen; TAN: total ammonia nitrogen; P: phosphorous; K: potassium;

The characteristics of manure will vary considerably as related to management strategies. In particular, flush water modifies the compact structure of solid manure, so precipitation and evaporation, bedding materials and also biological activity (U.S.D.A., 1999).

1.1.2. Animal waste and human health

Slurries can carry pathogens like bacteria, viruses and parasites that could harm human and animal health (Strauch and Ballarini, 1994); they also represent a potential source of contamination to soil, water and food. Slurry convey intestinal parasites, such as worms and protozoa (Bornay – Llinares et al., 2006; Reinoso and Becares, 2008) which are able to survive for more than one year in soil (Strauch and Ballarini, 1994), harmful bacteria such as Salmonella and Campylobacter (Watabe et al., 2003) and viruses such as Foot and Mouth Disease virus, Classical Swine Fever Virus, Swine Influenza virus, Porcine parvovirus, Aujeszky's Disease virus (Bøtner and Belsham, 2012). Their presence is related to many factors such as storage, temperature, and slurry's pH (Bicudo and Goyal, 2003).
Several techniques are used to reduce or eliminate the content of pathogens in slurries: sulfuric acid (H_2SO_4) addition has an inhibiting effect against bacteria and reduce NH_3 emissions (Ottosen et al., 2009), as well as solid – liquid separation which allows to obtain a solid fraction with a lower content of pathogenic bacteria (Watabe et al., 2003). Processes using a combination of chemical and physical treatments (use of flocculants, clarification

and heat) have proven to be very effective to reduce helminths and intestinal parasites (Reinoso and Becares, 2008). Viruses survival is related to temperature: slurry whose temperature is 5 °C has a more favorable environment than slurry whose temperature is 20 °C (Bøtner and Belsham, 2012). Survival period of Foot and Mouth disease at 5 °C is higher than 14 weeks, if temperature is 20 °C it is about 14 days, and if slurry is subjected to anaerobic digestion, in mesophilic or thermophilic conditions, survival time is further reduced to minutes (Bøtner and Belsham, 2012).

1.2. NITRATES AND HUMAN HEALTH

N is fundamental for life (Howarth, 2009), an essential component of amino acids, the basic elements of proteins, and nucleic acids (Galloway, 2014; IFIA, 2007; Galloway et al., 2004).

In agriculture N is an essential nutrient for crops; N is mainly supplied by manure, from the advent of agriculture to about 1850, from 1890 to 1930 it was supplied as coke oven and $CaCN_2$ (up to 40% of the total), and after 1930 the Haber – Bosch process is the main source of N (Galloway, 2014). The increased use of N in agriculture to raise crop production lead to environmental concerns (EFMA, site consulted in May 2012). NO_3^- is the most oxidized N form and acts as a strong oxidizing agent (Addiscott, 2005). In water N is mainly available as NO_3^- (Steinfeld et al., 2006), but also nitrites (NO_2^-) (Dennis and Wilson, 2003). N is lost in soil mainly through the leaching of NO_3^-, then nitrites (NO_2^-), N_2 and organic compounds (Powlson and Addiscott, 2005; Prosser, 2005).

NO_3^- are very common in soils, waters and foods, especially vegetables (Fan, 2011; Santamaria, 2006; Dennis and Wilson, 2003, Cammack et al., 1999; Duncan et al., 1997). They are also used as an antimicrobial agent in foods and are naturally produced by human body (Santamaria, 2006; U.S. EPA, 2007). NO_3^- are widely present in human diet (World Health Organization, 2007), but their high concentration in waters may cause serious harm to human health. A NO_3^- concentration exceeding $50 \text{ mg} * l^{-1}$ has adverse health effects (Fan, 2011). In atmosphere N is lost mainly as NH_3. NH_3 is an important precursor to fertilizers and it is an important industrial chemical. It is used as alkaline cleanser, refrigerant gas, for the synthesis of many chemical products such as polymers, pharmaceuticals, fibers, explosives just to name some.

Agriculture is considered the major contributor, livestock account about the 80% of the total emissions from agriculture (Vadella et al., 2013). NH_3 emissions contributes to acid rains (Renard et al., 2004), soils acidification (Lükeville and Alewell, 2008), and it is harmful for human and animal health (Parod, 2005; Barbieri et al., 1995).

1.2.1. Methemoglobinemia

The issue about NO_3^- in water for human consumption, arose in 1945 in U.S.A. (Fan and Steimberg, 1996; Shearer et al. 1972) and in early 1950s in Europe (Conrad, 1990) due to a possible correlation between NO_3^- and methemoglobinemia (MetHb). Since 1945 to early 1970s, about 2000 cases of MetHb in infants were reported worldwide (Shearer et al., 1972).

This condition, which affects more mainly children less than one year old, is caused by NO_3^- reduced, by bacterial enzymes, to NO_2^- which bind to hemoglobin to form MetHb and NO_2^- (Ward and Brendner, 2011). The consequence of this reaction is a reduced oxygen (O_2) flow to the tissues resulting in cyanosis (the so called "blue baby syndrome") and even coma and death (World Health Organization, 2007; U.S. EPA, 2007; Santamaria, 2006). Other health effects, following fetal exposure to elevated levels of NO_3^- in drinking water, include intrauterine growth delay (Bukowski et al., 2001).

The relationship between MetHb and high concentrations of NO_3^- is suggested by several authors (Sadeq et al., 2008; Vegh et al., 1997), while other authors suggest that this condition is related with the high concentration of bacteria in drinking water (IFIA, 2007; Addiscott, 2005; Shearer et al., 1972). High NO_3^- concentration in water could be a consequence of pollution by organic compounds that can be linked to bacterial contamination. In fact, most cases of MetHb were related to water from private wells, often without coverage and exposed to contamination (Addiscott, 2005). A study from Hungary reported that 93% of national cases of MetHb were associated to water from private wells. However, the study, did not include any data about bacterial contamination (Vegh et al., 1997).
The possible correlation between MetHb and bacterial contamination is also reported by other authors who also suggest, in some cases, a misdiagnosis of death. Death was not caused by MetHb but SIDS, the "sudden infant death syndrome" (Fan and Steinberg, 1996). The increased incidence of SIDS is, anyway, linked to high NO_3^- in water (George, et al., 2001).

1.2.2. Cancer

Nitrates in stomach react with amines to form nitrosamines, carcinogenic compounds both for humans and animals (Fan, 2011; Ward and Brendner, 2011; Santamaria, 2006; World Health Organization, 2007). Some authors suggest that these compounds could be linked to various type of cancer such as stomach cancer (Yang et al., 1998), non – Hodgkin lymphoma (Short, 1996), pediatric brain tumors (Preston – Martin et al., 1996) and also to diabetes mellitus in children (Santamaria, 2006). An epidemiological study conducted in Slovakia shows a positive correlation between NO_3^- and cancer of the digestive tract, non – Hodgkin lymphoma, and even with liver cancer (Gulis et al., 2002), while another epidemiologic study showed an association of NO_3^- in drinking water and the incidence of urothelial cancer in both genders (Volkmer et al., 2005).
Other studies, however, demonstrate there is no association between NO_3^- and colon cancer (Yang et al., 2007), stomach cancer (Addiscott, 2005; Van Loon et al., 1997), prostate cancer, renal tumors or penile tumors (Volkmer et al., 2005) and diabetes mellitus in children (Moltchanova et al., 2004).

The link between NO_3^- and health is controversial and unclear: studies demonstrates that NO_3^- is a positive agent to human health preventing microbial infections, reducing hypertension and cardiovascular diseases (Du et al., 2007; Santamaria, 2005; Duncan et al., 1997). In this perspective, NO_3^- could be considered an important and cheap form of treatment for gastroenteritis (Addiscott, 2009). Other authors suggest that it is impossible to establish a link between a maximum allowable level of NO_3^- in water and MetHb (Yang et al., 2007; Addiscott, 2005; Fan and Steinberg, 1996) while others suggest to adjust the European thresholds for NO_3^- in drinking water, ($50 \text{ mg} * l^{-1}$), to the U.S.A. standard, ($10 \text{ mg} * l^{-1}$) (Volkmer et al., 2005).

1.3. ENVIRONMENTAL POLLUTION

1.3.1. Air pollution

Livestock are responsible for gaseous emissions of methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), ammonia (NH_3) and also odors. It is estimated that 14.5% – 18% of anthropogenic greenhouse gases (GHG) CH_4, CO_2, N_2O, comes from livestock (Gerber et al., 2013; Steinfeld et al., 2010). Beef and cattle milk production account for the majority of emissions, contributing for 41 and 20% of the sector's emissions. Pig meat and poultry, both meat and eggs, contribute respectively to 9% and 8% to the sector's emissions (Gerber et al., 2013). 84% is produced by feed production, feed processing and enteric fermentation from ruminant, 10% from animal waste storage and treatments applied (Gerber et al., 2013). In Europe, 10% of the total GHG emissions comes from agricultural activities and ruminant sector contributes for 56% (Schils et al., 2005).
The main source of CH_4 is animal manure management (25% of the total emissions), major source of CO_2 is land use (32% of the total emissions), and major source of N_2O is manure management (Zervas and Tsiplakou, 2012). Other authors estimate that CH_4 released from manure contributes for 5% – 10% of the global emissions (Martinez et al., 2003).
Gaseous emissions from livestock, excluding enteric fermentation, come from manure removal, storage and spreading operations (Thorne, 2011; Steinfeld et al., 2006). Gaseous emissions are influenced by slurries nature, both quantitatively and qualitatively. Other important factors are the animal physiological stage and nutrition (Philippe and Nicks, 2015). According to studies conducted in Netherlands, NH_3 and odors emissions from pig slurry are twice than those from cattle slurry (De Bode, 1990). There are many factors that affects gaseous emissions and odors: exposed slurry area, climatic conditions, treatments, soil structure, time spent on soil surface, just to name a few (De Bode, 1990).
CO_2 is considered the main greenhouse gas, as well as the reference gas for the quantification of this effect (U.S. EPA, 2002). CH_4 and N_2O are gases whose potential greenhouse effect is, respectively, 21 and 310 times higher than CO_2, covering a time period of 100 years (U.S. EPA, 2002). Some authors blame the manure for a high percentage of emissions on a global level: 5% to 30% for CH_4 and up to 18% for N_2O (Pattey et al., 2005); other authors quantify the overall contribution of these GHG to 10% (Bertora et. al., 2008). Contribution from agriculture is estimated from 65% to 80% of the total anthropogenic N_2O (Steinfeld et al., 2006; Houghton et al., 1990).
While CH_4, CO_2, N_2O are fundamental to the greenhouse effect, NH_3 contributes to the phenomenon of acid rains (Steinfeld et al., 2006; Blake, 2005). Livestock are responsible for almost 64% of anthropogenic NH_3 emissions (Steinfeld et al., 2006). The 50% of NH_3 emissions from agricultural activities in Europe comes from livestock, reaching peaks of 70% in areas with a large presence of intensive livestock (Sommer and Hutching, 2001). In U.S.A. the 55% of the total NH_3 are from livestock (Anderson et al., 2003), while in South Korea it is estimated it contributes for 70% (Lee and Park, 2001).
NH_3 is a harmful gas to human and animal health, responsible for stress, respiratory diseases, gastro – intestinal diseases and it also weakens defensive mechanisms and decreases appetite (Parod, 2005; Barbieri et al., 1995). These phenomena are enhanced by

NH_3 high solubility in water and dusts. NH_3 and dusts act synergistically causing chronic pulmonary disease (Williams, 1995). People who live in rural areas are potentially most vulnerable to health problems than people which do not live in rural areas (Havlíková et al., 2008).

NH_3, due to its solubility, it is deposited on building's surfaces and equipment, favoring corrosive phenomena. NH_3 molecules could be released by dry deposition (Steinfeld et al., 2006; Blake, 2005), at low distances from the sources, or by wet deposition reaching the ground as precipitation (Steinfeld et al., 2006; Steffens and Benedetti, 1993). NH_3 contributes to the phenomenon of acid rain, acting as a catalyst for the oxidation of sulphur dioxide (SO_2) to sulfur trioxide (SO_3), reacts with acidic compounds in the atmosphere, such as hydrogen sulphide (H_2S), HNO_3 and hydrochloric acid (HCl) and can also form ammonium (NH_4^+) salts that are partially responsible for smog (Renard et al., 2004). NH_3, with SO_2 and NO_x form ammonium nitrate (NH_4NO_3), ammonium hydrogen sulfate (NH_4HSO_4) and ammonium sulfate ($(NH_4)_2SO_4$) (Galloway, 2014) which are important components of airborne fine particular matter, $PM_{2,5}$ (Battye et al., 2003; Anderson et al., 2003; Hristov, 2011). The direct $PM_{2.5}$ emissions from husbandry is negligible, while the indirect contribution ranges between 5% to 11% depending on model and compounds (Hristov, 2011). Epidemiologic evidences showed a link between episodically elevated particulate air pollution and daily mortality and also a reduced life expectancy of 2 years (Dockery, 2009).

1.3.2. Water pollution

Increase in N levels of groundwater, surface water, rivers and lakes, is, often, followed by the eutrophication phenomena (D.lgs. 29 gennaio 2007; Steinfeld et al., 2006), a worldwide environmental problem (Yang et al., 2008; Leaf and Chatterjee, 1999). It is estimated that 30% – 40% of lakes and reservoirs are affected by this phenomena (Yang et al., 2008).

Eutrophication is studied since the mid of 1960s, it is defined as "an enrichment of nutritive elements in waters that causes an increased production of algae and aquatic plants, the depletion of fishes, the general degradation of the water quality and other effects that reduce and preclude their use" (OECD, site consulted in May 2012) or "is the enrichment of the environment with nutrients and the concomitant production of undesirable effects" (de Jong and Elliott, 2001), or "the enrichment of water by nitrogen compounds, which causes rapid growth of algae and plants, with the disruption of the balance between organisms and deterioration of water quality" (Directive 91/676/EEC).

Eutrophication occurs when an excess of NO_3^- and phosphates (PO_4^{3-}) in water leads to an uncontrolled growth of autotrophic organisms, mainly phototrophs, resulting in a disturbance of the aquatic ecosystem (Steinfeld et al., 2006; Gold and Sims, 2005). The effects are turbidity, increasing of decomposed organic matter (OM) and the reduction of dissolved O_2 due to degradative processes. Under these conditions life for higher organisms becomes very difficult. In anoxic zones, where water exchange rate is low, fermentation processes may occur with release of toxic byproducts which further reduces aquatic life (Gold and Sims, 2005; Vezjak et al., 1998).

In addition to these effect on environment, proliferation of harmful algae could also have a harmful effect on human and animal health (Burkholder and Glibert, 2013; Howarth, 2009; Burkholder, 2003; Burkholder, 1998). Harmful algae produce toxins that act at molecular level damaging cells, tissues and organs (Burkholder, 1998). Toxins which are able to damaging nervous system, digestive and respiratory apparatus and skin have been identified (World Health Organization, 2002; Burkholder, 1998). People poisoned with these toxins show symptoms such as vomit, diarrhea, headache, sore throat, fever, and skin irritation (World Health Organization, 2002).

Eutrophication is not a fully understood phenomenon (Yang et al., 2008). It is influenced by hydrodynamics, water salinity, light, temperature, turbidity, microbes, biodiversity and most important, nutrient level, in particular total N and P (de Jong and Elliott, 2001; Yang et al., 2008; Leaf and Chatterjee, 1999). NO_3^- in water, with PO_4^{3-} as limiting agent, (Addiscott, 2005; Burkholder, 2003; Leaf and Chatterjee, 1999), are often referred to be one of the main, if not the main, cause of eutrophication (Thorburn et al., 2003; Nixon, 2009). Several studies show that NO_3^- pollution is mainly caused by agro – zootechnical activities (Steinfeld et al., 2006; Almasri and Kaluarachchi 2004; World Health Organization, 2002).

Eutrophication it is not only a pollution problem. It should be viewed as a major ecological change and this should be keep in mind by scientists, politicians and regulators (Nixon, 2009).

1.4. ENVIRONMENTAL POLICIES AND LAWS

The concern about nitrates in water arises in the 1970s in relation to the eutrophication phenomenon. Eutrophication has been the subject of debate, even outside the scientific community. The debate culminated in the approval of the Council Directive 75/440/EEC of 16 June 1975, concerning the quality required of surface water intended for the abstraction of drinking water in the Member States, and the Council Directive 80/778/EEC of 15 July 1980, relating to the quality of water intended for human consumption (Conrad, 1990).

Both Directives set threshold limits for chemical, physical and bacteriological properties of water at which no adverse health effects are likely to occur. The maximum threshold for NO_3^- was set to 50 mg $* l^{-1}$.

The Council Directive 98/83/EC of 3 November 1998 is a revision of the Council Directive 80/778/EEC on the quality of water intended for human consumption. This Council Directive sets new standards and introduces a series of additional notes. The maximum admissible concentration for NO_3^- is 50mg $* l^{-1}$, but an additional note states that the Member States must ensure the following condition: $[NO_3^-]/50 + [NO_2^-]/3 \leq 1$. Values reported between square brackets represent the concentration in mg $* l^{-1}$ for NO_3^- and NO_2^-, and the value of 0.10 mg $* l^{-1}$ for NO_2^- is complied with ex water treatment works.

The concern of NO_3^- from agro – livestock activities has been taken into account for the first time by the Council Directive 91/676/EEC of 12 December 1991. This Directive aims to protect water quality across Europe by preventing NO_3^- from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices.

The Directive 91/676/EEC was implemented by:

- identification of waters polluted or at risk of pollution (surface freshwaters or groundwater with a concentration of NO_3^- > 50 mg $* l^{-1}$);
- identification of areas which drain into polluted waters or are at risk of pollution and which contribute to water pollution. These areas are designated as Nitrates Vulnerable Zones (NVZs), while the other areas are designated as Ordinary Zones (OZs). Member States, instead of identifying NVZs, can also choose to apply measures to the whole territory;
- establishment of Code of Good Agricultural Practice (CoGAP) and Nitrates Action Programme (NAP) to be implemented by farmers on a voluntary and compulsory basis, respectively. The Code should include a number of measures, limiting the periods when N fertilizers can be applied to soils, the conditions for their application, requirements for adequate storage of livestock slurries and manure, and crop rotations. According to Directive 91/676/EEC, the maximum amount of N from livestock manure that can be applied in NVZs on yearly basis is 170 kg $*$ ha^{-1}, while in OZs is 340 kg $*$ ha^{-1};
- Member States, every four years, are required to report on: NO_3^- concentrations in groundwater and surface waters and their eutrophication, the evaluation of the NAP on water quality and the estimate of future trends. Furthermore, Member States are required to revise NVZs and Action Programs.

Directive 91/676/EEC was adopted in Italy by the D.lgs. 11 maggio 1999 n. 152. At the same time the Codice di Buona Pratica Agricola (CBPA) was approved by the D.M. 19 aprile 1999. The CBPA goal is to contribute to a better protection of all waters from NO_3^- pollution, reducing the environmental impact of agriculture, through a careful management of N balance. The CBPA does not have binding effects, but should be implemented by farmers on a voluntary basis as reported on art. 4 of Directive 91/676/EEC.
Reports provided by the EC Member States, regarding year 2000, describe a negative situation for Italy. Data concerning water quality predictions and data concerning agricultural practices were "insufficient" and data concerning NVZs were considered as "moderate" (European Commission, 2002).
D.lgs. 3 aprile 2006 n. 152 abrogates D.lgs. 11 maggio 1999 n. 152, although reproduces it substantially. The D.M. aprile 7th 2006, (Criteri e norme tecniche generali per la disciplina regionale dell'utilizzazione agronomica degli effluenti di allevamento, di cui all'articolo 38 del D.lgs. 11 maggio 1999 n. 152), regulates manure management and its agronomic use (production, storage, fermentation and maturation, transport and spreading operations) in NVZs under article 92 of D.Lgs. 3 aprile 2006 n. 152.
Council Directive 96/61/EC of 24 September 1996 concerning Integrated Pollution Prevention and Control (IPPC) was adopted in Italy by D.lgs. 18 febbraio 2005, n. 59. The IPPC is a framework directive aiming at a high level of protection for the environment, it allows to operate industry with conditions to be based on "best available techniques" (BAT). Regarding livestock production the Council Directive classifies, as sources of pollution, livestock with more than 2,000 pigs (> 30 kg) or more than 750 sows, or more than 40,000 poultry.
D.Lgs. 29 gennaio 2007, (Emanazione di linee guida per l'individuazione e l'utilizzazione delle migliorie tecniche disponibili, in materia di allevamenti, macelli e trattamento di carcasse, per le attività elencate nell'allegato I del D.lgs. 18 febbraio 2005, n. 59) identifies the BAT to prevent and reduce pollution from livestock. The critical points are identified as follow:

- air: manure collection and storage operations;
- water and soil: manure spreading operations.

Most of the nutrients are lost during and after spreading operations. Focusing on water pollution, the main responsible is N that usually leach as NO_3^-.
The Commission Implementing Decision of 3 November 2011 on granting the derogation requested by Italy for the Regions of Emilia Romagna, Lombardia, Piemonte and Veneto, pursuant to Council Directive 91/676/EEC concerning the protection of waters against pollution caused by NO_3^- from agricultural sources, allows the application of N 250 $kg * ha^{-1} * year^{-1}$ derived from manure in NVZs.
The designated NVZs to which the NAP apply cover about 63% of the utilized agricultural area (SAU – superficie agraria utile) of Emilia Romagna, 82% of the SAU of Lombardia 38% of the SAU of Piemonte and 87% of the SAU of Veneto. Water quality data submitted show that for groundwater in the Regions of Emilia Romagna, Lombardia, Piemonte and

Veneto 89% of groundwater bodies have a mean NO_3^- concentrations lower than 50 $mg * l^{-1}$ NO_3^- and 63% have a mean NO_3^- concentration below 25 $mg * l^{-1}$ NO_3^-. For surface waters, more than 98% of monitoring sites has a mean NO_3^- concentration below 25 $mg * l^{-1}$ and NO_3^- concentration never exceed 50 $mg * l^{-1}$ NO_3^-. The report supporting the request of the derogation indicates that the proposed amount of 250 $kg * ha^{-1}$ of N per year from cattle and pig manure is justified on the basis of objective criteria such as high net precipitation, long growing seasons and high yields of crops receiving high N uptake.
Farmers, who want to benefit from this derogation, are obliged to implement a rigorous manure and crop management plan. Each year farmers shall notify to authorities informations such:

- the type of treatment;
- the characteristics of the treatment plant;
- the amount of treated manure;
- the amount and content of N and P;
- the destination for both solid and treated fraction.

At the date of 15 February 2012 the following derogation requests were submitted (Baccino, 2012):

- Lombardia: 1,036 requests from 9,987 farms; 7% of the requests regards pig livestock;
- Piemonte: 42 from more than 4,000 farms; most of the requests concern dairy cattle;
- Veneto: 24 requests from 6,025 farms; no requests for pig livestock;
- Emilia Romagna: 10 requests from more than 4,000 farms.

The derogation was also granted to other EU countries: Denmark, Netherlands, Germany, United Kingdom and Belgium.

1.5. TREATMENTS

Animal slurry production in Europe is estimated in 1.4 billion tons (Agro Business Park, 2011). The two main contributors are France and Germany (Agro Business Park, 2011). In order to minimize adverse environmental effects, various technologies have been proposed, based on physical, chemical and biological treatments.
The D.Lgs. 29 gennaio 2007 reports that air pollution is very hard to reduce, because biological processes are difficult to control, while waste control is easier. Some of the developed treatments mitigate slurry's environmental impact and allow to manage easily GHG emissions (Phillipe and Nicks, 2015).
Manure is responsible of N leaching which pollutes soils, surface waters and groundwaters (Steinfeld et al., 2006; Gold and Sims, 2005). D.Lgs. 29 gennaio 2007 focuses not only to environment but also to the economic aspects, stating a dichotomy between environmental and economic sustainability.

1.5.1. Solid liquid separation

Solid liquid separation is a physical treatment which aims to separate slurry into a liquid, clarified fraction and a solid fraction. The liquid fraction contains inorganic N, most as NH_4^+ (Bertora et al., 2008) and K; the solid fraction contains most of the carbon (C) (Peters and Jensen, 2010). The solid fraction, rich in matter may be composted (Fangueiro et al., 2010; Peters and Jensen, 2010) or used to produce energy (Peters and Jensen, 2010). The liquid fraction may be used for fertigation (Fangueiro et al., 2010). Most of the nutrients, like N and P, are suspended in small particles, with a diameter < 0.5 mm (Dinuccio et al., 2012).
Solid liquid separation is performed mechanically, typically using screw presses, drums, and centrifuges. This kind of equipment is simple and allow a mild N separation (VVAA, Progetto RiduCa Reflui, 2012).
Separation can be also achieved by sieves which separate slurry according to the size of the particles. The solid – liquid separation can be improved through the use of chemicals which act as flocculants. These substances are usually cations, such as ferric chloride ($FeCl_3$), or polymers such as polyacrylamide (PAM) which allows particles aggregation and facilitates the subsequent separation (Agro Business Park, 2011; Fangueiro et al., 2010).
The distribution of the separated particles varies significantly depending on slurry type. Particles with a diameter of < 100 μm represents the 97.9% of the whole pig slurry and this fraction is also the richest in N (Fangueiro et al., 2010). According to Aust (Aust et al., 2009) about 25% of the DM content had particle sizes > 2000 μm, 48% of the DM was present in the fractions < 63 μm. This pattern is not so evident when cattle's slurry is involved (Fangueiro et al., 2010). Solid liquid separation determines a different content in OM than raw slurry, resulting in a different degradation and a NH_3, N_2O, CH_4 emission pattern (Moset et al., 2011).

1.5.2. Biological treatment of nitrification – denitrification

Biological treatment based on nitrificating and denitrificating bacteria provides an initial N oxidation, mainly in the form of NH_4^+, to NO_2 and NO_3^-(Galloway, 2014; Agro Business Park, 2011; Rajagopal and Beline, 2011; Howarth 2009). Subsequently the NO_3^- is converted in N_2 (Galloway, 2014; Agro Business Park, 2011; Rajagopal and Beline, 2011; Howarth 2009) and the OM is oxidized into CO_2 both released in atmosphere (Progetto RiduCa Reflui, 2012; Melse and Verdous, 2005). This treatment reduce N by 70% – 80% (Agro Business Park, 2011; Rajagopal and Beline, 2011; Beline and Martinez, 2002). Anyway N_2O production is relatively high: it equals the 2 – 3% of Total Kjeldal Nitrogen (TKN). This fact could be explained by the fact that NO_2 is a byproduct of the nitrification and denitrification bacteria (Agro Business Park, 2011; Melse and Verdous, 2005).

1.5.3. Aerobic digestion

Aerobic digestion is a process which degrades OM to CO_2 (Agro Business Park, 2011; Mohaibes and Heinonen – Tanski, 2004). The process is carried out by aerobic microorganisms (Agro Business Park, 2011). O_2 is blow into slurry to reduce the activity of anaerobic microorganisms, which produce NH_4^+, sulphidric compounds and odors. Aerobic digestion reduces NH_3 by 30% – 50%, if applied after a separation treatment, and reduces CH_4 and N_2O emissions by 55% (Loyon et al., 2007). The process, if conducted with an excessive aeration, may produce NH_3 and, in some conditions, N_2O.

1.5.4. Anaerobic digestion

Anaerobic digestion is a biological process in which slurry is sent to a reactor in order to produce biogas, a gas characterized by a CH_4 content from 50% to 75%, CO_2 from 25% to 40% depending on animal and breed (Chiumenti et al. 2008). The process could be applied in mesophilic (25 – 45 °C) or thermophilic (45 – 60 °C), single – stage or multi – stage systems. This technology is not directly aimed at reducing NO_3^- but it can play an interesting role as a source of energy supply, in order to make the treatments to reduce N more economically sustainable. The gas produced can be used for combustion or in cogeneration plants to produce electric energy and heat (Phillipe and Nicks, 2014; Scholz and Meyer – Aurich 2011; Chiumenti et al, 2008). Anaerobic digestion reduces GHG emissions (Agro Business Park, 2011; Scholz and Meyer – Aurich 2011; Amon et al., 2006). It avoids CH_4 emission, use of fossil fuels, and also reduces CO_2 emissions (Phillipe and Nicks, 2014; Bachmaier et al., 2010). In Europe it is estimated that 6.4% of the slurry is treated by anaerobic digestion (Agro Business Park, 2011). Anaerobic digestion also reduces bacteria like Escherichia coli and fecal coliform (Saunders et al., 2012; Bicudo and Goyal, 2003).

1.5.5. Ultra – filtration and reverse osmosis

Ultra – filtration is a technology using membranes which act as filters. These membranes consist of polymeric ceramic materials. The slurry is separated into permeate, the liquid fraction, and a solid one. The liquid is then sent to reverse osmosis, with further production of permeate and solid fraction. N, P, chemical oxygen demand (COD) and coliforms abatement in liquid fraction is high (99%) (Fugerè et al., 2005) while the CH_4 production is not influenced by the process (Melse and Verdoes, 2005). Ultra – filtration is a complex and expensive treatment (VVAA, Progetto RiduCa Reflui, 2012; Chiumenti et al., 2008; Melse and Verdoes, 2005).

1.5.6. Process of evaporation in vacuum condition

Evaporation process evaporates the water contained in slurry in order to concentrate it. The process usually follows treatments such as a nitrification – denitrification in order to avoid emissions into atmosphere (Agro Business Park, 2011). Evaporation is carried out in depression, allowing slurry to boil at a lower temperature. The process, which can be single – stage or multi – stage, allows to obtain a concentrated fraction and a distilled fraction. Preliminary results, obtained with a pilot plant operating on separated effluents from a biogas plant, showed an increased concentration of N (up to 97% in a two – stage system) (VVAA, Progetto RiduCa Reflui, 2012). This process is particularly expensive, compared to others like straw filtration, mechanical separation and microfiltration, and nitrification – denitrification system, and the cost is estimated up to $17.2\ € * t^{-1}$(Melse and Verdoes, 2005).

1.5.7. Composting

Composting is a biological process operated by bacteria, fungi and actinomycetes under aerobic conditions which stabilizes the OM of slurry and it is enhanced by the addition of other materials as bulking agents and amendments (U.S.D.A., 1999). Compost has been used for many centuries to improve soil qualities (Imbeah, 1997). Organic substances are quantitatively and qualitatively modified during maturation: their weight and molecular structure varies as the process evolves (Adani, 1999). The mass temperature raises up to 50 – 70 °C. Properly composted solid manure significantly reduces the volume of material spread to land and the amount of odour released (European Commission, 2003).
It allows to transport the sewage easier and it allows also a direct control of N spread on soil (Piccinini and Rossi, 1999).
NO_3^- is fixed by bacteria into stable organic compounds, therefore NO_3^- leaching is avoided (European Commission, 2003). Composting is also useful to sanitize pig slurry, as it reduces pathogenic microorganisms and also phytotoxic compounds (European Commission, 2003; Ros et al., 2006) and weed seeds (U.S.D.A., 1999) resulting in is a safer material as compared to raw slurry.

1.6. STORAGE

Slurries are stored for varying periods prior to their agronomic use. Timing and storage temperature affect the nature of slurry, modifying its characteristics. Emissions from storage contributes up to 10% of emissions from agriculture (Søren and Per, 2005).
The use of rigid covers allows a reduction of NH_3 emissions estimated between 70% and 90% Also the use of movable coverings, such as PVC sheets, is very effective although, when slurry is mixed, it is possible to have an increase of gaseous emissions (European Commission, 2003). Floating covers also reduce emissions, although some materials like peat or polystyrene have a negative effect by increasing emissions of GHG (European Commission, 2003). Formation of a surface crust, if slurry has an adequate DM content, could be useful in reducing emissions into atmosphere, with an estimated reduction of NH_3 emissions by 60% (Smith et al., 2007).

1.7. SPREADING

The amount of elements lost in soil are a function of the amount of slurry applied and their concentration (European Commission, 2003). During this phase, N is lost by volatilization and by leaching. NH_3 emissions resulting from spreading are around 37% of the total NH_3, although variability is extremely high according to the applied spreading method (ECETOC, 1994). In Italy it is estimated that 20% of NH_3 emissions from agricultural sources is due to the spreading of manure (Condor and Valli, 2011).
Factors which contribute to emissions are:

- chemical and physical characteristics of the slurry, in particular DM content;
- weather conditions: temperature, wind speed and rainfall affect NH_3 emissions; in particular at a temperature of 30°C approximately half of the total N is lost as NH_3;
- spreading technique (Atta, 2008).

Slurry spreading is also a main cause of the NO_3^- leaching which is responsible of groundwater pollution. This process is influenced by the above indicated factors, as well as characteristics (Di and Cameron, 2000), slurry organic matter (quantity and quality), slurry pH, crop rotation and spreading techniques (Kayser et al. 2008; European Commission, 2003). Adequate spreading techniques allow both to limit emissions into atmosphere and NO_3^- leaching, increasing the pool of nutrients available for crops (European Commission, 2003).

1.8. MODELS

A system is a conceptual entity defined by an observer who gives a meaning to certain states (conditions, properties) perceived in the real world (Danuso, 2011); it can be also defined as a set of components and their relationships that have been grouped together to study a portion of the world (Peart, 1998) or, as originally defined in the late 60s, a complex of interacting elements (von Bertalanffy, 1968).

A model could be considered as a simplified representation and a concrete implementation of a system. A model can be used to simulate and provide quantitative solutions (Danuso, 2011; Jørgensen, 1994) influenced by the personal vision of its creator and implemented to fulfill specific purposes.

Agro – ecosystem models are, mainly, mathematical models introduced for the first time in the late 1960s to estimate biomass production as a function of photosynthetically active radiation (Donatelli, 2011). In the 1970s they were introduced with management purposes becoming more complex (Peart, 1998; Jørgensen, 1994). In particular crop models become increasingly highly detailed as a result of the implementation of new knowledge; however, in the last years this approach has been criticized and simplified models aimed at estimating biomass accumulation have been developed together with management tools at different levels (Donatelli, 2011). Models are not only focused on crops, but also on livestock, energy and environmental impact (Danuso, 2011; Peart, 1998).

Examples of widespread mathematical models, simulating bio – physical processes are SUCROS (van Keulen et al., 1982) EPIC (U.S.D.A., 1990), CERES – DSSAT (Jones et al., 1984), WOFOST (van Keulen and Wolf, 1986), SOILN model (Johnsson et al., 1987), STICS (Brisson et al., 1998), CropSyst (Stöckle, 1998), DAISY (Hansen et al., 1990), SWAT (Arnold et al. 1998), ORYZA (Bouman et al., 2001), APSIM (Keating et al., 2003), WARM (Confalonieri et al., 2009).

These models simulate also N dynamics in the plant – soil system. N dynamics are particular important to plant growth: it also allows to estimate pollution caused by leached NO_3^- and NO_2 emissions (Donatelli, 2011).

Several models were compared to estimate N balance from agro – ecosystems (de Vries et al., 2011): INTEGRATOR (de Vries et al., 2011), IDEAg (Leip et al., 2008), MITERRA (Velthof et al., 2007), IMAGE (Bouwman et al., 2006). INTEGRATOR uses empirical models and a GIS environment to estimate N emissions at European scale; IDEAg is a framework which employs the CAPRI model, an agricultural economic model, (Britz et al., 2005) and the DNDC model (Li et al., 2006). IDEAg has been developed to estimate GHG at European scale and manure contribution has been linked to livestock density. MITERRA have been developed at Wageningen University to evaluate also N leaching at both continental level (Europe) and country level. It is built on other models, and manure contribution to N leaching was estimated with an expert judgment. IMAGE estimates N balance at global level and livestock contribution was estimated with the FAOSTAT data. The compared models shows interspersed estimates for N_2O, NO_x and N leached (de Vries et al., 2011).

In most cropping system models the dynamics of fungal and bacteria soil communities, affecting the transformations of OM to mineral N, are ignored. These dynamics are modeled only indirectly as responses to temperature and water which impact on microbial communities (Donatelli, 2011), or are modeled as hydrological or biogeochemical processes (Li et al., 2006; Whitmore, 1995). The denitrification – decomposition model DNDC (Li et al., 2006) simulates N leaching linking microbiological activities to temperature, pH, soil moisture, substrate concentration gradients and it predict also CO_2, NO, NO_2, CH_4 and NH_3 emissions (Li C.S., 2000); it was modified to consider also management practices (Li et al., 2006). DNDC model was also used in several studies to estimates NO_2 fluxes at large scales in Europe (Leip et al., 2011).

A further evolution in cropping system models is the simulation of the interactions between genotype, management and environment (Holzworth et al. 2014; Casadebaigh et al., 2011).

A model mainly dedicated to animal waste management is MAGMA, which also assists the user in choosing alternative management strategies (Guerrin, 2001). APSIM evolved from a cropping system model into a more complex agro – ecosystem model which considers also the interactions between crops and livestock (Holzworth et al. 2014).

Modeling is moving towards new solutions like modular systems giving more attention to components than parameters. This approach allows model's expansion with the addiction on of new components. The main simulation model and the other components should not be modified by the new component. This approach facilitates comparison between models, their components, and allows an easier model update (Confalonieri, 2012; Jones et al., 2001). Different versions of SUCROS has been developed for specific purposes adding different crops and modifying the existing parameters (Jones et al. 2001). The APSIM model has been also developed as a series of separated modules, giving it a significant flexibility (Jones et al. 2001). A model based on modular approach is ARMOSA, a dynamic model that simulates the cropping systems at field scale, developed to estimate the impact of different crop management practices on soil N and C cycles and groundwater NO_3^- pollution from agricultural sources (Perego et al., 2013; Acutis et al., 2007).

A further development has been achieved by a framework capable of connecting different models and databases. User does not install programs, and is not limited by operating system and processor (Kiura et al., 2011). This approach moves research towards databases: data is often difficult to obtain and should be properly manipulated. Data used for a model, even if properly manipulated, should be manipulated again in order to use it in another model. The output of a model can't be used as input for another model. This could be overcome developing of an "intelligent hub" which elaborate database adequately (Kiura et al., 2012).

1.9. DECISION SUPPORT SYSTEM

A DSS represents a concept of the role of computers within the decision making process (Keen, 1980). DSS were born in the 1970s as a practical approach for applying computers to the decision problems of management (Alter, 1980); in fact, before the diffusion of PCs they focused on interactive calculations in semi – structured systems (Alter, 2004) and then evolved into complex systems. Since the 80s DSS, due to technological improvement, evolved in Group Decision Support Systems (GDSS), Distributed Decision Support Systems (DDSS), Integrated Decisions Support Systems (IGDS) and in the 90s web based DSS become a research field (Tian et al., 2007).

A DSS is an interactive computer – based system which support user in making decision through interactive procedures, using data and models to identify and solve problems (Rauscher, 1999). A DSS has many advantages such as a better approach, in complex situations, than humans and facilitating the integration of knowledge (Antonopoulou et al., 2010; Knight, 1997).

DSS are widely used in industry, economy, telecommunications and transport, to name few.

Agricultural DSS are software applications which describe various biophysical processes in farming systems and their response to different management practices and or climatic variability (Jakku and Thornburn, 2010). DSS in agriculture are applied to any activity in crop production such as pest control, (Knight, 1997), weed management (Parson et al., 2009) plantation, harvest, fertilization, irrigation (Antonopoulou et al., 2010; Bergez, 2001) or designed for the management of a specific crop such as GOSSYM, designed for cotton management (Hodeges et al., 1998), WHEATMAN designed for wheat management (Woodroof, 1992), or to assess the impact of climate change (Wenkel et al., 2013). Examples of web based DSS are WebGro, developed in U.S.A. to help soybean producers, which is built on CROPGRO – soybean model (Paz et al., 2004), WebHadss, developed in North Caroline, U.S.A., designed for weed management (Bennet et al., 2003), GPFARM, Great Plains Framework for Agricultural Resource Managemet developed in U.S.A., which provides an analysis of production, environmental and economic impact at farm level (Ascough II et al., 2001) and GMDSSCM (growth model – based decision support system for crop management), developed in China to evaluate management strategies in different environments and genotypes for wheat, cotton, rice and rape (Zhu et al., 2007).

According to Pimenidis even if there were a lot of initiatives to reduce the digital divide the problem is still present. In fact large rural areas and also some urban areas, especially in the poorest nations, are not able to connect to the world wide web (Pimenidis et al., 2009) so, even if there is a plethora of DSS, most of them are underused (Antonopoulou et al., 2010). A solution comes from mobile devices and wireless network since their penetration is wide (Pimenidis et al., 2009). A DSS developed considering these aspects is MAFIC – DSS (Antonopoulou et al., 2010).

Anyway, most of the modern DSS consider several aspects in a unique frameworks providing to agronomists, policy makers and farmers solutions deriving from collected, stored and manipulated data (Antonopoulou et al., 2010). Most of the time DSS consists in a model or more models coupled with databases and assessment tools and a graphic interface (Wenkel et al., 2013).

Based on different approaches different decision support systems there have been developed to manage animal waste. As reviewed by Karmakar et al., (2007), most of DSS designed to manage manure are focused only to a particular aspect of manure management, (e.g. nutrient balance), examples are MMP, developed at Purdue University in 2000, WISPer, developed at University of Winsconsin (Bullington and Combs, 1994), NMPM developed at University of Minnesota (U.S.D.A. – N.R.C.S., 2001), VMNM developed at University of Vermont (Jokela et al., 1995), AEMIS developed at Utah State University (Harrison et al., 2005).

Only a few DSS are developed to consider the whole manure balance across their production, storage, treatment and spreading. DAFOSYM, developed at Michigan State University in 1995 (Borton et al., 1995) deals with dairy manure production, collection, storage, and land application. MAGMA (Modèle d'Aide à la Gestion des Matières Organiques au Niveau de l'Exploitation Agricole, Guerrin, 2001), and ISSM (Integrated Swine Manure Management), developed for the Canadian Prairie provinces (Karmakar et al. 2010), focus on environmental, agronomic, social and health, GHG, and economic issues. ValorE, Valorisation of Effluents, (Acutis et al. 2014) has been developed to cope with different livestock (cattle, swine, poultry, sheep, goats and horses). It also suggest and analyzes alternative manure management choices at farm and also territorial scale.

PURPOSE

Manure is often considered more a problem than a resource and it is very difficult for farmers to choose the "best solution" both for management and environmental purposes.
The purpose of the doctoral work, carried out in the framework of the Ager SEES PIG project "Multi – regional Solutions to improve the Environmental and Economic Sustainability of Pig manure management in the Regions of the Po and Veneto basin", is to design tools aimed at supporting farmers, administrators and technicians in choosing the best technological, environmental and economic solutions to manage manure at the farm and regional scale (within the Regions of the Po and Veneto basin Piemonte, Lombardia, Veneto and Friuli Venezia Giulia).
The Universities of Milano (Università degli Studi di Milano), Torino (Università degli Studi di Torino), Padova (Università degli Studi di Padova) and Udine (Università di Udine) cooperate in the project.
The unit of Udine focuses its attention to:

- data collection and implementation of a relational database;
- crop simulation;
- implementation of a client – server system;
- development of a modeling approach to estimate the amount of nitrates from agro – livestock activities.

For our purposes, the cropping system simulation model has been used to simulate crops and crop rotations in order to evaluate N leached, NH_3 emissions and percolated water. The key point is the contribution of N from livestock, considered as an element of strong environmental pressure. Crops and rotations are seen not only under a productive point of view but also as alternative systems, with different degrees of effectiveness, to lower NO_3^- pollution.
As the user run simulations via a DSS, based on a user friendly WebGIS interface, most of the potential problems associated to cropping system simulation model, database and also input are bypassed. The user does not need to download any software, therefore operating system and processor are not an obstacle to run the DSS; in effects he does not run the cropping system simulation model directly, as all the simulations output are preloaded into the DSS. The user can design alternative scenarios changing crops, crop rotations, irrigation, fertilization, and also modifying the cadastral units (the equivalent of "particelle catastali") and get an answer on the level of NO_3^- leached, percolated water and NH_3 emissions.
The DSS operates at two levels of detail: high, where outputs are calculated for each cadastral unit of a farm, and low, where outputs are cumulated at municipality level. Since each element is multiplicative and contributes to rise the computational complexity considering the large surface area, (Veneto and Po basin), the levels of detail (municipality and cadastral unit), the number of crops, crop rotations, soils, climate and management options a huge number of simulations should be required, leading to time consuming

activity requiring high computing power. Different methods to lower computational complexity and, accordingly, the working time to run the simulations have been developed and statistically evaluated. Simulation outputs are then manipulated to be preloaded into the DSS.
Although the project namely regarded pigs, data from cattle livestock were also collected to obtain a more detailed view. Data regarding cattle livestock were collected only in municipality where, at least, a pig livestock exists.
Research activity has been organized as follows:

- collection of livestock data;
- identification of sample areas;
- collection of soil data and regulatory limits in the sample areas;
- collection of climate data from the weather stations in the sample areas;
- collection of technologic data (physical and chemical characteristics of animal wastes;
- development of procedures to lower the computational complexity;
- simulation of the soil – climate – crop – crop rotation – management – manure combinations;
- implementation of user friendly client – server system with a WebGIS interface.

The collection of livestock data is necessary to estimate the N from pig and cattle manure. The estimated N from manure is necessary to identify environmentally stressed municipalities and, therefore, to define the sample areas.
Soil and climate data are inputs to run the cropping system simulation model. The agronomic module operates at two level of details. At high level of detail it needs highly detailed data: each cadastral unit has been identified with a soil type and climate data has been available at daily step. At low level of detail data is less detailed: for each municipality the main soil and a climate zone have been identified.
Regulatory limits and SAU have been collected. Regulatory limits, SAU and N from manure allows to identify situations where the regulatory limits are exceeded or are close to the limits .
Technological data allows to identify animal wastes by their chemical and physical properties. Animal wastes with similar chemical and physical properties have been grouped together in classes. Each identified class is an input for the cropping system simulation model. All the collected and manipulated data is an input for the cropping system simulation model.
Each simulation run with the cropping system simulation model provides a value for N leached, NH_3 emissions and percolated water. With this approach the outputs are quantized. A set of procedures have been developed to reduce the high number of simulations and to manipulate their outputs to obtain a series of multiple regression lines. The multiple regression lines allows to to switch from a quantized to a continuous estimation; the calculated regression lines are preloaded into the DSS.

2 MATERIALS AND METHODS

The purpose of this part is to describe the collected data (livestock, soil, climate), sample area and the chosen cropping system simulation model.

Livestock data have been collected to estimate the potentially available N from manure and to define the study area. The number of pigs and cattle was collected for Piemonte, Lombardia, Veneto and Friuli Venezia Giulia. The number of pigs was available at livestock level while the number of cattle was available only aggregated at municipal level. The N from manure has been estimated according to the values reported in the D.Lgs 7 aprile 2006 which reports the N produced for item in a year (see section 2.1).

Soil data have been collected for the 4 regions in the Veneto – Po basin. Soil data for Lombardia and Friuli Venezia Giulia was highly detailed while data for Piemonte and Lombardia was less detailed. In fact, for Piemonte and Veneto, the only available data was soil texture at the municipal level. Soil data is a necessary input for the cropping system simulation model (see section 2.2).

Similarly climate data has been collected. Climate data had different level of detail among regions: high for Lombardia and Friuli Venezia Giulia, low for Piemonte and Veneto. Climate data is a necessary input for the cropping system simulation model (see section 2.3).

For each municipality also SAU and regulatory limits were collected: each municipality was classified as located in NVZs or OZs or partially vulnerable areas.

The estimates of N from manure, SAU and regulatory limits allowed to select the sample areas: Pieve Fissiraga and Corte Palasio, located in Lombardia, and San Quirino, located in Friuli Venezia Giulia. These designated areas were also selected because data input were available at a very high level of detail (see section 2.4).

The cropping system simulation model has to allow to estimate N leached in groundwater, N gaseous losses as NH_3 and percolated water. Due to the purpose of the work the CropSyst simulation model has been chosen (see section 2.5). Its main characteristics, features and past research activities are reported. Collected and technological data (see section 3.2.1), have been properly manipulated to be used as inputs for the selected cropping system simulation model (see section 3).

2.1. LIVESTOCK DATA

Livestock data were collected in Piemonte, Lombardia, Veneto and Friuli Venezia Giulia regions. Swine and cattle livestock data were collected. Cattle livestock data were collected to obtain a more detailed view.

Livestock data have been mainly used to define the study area and to estimate the potentially available N from manure.

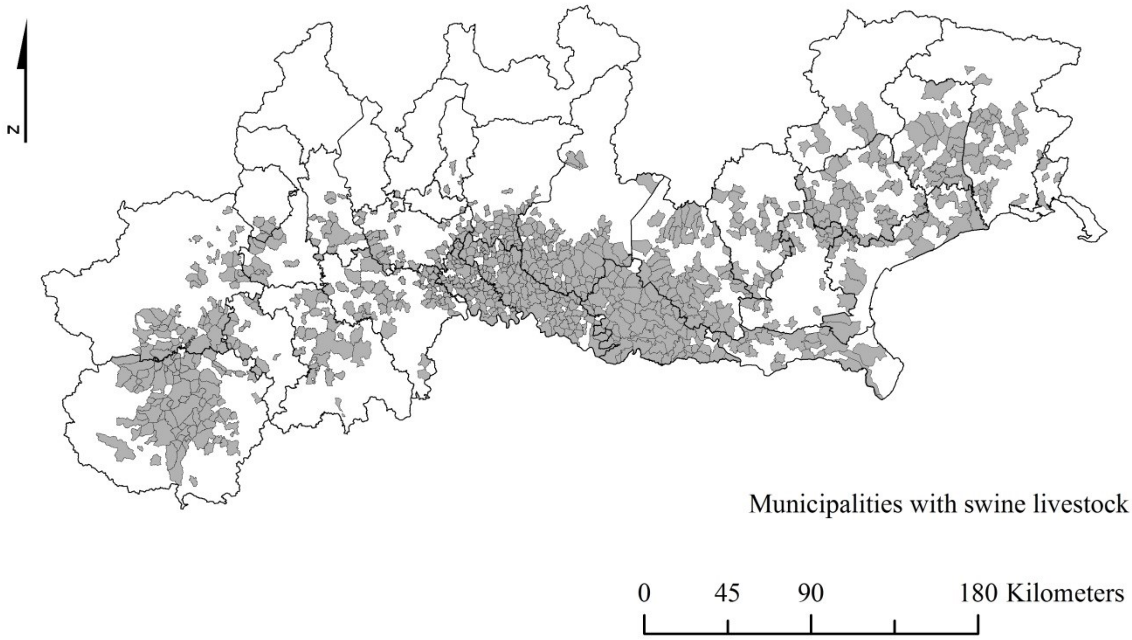
Livestock size in Piemonte, Lombardia, Veneto and Friuli Venezia Giulia were extracted from the Banca Dati Nazionale di Teramo (BDN, Istituto Zooprofilattico Sperimentale dell'Abruzzo e Molise "G. Caporale "). Data collected were:

- swine: number of pigs, both fattening and breeding pigs. Data were updated to March 2012; data regarding farms with few units were omitted. The number of units for each livestock was available;
- cattle: number of dairy cows and beef. The number of cattle was the total for each municipality where at least one pig farm was recorded. The number of cattle for each livestock was not available. Data regarding farms with few units were omitted. Data were updated to 1 December 2011.

2.1.2. Pig livestock data

Collected data regard fattening pigs and breeding pigs. Data were collected from 3,220 swine farms distributed in 861 municipalities (Fig. 1). For each Region, table 2 to 5, report data aggregated at province level.

Figure 1. Distribution swine livestock in the study area



Piemonte:

- number of municipalities with at least one pig farm: 198;
- number of farms: 896;
- number of breeding pigs: 60,037;
- number of fattening pigs: 997,334;
- number of pigs: 1,060,371.

Table 2. Number of pig farms, pigs, average number of pigs in Piemonte

Province	Number of farms	Number of pigs	Average number of pigs per farm	Percentage
Alessandria	22	31,350	1,425	3.0
Asti	21	16,076	766	1.5
Biella	10	32,780	3,278	3.1
Cuneo	670	746,590	1,114	70.4
Novara	18	42,890	2,383	4.0
Torino	138	173,656	1,258	16.4
Vercelli	17	17,029	1,002	1.6
TOTAL	896	1,060,371	1,183	-

The 6° Censimento Generale dell'Agricoltura (ISTAT, 2010) counted 1,108,894 pigs in Piemonte. The difference between collected and reported data is –4.6%. The province with the highest number of pigs is Cuneo, which represents the 70.4% of the total.

Lombardia:

- number of municipalities with at least one pig farm: 419;
- number of farms: 1,807;
- number of breeding pigs: 307,789;
- number of fattening pigs: 3,803,635;
- number of pigs: 4,111,424.

Table 3. Number of pig farms, pigs, average number of pigs in Lombardia

Province	Number of farms	Number of pigs	Average number of pigs per farm	Percentage
Bergamo	113	274,530	2,429	6,7
Brescia	565	1.168,128	2,067	28,4
Como	1	1,100	1,100	0,0
Cremona	338	854,649	2,529	20,8
Lecco	4	2,085	521	0,1
Lodi	178	374,876	2,106	9,1
Monza-B.	3	3,080	1,027	0,1
Milano	51	72,581	1,423	1,8
Mantova	459	1.085,334	2,365	26,4
Pavia	94	274,591	2,921	6,7
Varese	1	470	470	0,0
TOTAL	1,807	4,111,424	2,275	-

The 6° Censimento Generale dell'Agricoltura (ISTAT, 2010) counted 4,824,579 pigs in Lombardia. The difference between collected and reported data is –17.3%. The provinces with the highest number of pigs are Brescia, Cremona, Mantova which represent, respectively, 28.4%, 20.8% and 26.4% of the total.

Veneto:

- number of municipalities with at least one pig farm: 185;
- number of farms: 385;
- number of breeding pigs: 53,508;
- number of fattening pigs: 599,577;
- number of pigs: 653,085.

Table 4. Number of pig farms, pigs, average number of pigs in Veneto

Province	Number of farms	Number of pigs	Average number of pigs per farm	Percentage
Belluno	5	7,820	1,564	1.2
Padova	64	102,195	1,597	15.6
Rovigo	30	59,323	1,977	9.1
Treviso	73	102,540	1,405	15.7
Venezia	27	42,431	1,572	6.5
Vicenza	41	60,369	1,472	9.2
Verona	145	278,407	1,920	42.6
TOTAL	185	653,085	1,696	-

The 6° Censimento Generale dell'Agricoltura (ISTAT, 2010) counted 798,242 pigs in Veneto. The difference between collected and reported data is –22.2%. The province with the highest number of pigs is Verona, which represents the 42.6% of the total.

Friuli Venezia Giulia:

- number of municipalities with at least one pig farm: 59;
- number of farms: 132;
- number of breeding pigs: 23,275;
- number of fattening pigs: 161,874;
- number of pigs: 185,149.

Table 5. Number of pig farms, pigs, average number of pigs in Friuli Venezia Giulia

Province	Number of farms	Number of pigs	Average number of pigs	Percentage
Gorizia	4	8,565	1,279	4.6
Pordenone	64	109,112	853	58.9
Udine	64	67,451	779	36.4
TOTAL	132	185,149	1,402	-

The province of Trieste is not reported because there are not swine farms with a significant number of items. The 6° Censimento Generale dell'Agricoltura (ISTAT, 2010) counted 174,666 pigs in Friuli Venezia Giulia. The difference between collected and reported data is + 5.7%. The province with the highest number of pigs is Pordenone, which represents the 58.9% of the total.

2.1.3. Cattle livestock data

Data collected regards dairy cows and beefs.
Data were collected one every municipality hosting, at least, one pig farm aiming to the lack of any information at the single livestock level, data have been collected at the munic-

ipal level. The term heifer refers to both heifer and bred heifer. For each region, tables 6 to 9, report data aggregated at the provincial level. Data were updated to 1 December 2011.

Table 6. Number of heifers, dairy cows and beefs in Piemonte

Province	Heifer	Dairy cows	Beef	TOTAL
Alessandria	3,935	2,349	17,685	23,969
Asti	936	967	19,437	21,170
Biella	1,199	780	2,131	4,110
Cuneo	60,320	56,078	249,067	365,465
Novara	1,822	1,690	1,333	4,845
Torino	33,067	23,656	73,131	129,854
Vercelli	726	338	2,357	3,421
				552,834

Table 7. Number of heifers, dairy cows and beefs in Lombardia

Province	Heifer	Dairy cows	Beef	TOTAL
Bergamo	29,982	28,369	26,209	84,560
Brescia	386,309	116,066	148,871	386,309
Como	0	0	147	147
Cremona	121,673	116,073	33,537	271,283
Lecco	573	402	485	1,460
Lodi	41,401	39,515	15,568	94,484
Monza-Brianza	8	5	30	43
Milano	16,065	15,505	6,065	37,635
Mantova	93,348	61,171	154,870	309,389
Pavia	945,446	5,151	3,943	14,540
Varese	0	0	41	41
				1,201,891

Table 8. Number of heifers, dairy cows and beefs in Veneto

Province	Heifer	Dairy cows	Beef	TOTAL
Belluno	2,062	2,175	2,280	6,517
Padova	13,526	13,328	34,068	60,922
Rovigo	1,826	1,663	28,613	32,102
Treviso	10,946	10,818	75,801	97,565
Venezia	3,478	3,125	28,148	34,751
Vicenza	15,419	15,576	24,288	55,283
Verona	28,736	28,121	94,560	151,417
				438,557

Table 9. Number of heifers, dairy cows and beefs in Friuli Venezia Giulia

Province	Heifer	Dairy cows	Beef	TOTAL
Gorizia	1,257	1,413	91	2,779
Pordenone	10,230	10,132	7,085	27,447
Udine	9,193	9,565	5,158	23,916
				54,142

The Region with the highest number of cattle is Lombardia (1,201,891 items), followed by Piemonte (552,834 items), Veneto (438,557 items), and Friuli Venezia Giulia (54,142 items). The trend is similar to the number of swine, with a smaller gap among regions.

2.2. SOIL DATA

Region: Lombardia.
Source: ERSAF.
Description: digital mapping of soil map units; data are organized in 4 hierarchical levels representing units on 1: 50,000 scale. The Soil typological unit (STU) is classified according to WRB (FAO, 1998). Each STU and can be associated with other typological units in different percentages. The soils are identified according to Soil Taxonomy classification developed by the US Department of Agriculture. Soils are divided into horizons, each horizon characterized by thickness, pH, cation – exchange capacity, texture, coarse gravel, OM, organic carbon (C), and drainage capacity.

Region: Friuli Venezia Giulia.
Source: ERSA FVG.
Description: digital mapping of soil map units; each unit is a patch of 1 to 3 soil types, reporting the respective percentage. Soil types are not geo – referenced within the soil map unit; each type of soil is classified according to WRB (FAO, 1998). Soils are divided into horizons, each horizon characterized by thickness, pH, cation – exchange capacity, texture, skeleton, bulk density, organic matter and organic carbon (C), albedo. For each horizon, field capacity and wilting point are estimated with optimized pedotransfer functions (PTF). The PTF are optimized for the soils of the Region, according to gravel and OM content.

Regions: Veneto and Piemonte.
The only available data is soil textures at the municipality level. Other data such as AWC, horizons thickness, pH, cation – exchange capacity, texture, gravel content, bulk density, OM and organic carbon (C), albedo are not available. The most representative soil texture is taken as reference for the entire municipality. Each soil texture (or soil texture combinations) has been associated to a known soil from Lombardia or Friuli Venezia Giulia. AWC is estimated as a function of soil texture (Tab. 10):

Table 10. Soil textures and AWC

Soil texture	AWC	Identified soil texture
Clay	> 200	Clay
Clay – silty	> 200	
Clay – silty – loam	> 200	
Loamy	100 – 200	Loam
Clay – loam	100 – 200	
Silty – loam	100 – 200	
Sandy – clay – loam	100 – 200	
Loam – sandy	< 100	Sandy
Sandy	< 100	
Sandy – loam	< 100	

2.3. CLIMATE DATA

Region: Lombardia.
Source: ARPA Lombardia.
Description: weather stations location and meteorological data. Meteorological data are: cumulated daily rainfall (mm) and solar radiation ($MJ * m^{-2}$), average daily air temperature (°C), relative humidity (%), wind speed ($m * s^{-1}$).
5 weather stations were selected within the study area:

- Cavenago: data from 2002 to 2012;
- Lodi: (2003 to 2011);
- San Colombano al Lambro: (2001 to 2012);
- Sant'Angelo Lodigiano: (2001 to 2012);
- Crema: (1993 to 2012).

Region: Friuli Venezia Giulia.
Source: ARPA FVG – OSMER; SAASD (Settore Agricoltura Aziende Sperimentali e Dimostrative) – no more active since 2006;
Description: weather stations location and meteorological data. Meteorological data are: cumulated daily rainfall (mm) and solar radiation ($MJ * m^{-2}$), average daily air temperature (°C), relative humidity (%), wind speed ($m * s^{-1}$).
10 weather stations were identified within the study area.

- Vivaro: data from 1990 to 2009;
- Caneva: (1992 to 2006);
- Località Fratta – vivaio forestale: (1992 to 2006);
- Pordenone: (1995 to 2009);
- Spilimbergo Istriago: (1992 to 2006);
- Forcate – Fontanafredda: (1992 to 2006);
- Travesio: (1992 to 2006);
- Montereale Valcellina: (1992 to 2006);
- Sedrano di San Quirino: (1992 to 2006);
- San Martino al Tagliamento: (1992 to 2006).

Climate data were spatialized using a linear interpolation (Voronoi diagram). Weather stations are seen as a set of *n* distinct points in the sample area. Neighboring points are divided with straight equidistant lines. The sample area is divided into polygons: a polygon for each point (*n* points = *n* polygons). Therefore each polygon is associated to a weather station and, consequently, a climate.
Data sets are often incomplete. Missing data, over 30 years, were generated with ClimGen, climatic generator, version 4.06.08 (Stöckle et al., 2013).

Climate data were manipulated as follow:

- estimate data using Shepard's inverse method;
- interpolate with Voronoi diagram via GIS to define climate in each polygon;
- generate missing data with ClimGen to obtain complete climate series of 30 years.

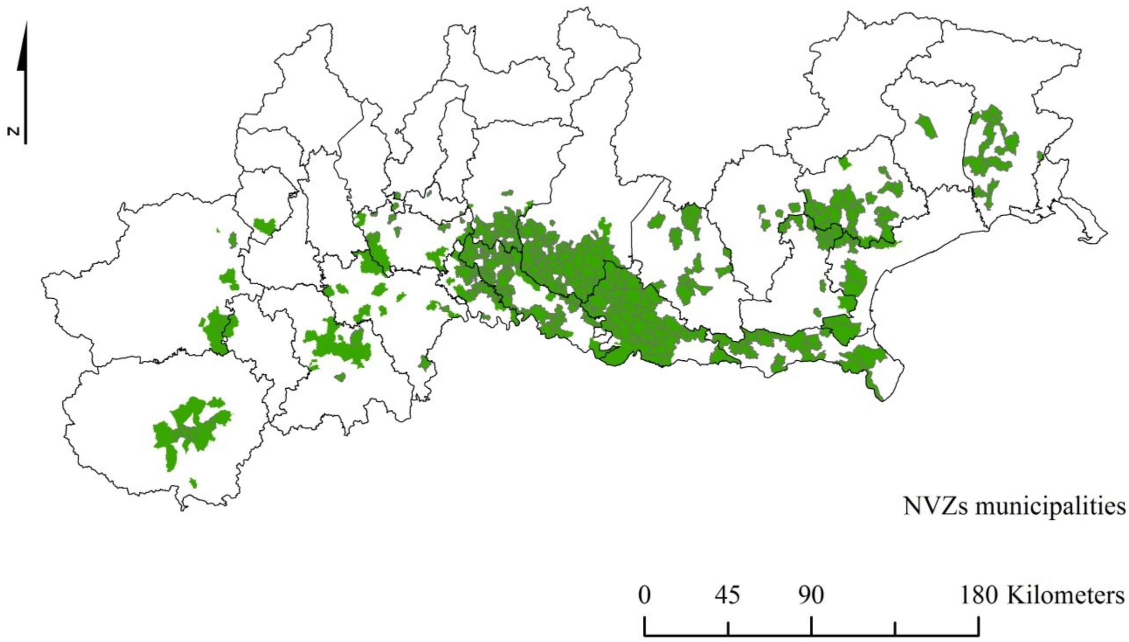
Region: Veneto and Piemonte;
Source: ISPRA – SCIA Sistema nazionale per la raccolta l'elaborazione e la diffusione di dati climatici di interesse ambientale;
Description: Meteorological data are: average rainfall precipitation (mm) from 1961 to 1990, for each municipality in the Po – Veneto Basin with, at least, one pig farm. These data is arbitrarily divided in 4 climatic zones. The range of the 4 identified climatic zones is: 629 – 1012 mm, 1013 – 1395 mm, 1396 – 1779, 1880 – 2162 mm.
The mean value of each climatic zone is therefore associated with a known weather station from the sample areas.

2.4. SAMPLE AREAS

Sample areas have been selected according to the following criteria:

- municipalities with a high number of swine;
- municipalities located in NVZs or OZs or partially vulnerable areas (Fig.2);
- different livestock pressure based on the ratio total N from manure/SAU;

Figure 2. Municipalities in NVZs or partially NVZs



The following data was collected, in order to identify sample areas:

- swine livestock data: number of fattening and breeding pigs (see section 2.1.1);
- cattle livestock data: number of heifers, dairy cows and beefs. (see section 2.1.2);
- SAU (ha) for each municipality;
- localization of NVZs, OZs, and partially vulnerable areas;

The collected data have been used to estimate the amount of N from swine and cattle manure for each municipality. For this purpose the following values were used:

- breeding pigs: 26.4 kg N $* \text{item}^{-1} * \text{year}^{-1}$, (this value refers to a sow with piglets with a weight ≤ 30 kg);
- fattening pigs: 9.8 kg N $* \text{item}^{-1} * \text{year}^{-1}$;

- heifer: 36.0 kg N $*$ item^{-1} $*$ year^{-1};
- dairy cows: 83 kg N $*$ item^{-1} $*$ year^{-1};
- beef: kg $*$ N item^{-1} $*$ year^{-1}.

These values are reported in the D.Lgs 7 Aprile 2006 (Criteri e norme tecniche generali per la disciplina regionale dell'utilizzazione agronomica degli effluenti di allevamento, di cui all'articolo 38 del decreto legislativo 11 maggio 1999, n. 152, Tabella 2 – Azoto prodotto da animali di interesse zootecnico: valori al campo per anno al netto delle perdite per emissioni di ammoniaca; ripartizione dell'azoto tra liquame e letame). N produced by livestock: annual values available at the field, considering NH_3 emission losses; N ratio between slurry and manure).

Using these conversion factors, the following values of N produced by swine were estimated at the single livestock level:

- N from breeding pigs (kg $*$ year^{-1});
- N from fattening pigs (kg $*$ year^{-1});
- total N (breeding and fattening pigs) (kg $*$ year^{-1});
- total N from breeding pigs (kg $*$ year^{-1});

and, at the municipal level:

- total N from fattening pigs (kg $*$ year^{-1});
- total N (breeding and fattening pigs) (kg $*$ year^{-1}).

Similarly the following values of N produced by cattle were estimated at the municipal level:

- N from heifers (kg $*$ year^{-1});
- N from dairy cows (kg $*$ year^{-1});
- N from beef (kg $*$ year^{-1});
- total N (heifers, dairy cows and beefs) (kg $*$ year^{-1}).

These estimates allowed to:

- calculate the total N (swine and cattle) available for each municipality (kg $*$ year^{-1});
- classify municipalities according to pollutant's nature: i.e. with a prevalence of N from pig manure or with a prevalence of N from cattle manure.

Fig. 3 reports the classification of municipalities in the study area; table 11 resumes the partitioning of swine and cattle N in the four regions of the study area.

Figure 3. Municipalities according to the origin of N

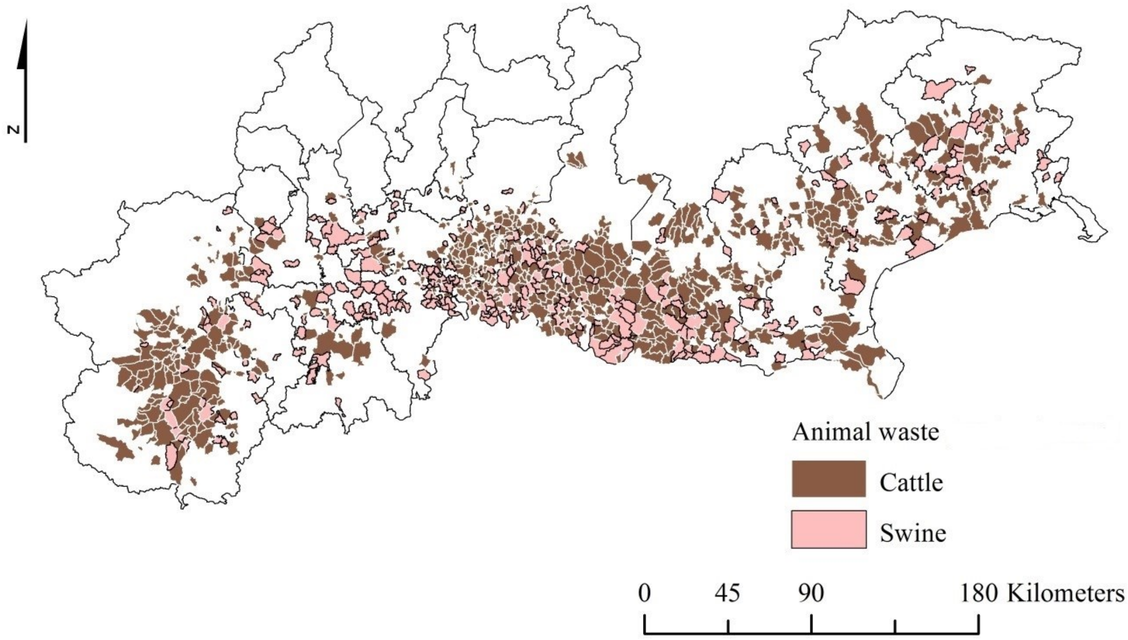


Table 11. Percentage of for swine and cattle N in the regions of the study area. Values are aggregated for each region

Region	Swine N (%)	Cattle N (%)
Piemonte	33.0	77.0
Lombardia	57.1	42.9
Veneto	71.8	28.2
Friuli Venezia Giulia	56.9	43.1

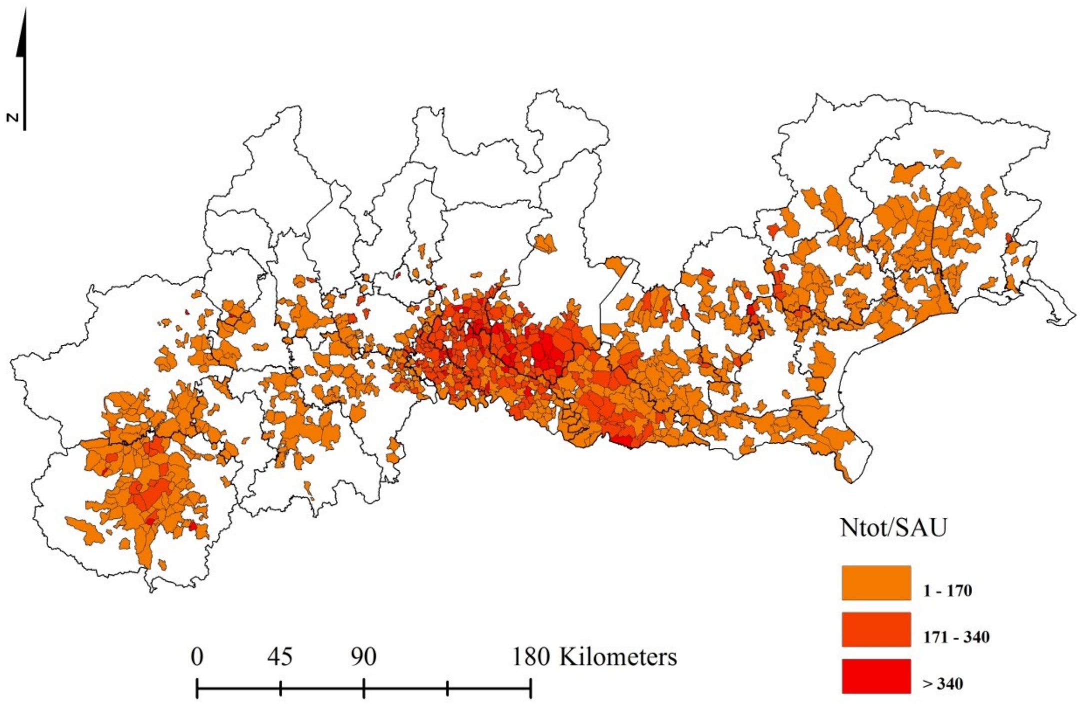
SAU represents the total surface area classified as arable land, permanent pasture and meadow, permanent crops and kitchen gardens. Table 12 reports SAU in the regions of the study area classified as arable (a), permanent meadows and pastures (p – m) according to the 6° Censimento Generale dell'Agricoltura (ISTAT, 2010). In the same table, the number of municipalities totally or partially located in NVZs or OZs are also reported. The knowledge of the estimated N production and SAU, and together with the maximum amount of N from livestock in NVZs and OZs allowed to:

- calculate the amount of potentially spreadable N for each municipality ($kg * ha^{-1}$);
- identify municipalities where the regulatory limits ($N > 170\ kg * ha^{-1}$; $N > 250\ kg * ha^{-1}$) are exceeded or are close to the limits (warning conditions) ($N > 340\ kg * ha^{-1}$) (Fig.4);

Table 12. Municipalities (NVZs, partially NVZs, OZ), SAU distribution (arable, permanent pasture, meadows), municipalities exceeding regulatory limits

	N of municipalities in			SAU distribution (%)		N of municipalities exceeding the limits of	
Region	NVZs	NVZs (p)	OZ	SAU (a)	SAU (p – m)	170 $kg * ha^{-1}$	340 $kg * ha^{-1}$
Piemonte	13	106	79	66.2	26.5	18	9
Lombardia	222	84	113	90.5	7.6	199	106
Veneto	98	6	81	73.5	15.7	16	4
FVG	27	-	32	79.3	9	-	-

Figure 4. Municipalities and total nitrogen production and SAU ratio ($kg * ha^{-1}$)

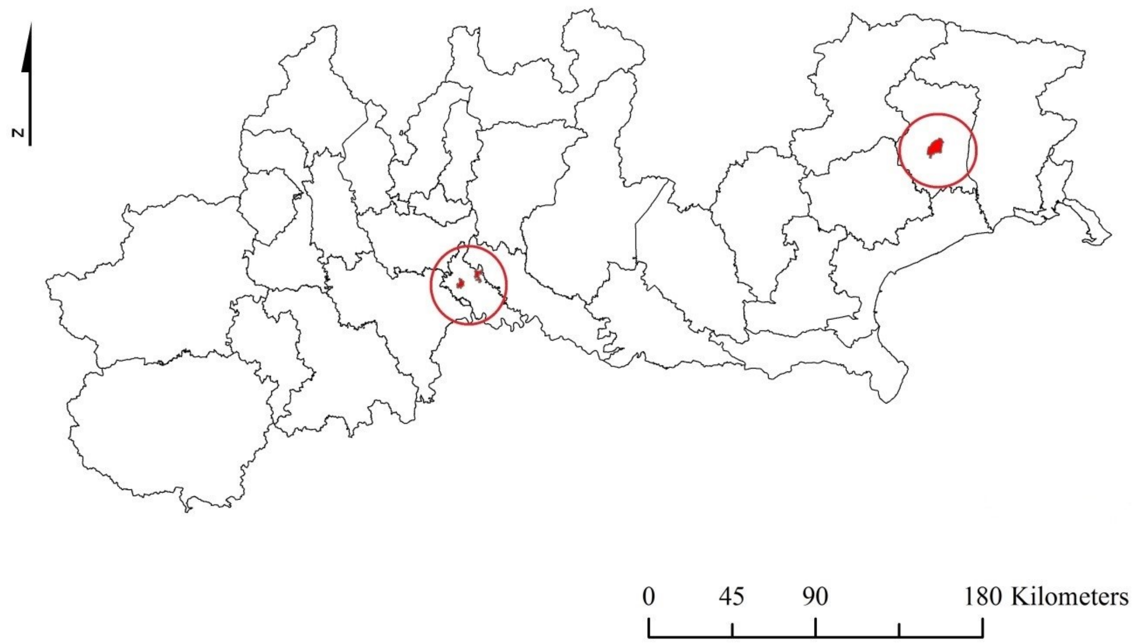


As previously described simulations were run at two levels of detail. In a few sample areas, outputs have been produced at the cadastral unit level, considering also an additional buffer area of 3 km, while outputs for the other areas, representing the large majority of the study area, have been produced at the municipal level. In order to obtain outputs at the cadastral unit level simulations have been run starting from highly detailed input data, while at the municipal level required less detailed input data. Accordingly, the following sample areas were selected: Corte Palasio, Pieve Fissiraga and San Quirino. Corte Palasio and Pieve Fissiraga are located in the province of Lodi (LO, Lombardia), while San Quirino is located in the province of Pordenone (PN, Friuli Venezia Giulia). The designated areas fall both in NVZs and OZs. Although these municipalities are not the most environmentally stressed areas in Lombardia and Friuli Venezia Giulia, they were selected because data input were available at a very high level of detail. The main characteristics of the sample areas are reported in Tab. 13 and Fig. 5.

Table 13. Sample areas and their characteristics

Municipalities	Region	Vulnerability	Swine livestock	Number of swine	Number of cattle	N from manure ($kg * ha^{-1}$)
Corte Palasio	Lombardia	NVZs	9	15,798	3,613	348
Pieve Fissiraga	Lombardia	OZs	10	20,860	2,691	305
San Quirino	FVG	OZs	4	22,801	2,608	167

Figure 5. Sample areas



2.5. CROPPING SYSTEM SIMULATION MODEL

According to the purposes of the work, the cropping system simulation model has to provide sounds of estimate N leached in groundwater, gaseous N losses from agro – livestock activities – particularly related to manure spreading – percolated water, the latter allowing to calculate the concentration of N leached.
In a preliminary stage different freely available models were examined; the survey suggested to neglect models meeting one or more of the following features:

- inability to estimate N leached, gaseous N, percolated water;
- lack of technical support and feedback by the developers;
- poorly utilized, (no publications) and poorly documented;

Taking into account all the above listed features, CropSyst model has been preferred (Stöckle et al., 1994). CropSyst it is a deterministic multi – year, multi – crop, daily time step cropping system simulation model for a wide range of crops, written in Turbo Pascal for DOS, in C++ for the Windows version. It simulates, soil water budget, soil – plant N budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water. It uses, as data input, on soil, crops, cropping system management and a series of options like N fertilization, both mineral and organic, irrigation, tillage and residue management, and weather.
A GIS module allows to simulate homogeneous territorial units characterized by a combination of soil, weather, crop rotation and management at a large scale.
The model is well documented, widely used, and it is continuously evolving. In this work version is 4.15.24 (Stöckle et al., 2013). The model has been extensively applied in case studies worldwide, also with grid – based framework for regional analyses, and has been incorporated into hydrologic models, decision – support tools, and also multi – model assessment tool (Stöckle et al., 2014).
Past research activities, also conducted in stressful conditions, have shown the model is well suited to simulate crops and N balance in Italy, especially in the North of Italy (Bechini et al., 2006; Bellocchi et al., 2006; Confalonieri et al., 2006; Confalonieri and Bechini, 2004; Confalonieri and Bocchi, 2005; Morari et al., 2004; Stöckle et al., 2003; Giardini et al., 1998; Donatelli et al., 1996, 1997). In Italy, CropSyst has also been applied to evaluate the prospective climate change upon maize production and the water footprint until 2050 in the study area of Persico Dosimo in the province of Cremona, Lombardia, representative of the agricultural area of the Po valley (Bocchiola et al. 2012). CropSyst was also included in a software, Va.Te (VAlutazioni TErritoriali dei PUA e dei PUAS in Regione Lombardia), developed to support both preparation and evaluation of N fertilizing plans for livestock farms (Bechini et al. 2008). Va.Te integrates CropSyst and Regione Lombardia’s agricultural databases.
CropSyst was also included into a bio – economic modelling framework, (FLEOM Farm – Level Economic – Ecological Optimization Model), developed to optimize both land and resources use at farm level while at the same time evaluating economic and environmental

impacts (Sommer et al., 2010). The study area of FLEOM is the Khorezm region in western Uzbekistan.

The water balance is modeled with precipitation, irrigation, runoff, rainfall intercepted by crop and surface residue surface runoff, soil and residue evaporation, infiltration through soil layers, transpiration, deep percolation and water storage in the soil profile and infiltrated into the soil. User is able to calculate the redistribution of water budget in both soil profile and evapotranspiration in several ways. Water redistribution along the soil profile can be simulated by:

- cascade model: water enter in a layer, fills it to field capacity and the exceeding water goes to the next layer. Water penetrating beyond the root zone is lost as drainage;
- Richard's soil flow equation, (finite difference method) taking into account the water flow upward by capillary action; with this model, additional options are available.

In CropSyst two potential evapotranspiration models are available. The selection of the model is done automatically, once data available for each day is determined. To calculate evapotranspiration CropSyst provides two models: the Penman – Monteith and the Priestley – Taylor model. The latter requires maximum and minimum air temperature and solar radiation, while the former requires also maximum and minimum relative humidity or dew point temperature and wind.

The N balance is calculated in interaction with water balance, and includes N transformations (net mineralization, nitrification and denitrification), NH_4^+ sorption, symbiotic N fixation, crop N demand and crop N uptake (Stöckle et al., 2003). N transformations are simulated using a first – order kinetics, assuming they occur in the first 30 – 50 cm of soil. Crop N uptake is determined as the lower between crop N demand and potential N uptake. Crop N demand is the amount of N the crop needs to meet its potential growth, as limited by light, temperature and water, plus any deficiency demand. Crop growth is simulated as a function of temperature, of light radiation, water, N and CO_2.

User can set simulations selecting modules, e.g., salinity simulation, erosion simulation, N simulation can be in turn disabled. With some modules disabled, parameterization is simplified and simulations can run faster.

Simulations return daily, seasonally and annually outputs. The model returns as output the amount of N leached, percolated water, N uptake by crops, N mineralized, N lost by volatilization, and yield. Additional output that can be used for the calibration phase are the dates corresponding to the phenological stages of various crops, the aboveground biomass, N mineralized from organic matter and crop residues, the accumulation of OM in the soil.

The model allows to run simulations at large scale via a GIS module which associates a simulation to each record of a .DBF file which corresponds to homogeneous territorial unit characterized by a combination of soil, weather, crop rotation and management. Crop rotation is a temporal sequence, of sequential seasons, of different crops on the same

territorial unit. Each crop is associated with a management practice. Simulations can be run for long time periods, (decades), allowing to predict future trends.
The interface allows to manipulate the files required to run simulations, set parameters in an opportune range and run simulations to obtain results both in text and graphic format.
In order to run a simulation the model requires the following files: Soil, Crop, Management, Biomatter, Rotation, Weather, Format, Scenery, Project.

The soil file (*.SIL) describes soil physical and chemical characteristics: hydrologic group, hydrologic conditions – both used for the calculation of surface runoff (SCS Curve Number method – US Soil Conservation Service, 1972) – parameters to calculate erosion with the RUSLE equation (Revised Universal Soil Loss equation; Renard et al., 1997), albedo, both wet and dry. For each soil layer are also indicated: thickness, texture, field capacity, bulk density, permanent wilting point, bypass coefficient, saturated hydraulic conductivity, saturation, air entry potential, Campbell b value (Campbell, 1985), cation exchange capacity, and pH.
When unknown, field capacity, wilting point, bulk density, air entry potential, Campbell b value, saturated hydraulic conductivity, can be estimated using pedotransfer functions implemented within the model (Saxton et al., 1986).

Crop file (*.CRP) are used to define crops and crop rotations using the parameters listed in the following sections:

- classification: allows to select crop model, land use, life cycle, stem type, photosyntethic pathway, harvested biomass; each one with several options;
- emergence: calculates emergence, according to the thermal time or hydrothermal time model;
- thermal time accumulation is the basis for the simulating of crop phenology using base temperature, cut off temperature and resolution;
- transpiration calculates evapotranspiration;
- attainable growth calculates growth using both a transpiration dependent and a radiation dependent growth model;
- canopy growth can be simulated using a leaf area index model or a canopy cover based model;
- phenology calculates the thermal time to reach different phenologic stages;
- CO_2 the relationship between carbon dioxide concentration in the atmosphere and crop response; is an optional parameters;
- salinity crop response to salinity (optional parameter);
- nitrogen in this section simulate crop N uptake are considered; these are optional parameters;
- residue: parameters to simulate crop residue decomposition;
- hardiness: crop manages hardiness to cold;

- senescence: leaf area index (LAI) duration and senesced biomass fate, green area index (GAI), including in relation to water stress, and the fate of senescent biomass are considered;
- dormancy – seasonal: it is possible to choose between three modes, single season, multiple season, dormancy;
- harvest: harvest index (HI); HI sensitivity to water, N and temperature stress are considered;
- roots: parameters to specify the depth of the roots, length, density, and distribution are considered;
- vernalization: parameters to define the low temperature to promote flowering;
- photoperiod: parameters to define the development of a plant as a function to the relative lengths of days and nights to induce flowering;

The simulation model allows to use default parameters the main crops, suggesting the most sensitive. These parameters require an accurate calibration within a range provided by the model itself. A Crop calibrator utility available only for annual crops, allows to calibrate parameters for location and cultivar, it is. Inputs are: location – weather, phenology, biomass and LAI evolution and biomass growth and yield.

Management files (*.MGT) contain management parameters for each crop. Management events, irrigation, fertilization, harvest – clipping, tillage, residue, conservation and LCA, can be scheduled as actual dates, relative dates, or dates automatically computed by the model respecting the phenologic stage of plant development. Using the actual dates option user enters both year and day the event occurs. Actual events are applied only once during the simulation. In relative date mode, the year corresponds to the planting year. The relative year is then added to the crop planting year to calculate the actual date in which the event occurs. Usually relative dates are used with repeated crops and management rotations.

Harvest, clipping, irrigation, fertilization can be set as automatic. Irrigation and fertilization allows users to maximize the growth of crops, avoiding water and N stress.

Management file takes into account the following parameters:

- irrigation: it is possible to apply water to the available water content of the soil (AWC) whenever it falls below a specified threshold. For each irrigation event, user enters the applied amount of water;
- fertilization: automatic N fertilization is calculated by the model, based on soil N balance and crop requirements. Fertilizations could be applied in dates defined by the user. If fertilization is specified by the user it is possible to choose between organic and inorganic fertilizers, total amount and application method. The organic fertilizer is also defined by the file *.CS_biomatter, which specifies slurry chemical composition and decomposition time;
- harvest – clipping: it is possible to set automatic dates or specify the dates of harvest. In the automatic mode the clipping event happens when biomass and/or

LAI reach a certain threshold and/or passed a certain number of days from flowering and/or GAI's (Green Area Index) growth rate is low for 14 consecutive days.

Biomass harvest can be set in 3 ways:

- calculated by the model using harvest index (HI); the remaining biomass can be removed and to be sold for trade, removed from the field and remain unused, remain on the field as a residue or a standing residue, or remaining as a live standing plant tissue;
- calculated as a fixed amount; with this mode the removed amount is divided into the specified organic matter;
- calculated as a percentage of the biomass; the removed amount is the yield.

For each mode it is possible to select different options for biomass deposition, clipping, last clipping, grazing and defoliation.
Using the fixed amount and percentage modes the user also set the conditions for grazing and clipping specifying the minimum LAI and, or, minimum biomass. It is also possible to set a parameter to represent the biomass which cannot be removed by animals.
It is also possible to calculate the life cycle assessment (LCA), specifying the CO_2 equivalent for hectare. This is an optional module.

Biomatter file (*.CS_biomatter) specifies the chemical composition of the organic, the N and C content of biomass. Default values for plant residues and animal manure are available. The *CS_biomatter file allows to set also the half – life of organic matter i.e. the number of days required for the decay of 50% of the organic matter. This parameter can be set as a single pool or multiple pools.

Rotation file (*.ROT) set the sequence of crops over the years, associating each crop to a *.MGT and a *.CROP file. For each crop in rotation, sowing date and events are set. Sowing event can be fixed or conditional. Conditional sowing events are computed by the model based on soil and weather conditions.

Weather files (*.UED) report daily meteorological data: precipitation (mm), maximum and minimum temperature (°C), maximum and minimum relative humidity (%), solar radiation ($MJ * m^{-2}$), wind speed ($m * s^{-1}$), maximum, minimum and average dew point (°C), maximum solar irradiance and hours of daylight. User could enter longitude, latitude, altitude of each weather station.

Format file (*.FMT) specifies the selected variables for the reports (growing season, annual, daily) as well as the soil profile and the file type output.

Scenario files (*.CSN) combines *.UED, *.ROT, *.SIL and *.FMT files in order to run a simulation. The scenario files allows to set:

- submodels (environment, chemistry, evapotranspiration, soil, crop and OM);
- simulation period (starting and ending date for each simulation);
- initialization for soil profile and residues: water content, NH_4^+, NO_3^-, OM, salinity, thickness, and depth.

Project file (*.CSP) organizes several *.CSN files in a project. *.CSP file allows to run multiple simulations belonging to the same project, but with different scenarios. Optional module allows a GIS simulation, which uses a polygon attribute table, *.DBF file.

3 RESULTS

3.1. SIMULATION SERVER

In order to use a cropping system simulation model at a large scale, it is necessary to provide a link between the simulation model and input data as well as a link between the cropping simulation model and simulation outputs.
A relational database (simulation server) has been implemented in order to:

- store data in a homogeneous system;
- allow the exchange of information among the sections of the database (input, output and the cropping simulation model).

In the framework of the present work the minimum simulation unit is represented by the cadastral unit. Cadastral unit is the homogeneous element that is common to all data. Collected data (see sections 2.1, 2.2, 2.3) have been interpolated via GIS in order to characterize each cadastral unit.
The simulation server was implemented with MySQL from a conceptual Entity – Relationship (ER) model, using ChronoGeoGraph. The ER model conceptually describes a cropping systems at the cadastral unit. The ER model is composed by the following sections: cadastral units, soils, climate, rotations, and output.
The rotation section is the main core of the simulation server. It describes the sequence, of one or more crops, each with its management on a homogeneous area. Management are characterized by irrigation, fertilization, harvest – clipping and tillage attributes and dates.
The database has been populated using a MS Access interface as a front end. A Perl script, interfaced with the database, automatically produced the management and rotation files required to run simulations.

3.2. COMPUTATIONAL COMPLEXITY

As the CropSyst simulation model has been recognized to be rather unstable, time consuming in run simulations, unsuitable for non skilled users and, finally does not allow to control the simulation outputs, it has been decided that the DSS does not incorporate the cropping system simulation model, following this approach, none of the simulations are run in real time: therefore the simulations are pre run, considering all the combinations among inputs, analyzing and treating the outputs and finally loaded into the DSS. The user is allowed to modify crops and their area, as well as crop rotations, irrigation, fertilization (organic and mineral), cadastral units. These options define the coordinates required to extract the preloaded outputs from the database. The DSS algorithms return N leached ($kg * ha^{-1}$), N gaseous emissions ($kg * ha^{-1}$) and percolated water (mm) calculated values.
The number of simulations required to fulfill all the possible combinations is huge. The number considering:

- Noc: number of simulated crops;
- NoR: number of rotations;
- FSH: first and/or second harvest;
- CM: crop management;
- NS: number of soils;
- C: climate;
- SoI: systems of irrigation;
- CP: chemical and physical properties of animal waste;
- T: single or combined treatments applied to animal waste.

As each of the listed factors is multiplicative, the estimated number of simulations results in about $9*10^7$. In particular the number of rotations and crop management contribute significantly. Such huge a number of simulations is tremendously time consuming and requires very high computational power. As an example, simulation run with a PC with an Intel Xeon CPU E5645 @ 2.40 GHz, 12 GB RAM, takes, at least, 2.5 minutes, with GIS runner.
Therefore procedures aimed at lowering the computational complexity have been implemented mainly considering the following issues:

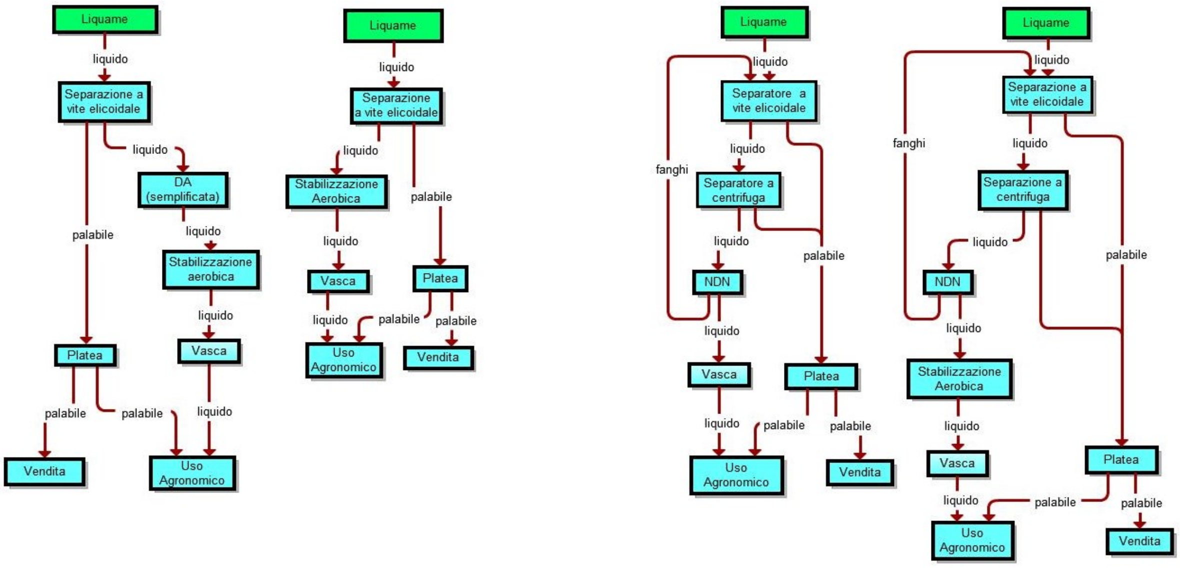
- technological data;
- crops and rotations;
- second harvest;
- soil – climate combinations.

The strategies are described in the following sections.

3.2.1. Technological data

Treatments and their combinations were identified by the Milan unit (Fig. 6). Each treatment, or combination of treatment, is identified by the chemical and physical properties of the manure, slurry, sludge or compost obtained. The same treatment applied under different conditions (e.g. farms) do not produce output in terms of the same chemical and physical properties. Moreover, the same treatment applied to swine or cattle do not produce the same output in terms of chemical and physical properties.

Figure 6. Treatments and their combinations



Effluent from each treatment is characterized with:

- volume $(m^3 * year^{-1})$;
- total ammonia nitrogen (TAN) $(kg * year^{-1})$;
- total Kjeldhal nitrogen (TKN) $(kg * year^{-1})$;
- total solids (TS) $(kg * year^{-1})$;
- total volatile solids (TVS) $(kg * year^{-1})$.

Chemical and physical data were measured from farms in Pieve Fissiraga and Corte Palasio.

For each treatment or combination of treatments the mean values of C/N and TAN/TKN were calculated. Then each treatment was associated with A decay parameter (days to 50% decomposition half – life days in CropSyst) was associated to each treatment and set to the default values provided by CropSyst.

For the purpose of the work the C/N ratio, TAN and TKN and days of decomposition have been recognized as the most significant parameters. A number of simulations were run to understand how the chemical and physical characteristics of animal wastes affecting N leached values, provided that DM and the C/N ratio, if constant, does not affect N leaching.

Different treatments which produce animal wastes with the similar C/N and TAN/TKN ratio were grouped in classes. For each class the mean value of C/N and TAN/TKN was calculated for swine (Tab. 14 and 15) and cattle (Tab. 16 and 17).

Table 14. Treatments, physical and chemical properties.
C/N values (swine)

Treatments – combinations	C/N	Mean C/N
AD centrifugation NDN (slurry)	1.85	1.9
AD centrifugation NDN (sludge)	5.5	
AD + biomasses (slurry)	6.6	
Centrifugation (slurry)	6.0	
AD – screw press (slurry)	6.4	6.6
AD (slurry)	6.9	
AD – centrifugation – stripping (slurry)	7.2	
Screw press (slurry)	8.6	
Raw slurry (slurry)	11.25	12.1
Composting (solid)	12.9	
AD – screw press (solid)	19.3	
AD centrifugation NDN (solid)	19.8	19.7
AD – centrifugation – stripping (solid)	19.8	
Manure (solid)	19.9	
Screw press (solid)	26.25	26.7
Centrifugation (solid)	27.05	

AD: anaerobic digestion; NDN: nitritrification – denitrification.

Table 15. Treatments, physical and chemical properties.
TAN/TKN values (swine)

Treatments – combinations	TAN/TKN	Mean TAN/TKN
AD – centrifugation NDN (sludge)	21.49	24
Composting (solid)	27.1	
Screw press (solid)	44.26	49
AD – screw press (solid)	45.25	
Centrifugation (solid)	53.11	
AD – centrifugation – stripping (slurry)	53.73	
Raw slurry (slurry)	66.39	69
AD – centrifugation NDN (solid)	67.06	
AD – centrifugation – stripping (solid)	68.78	
Screw press (slurry)	70.29	
Centrifugation (slurry)	70.81	
Manure (solid)	80.56	85
AD + biomasses – stripping (slurry)	83.34	
AD (slurry)	85.36	
AD – centrifugation NDN (slurry)	85.97	
AD – screw press (slurry)	89.32	

AD: anaerobic digestion; NDN: nitritrification – denitrification.

Table 16. Treatments, physical and chemical properties.
C/N values (cattle)

Treatments – combinations	C/N	Mean C/N
AD centrifugation NDN (slurry)	1.3	1.3
AD centrifugation NDN (sludge)	3.9	5.4
AD + biomasses (slurry)	4.0	
AD – screw press (slurry)	4.6	
AD (slurry)	5.1	
AD – centrifugation – stripping (slurry)	5.1	
Screw press (slurry)	6.4	
Raw slurry (slurry)	8.4	
AD – screw press (solid)	13.8	15.5
AD centrifugation NDN (solid)	14.1	
AD – centrifugation – stripping (solid)	14.1	
Composting (solid)	15.95	
Screw press (solid)	19.6	
Manure (solid)	37.35	37.4

Table 17. Treatments, physical and chemical properties.
TAN/TKN values (cattle)

Treatments – combinations	TAN/TKN	Mean TAN/TKN
AD centrifugation NDN (sludge)	22.56	25
Composting (solid)	28.2	
Screw press (solid)	37.33	42
AD – screw press (slurry)	47.49	
Raw slurry (slurry)	56.0	57
AD – centrifugation – stripping (slurry)	56.4	
Screw press (slurry)	59.29	
AD centrifugation NDN (solid)	70.38	74
AD (slurry)	72.0	
AD – centrifugation – stripping (solid)	72.19	
Manure (solid)	80.56	
AD + biomasses (slurry)	87.47	90
AD centrifugation NDN (liquid)	90.23	
AD – screw press (liquid)	93.75	

18 classes, 9 for swine and 9 for cattle have been identified. The classes for swine are reported in Tab. 18, while the classes for cattle are reported in Tab. 19.

Tab. 18. Classes for swine

Mean TAN/TKN	Mean C/N
24	6.6
49	6.6
	19.7
	26.7
69	6.6
	12.1
	19.7
85	1.9
	6.6

Tab. 19. Classes for cattle

Mean TAN/TKN	Mean C/N
25	5.4
	15.5
42	15.5
57	5.4
74	5.4
	15.5
	37.4
90	5.4
	1.3

Each treatment is associated to 3 values of decay: 110 days, 200 days and 550 days for swine. 200 days and 550 days for cattle.

3.2.2. Crop rotations

The number of simulations is largely determined by crops and crop rotations. The simulated crops were Alfalfa (Medicago Sativa), winter Barley (Hordeum vulgare), grain and silage Maize (Zea Mais), Soybean (Glycine max), Sugarbeet (Beta vulgaris), Suflower (Helianthus annuus), winter Wheat (Triticum aestivum), Ryegrass (Lolium). Table 20 reports the harvested areas of each crop in 4 regions of the study area.

Table 20. Harvested crops in the study area (ISTAT, 2010)

Crop	Piemonte (ha)	Lombardia (ha)	Veneto (ha)	FVG (ha)
Mais	192,215	242,436	246,177	91,404
Barley	24,856	17,357	8,295	8,285
Wheat	94,435	53,703	92,827	11,250
Soybean	6,725	28,347	76,825	28,315
Sunflower	5,474	1,213	1,295	407
Alfalfa	20,227	65,247	16,750	11,436
Ryegrass	3,382	35,151	1,757	126
Sugarbeet	938	6,852	14.791	215

All these crops have been simulated as main crops. A few of them have been considered as second crops, in the following sequences: Barley – Maize (grain/silage), Barley – Soybean. Set aside has been also simulated.

At the real farm level, the surface area cultivated by each crop is known, while data and crop rotations are usually unknown. As Cropsyst simulations based on crop rotations, a procedure aimed at rebuilding crop rotation from a single crop surface areas has been proposed. The rationale is to transfer a spatial distribution (area) into a temporal sequence (rotation). The proposed procedure is described below with an example.

Consider a 100 ha farm occupying 50 ha of the surface area with Maize, 25 ha with Barley and 25 ha with Soybean (Fig. 7):

- the crop whose surface is less representative is taken as unit; in this case Barley or Soybean is taken as unit;
- surface areas of singles crops are divided by the unit area to calculate their relative rates; in this case Maize = 2 (50/25), Barley = 1 (25/25), Soybean = 1 (25/25);
- the calculated rates are then transferred as temporal sequence: on the average of the whole farm surface area 2 years are cultivated with Maize, 1 year with Barley, 1 year with Soybean.

Figure 7. Spatial distribution of a hypothetical farm

Additional rules are:

- if the ratio does not return an integer, the numerical value is rounded;

- in order to reduce the number of simulations, crops representing less than 5% of the total surface area are not considered. In this case their area is proportionally redistributed to the other crops.

This method allows to build rotations with minimal data input, as in most cases happens in real farms.
The computational complexity is, mostly, given by the number of rotations. Considering simulation period of 30 years (the period over which each simulation is run) the number of rotations are calculated as permutation (including senseless rotations). The general rule to calculate the number of combinations with repetition is the following:

- $C_{n,k} = \binom{n+k-1}{n-1}$;
- n = number of simulated crops;
- k = number of years of simulation;

Given 2 crops, A and B, and a period of simulation of 30 years, the number of possible rotations is 31, including 2 senseless rotations built with only one of the 2 crops (rotation built only with crop A and rotation built only with crop B). Adding another crop, C, the number of rotations rises to 496, including senseless rotations where only one crop is available or one crop is not available.
As in this work 10 crops have to be simulated the total number of rotations is 211,915,132, including the senseless ones.
In order to reduce the number of rotations and, therefore, the number of simulations, 3 different procedures were tested.

The first procedure was previously proposed by Muzzolini (2009) in her PhD thesis "An integrated modelling approach to estimate nitrogen leached from agricultural land". The only common point between the present work and the work of Muzzolini is the estimate of N leached from agricultural land, while the starting point is different: in the former, crop and rotation data were unknown, while in the latter crop and rotations data were known. The Ager Sees Pig project involves Piemonte, Lombardia, Venezia and Friuli Venezia Giulia, while the PhD research was focused on Friuli Venezia Giulia.
The method was based upon agronomic, combinatorial and computational rules. Crop rotations resulting within a 5 years period were considered the same. Crop rotations, e.g., ABCDE, ACBDE were considered the same. There were built 7 different rotations with Maize (M), Soybean (S), Barley (B), Sunflower (Su), Wheat (W). Simulations were run for 40 years, in critical conditions: loamy skeletal soils, highly drained. One way Analysis of variance (ANOVA), α level = 0.05, test was applied. Previously, normal distribution was test. Results show the N leached values are not significantly different. This is the reference method, N leached is calculated as an arithmetic mean.

The most important rule is the combinatorial one which is the "core" of both second and third method, developed for the Ager SEES PIG project.

In order to compare the 3 methods, there were set simulations with a run period of 30 years, crops were Maize (M), Barley (B), Soybean (S). These crops were combined to build the following rotation: MBMSBM. The rotation is repeated 5 times over a simulation period of 30 years. The number of possible permutations, in accordance with the first method, are equal:

$$(\mathrm{MBMSBM}) * 5 = (\mathrm{MMBSBM}) * 5 = (\mathrm{BMBSMM}) * 5 \text{ etc.};$$

Crop management, soils and climate were the same for each method. Simulations were run with 2 soils and 2 climates (Tab. 21):

Table 21: soils and climate characteristics

Soil denomination	Soil characteristics	Climate denomination	Climate characteristics
RAU 3	Gravelly sandy loam soil	UED 24	1,870 mm
PRE 1	Silty clay loam soil – poorly drained	UED 20	1,047 mm

Soils and climate were combined to obtain the following combinations:
RAU 3 – UED 24;
RAU 3 – UED 20;
PRE 1 – UED 24;
PRE 1 – UED 20.

Second method: simulation of sorted blocks of mono successions. In 30 years of simulation there are:

$$(\mathrm{MBMSBM}) * 5 = 15\ \mathrm{M}, 10\ \mathrm{B}, 5\ \mathrm{S};$$

Maize is cultivated for 15 years, Barley for 10 years, Soybean for 5 years. N leached is calculated as an arithmetic mean inside each block, then the weighted mean is calculated for the entire simulation period.
Third method: each crop is simulated as mono successions for 30 years. N leached is calculated as a weighted mean. The 3 methods are illustrated in Tab. 22.

Table 22: methods to lowering the number of rotations

	Method 1	Method 2	Method 3
Simulation period		30 years	
Rotation over period	N cycles	Sorted blocks	Mono successions
Rotation	$(\text{MBMSBM}) * 5$	$15\ \text{M}, 10\ \text{B}, 5\ \text{S}$	$30\ \text{M}, 30\ \text{B}, 30\ \text{S}$
Permutations	equals	-	-
N leached computation	$\text{N} = \sum_{i=1}^{n} x_i$	$\text{N} = \sum_{i=1}^{n} x_i$ (per block)	$\text{N} = \frac{\sum_{i=1}^{n} x_i f_i}{\sum_{i=1}^{n} f_i}$ (per crop)

ANOVA, α level = 0.05, was used to test difference among the 3 methods; previously, normal distribution was tested with Saphiro test, homoscedasticy with Bartlett's test. The R system was used for statistical tests (R Core Team, 2013). The calculated p values were: 0.844 (RAU 3 – UED 24); 0.93 (RAU 3 – UED 20); 0.42 (PRE 1 – UED 24); 0.95 (PRE 1 – UED 20). There's no statistical difference among groups. The null hypothesis has not been rejected. The chosen method is the third one because is easier to set and greatly reduces the number of simulations.

3.2.3. Second harvest

Second harvest simulation is limited to the following sequences: Barley – Maize (grain), Barley – Maize (silage), Barley – Soybean. The number of simulation increase due to the combinations between organic N, (amount and type), inorganic N amount, and irrigation type:

$$\text{Norg}_1 * \text{Nmin}_1 * \text{I}_1 = \text{Norg}_2 * \text{Nmin}_2 * \text{I}_2$$

$\text{Norg}_{1,2}$ is the organic N supplied (type and amount), $\text{Nmin}_{1,2}$ is the amount of mineral N supplied and $\text{I}_{1,2}$ is the type of irrigation (no irrigation, sprinkler irrigation, surface irrigation).
The number of rotations with a second harvest has been calculated in 180,075 a very high number because the range of combinations between $\text{Norg}_1 * \text{Nmin}_1$ is wide.
In order to reduce the number of rotations and, therefore, the number of simulations, the following rules have been implemented:

- organic N is supplied as a single dose, related to the requirements of crops (Maize: $200\ \text{kg} * \text{ha}^{-1}$; Soybean: $0\ \text{kg} * \text{ha}^{-1}$);
- the same organic N source is supplied to both first and second harvest;
- Maize is always simulated as an irrigated crop;
- Soybean is always simulated as rainfed irrigated crop.

These rules allowed to reduce the number of rotations from 180,075 to 14,683.

3.2.4. Soil – climate combinations

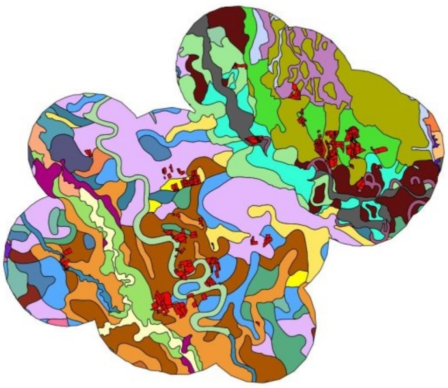
In order to take into account that farmers could cultivate soils actually not belonging to them when excess of manure must be disposed, the sample areas within which simulations have to be carried out are extended to a buffer of 3 km from the boundaries of each farm. As neighbor lands are the most likely to be rent for this purpose, the extent of the radius represents a compromise between the high level of detail and the number of simulations required: in fact the higher the distance, the higher the number of soils (Tab. 23), the number of climates and, therefore, the number of simulations (section 3.2).

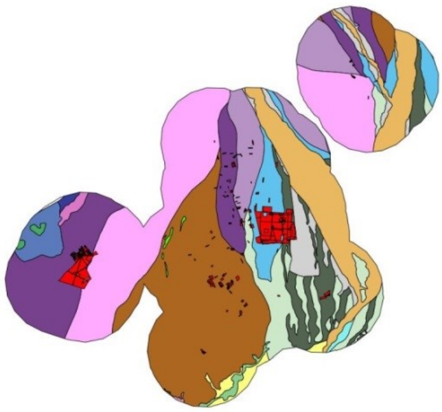
Table 23. Number of soils as a function of the extent of the buffer

Buffer (km)	Lombardia	Friuli Venezia Giulia
0.5	n.c.	10
1	n.c.	10
3	23	19
5	44	28

Soil maps for both sample area are reported in Fig. 8:

Figure 8. Soil maps within a 3 km buffer in Lombardia (left) and FVG (right)





A raw estimation, of the number of simulations due to the increase of the buffer radius in Friuli Venezia Giulia is reported in Table 24:

Table 24. Estimation of the number of simulations in FVG as a function of the extent of the buffer

Buffer (km)	Number of simulations
0.5	29,835
1	31,035
3	38,025
5	71,955

Soil – climate combination results by overlapping soil cartographic units and climate Voronoi polygons (section 2.3), as shown in Fig. 9. Within the 3 km buffer 65 soil – climate combinations FVG and, 100 soil – climate combinations in Lombardia have been identified.

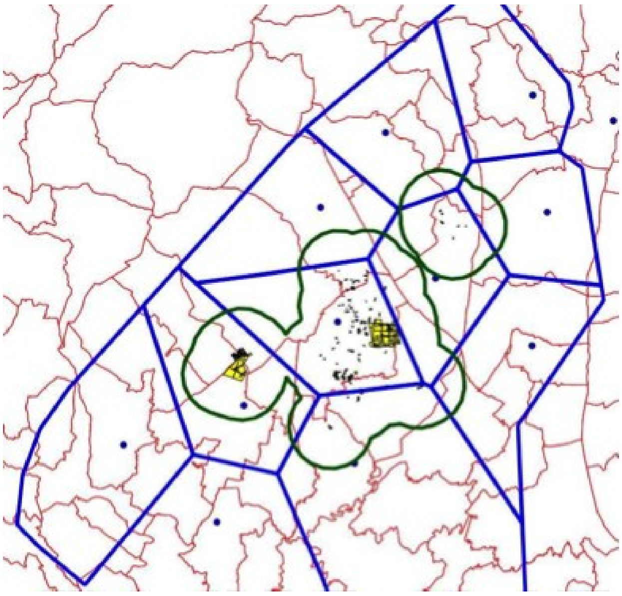


Figure 9. 3 km buffer grid and Voronoi polygons overlapped in the Friuli Venezia Giulia sample area

Soils and climate are multiplicative factors that increase the number of simulations. In order to reduce the number of simulations, while maintaining a high level of detail, the following procedure is proposed.

Soil – climate combinations have been pooled in groups according to their ability to produce outputs statistically non different, independently from their characteristics; N leached from soil has been considered as model variable. For this purpose, simulations have been run for each soil – climate combination considering the most representative crops: (Maize, Soybean, Barley, Alfalfa and set aside) and for each crop a restricted number of organic and mineral N.

N fertilization has been set as follow (Tab. 25):

Table 25. Organic and mineral N fertilization combinations

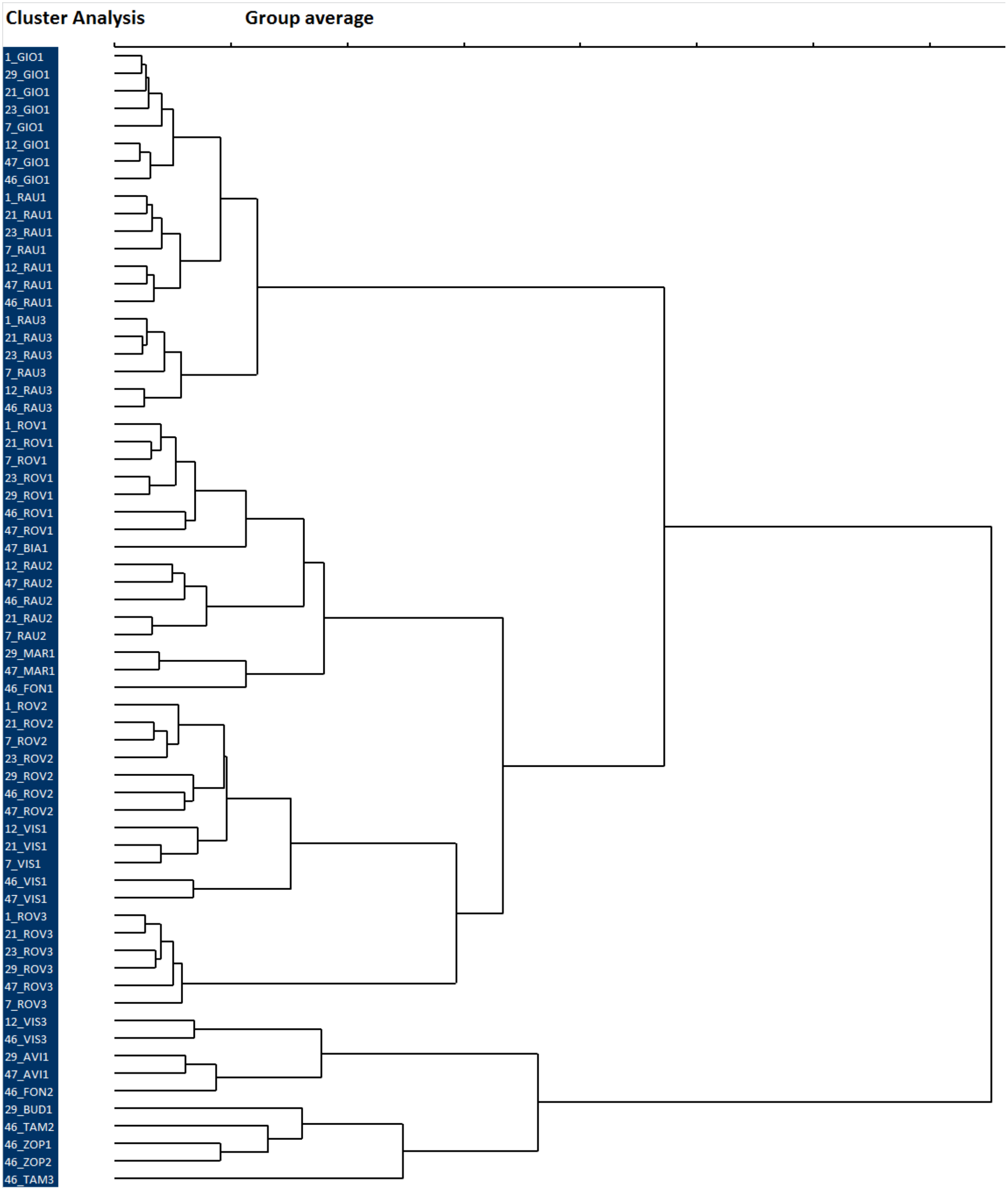
Maize ($kg * ha^{-1}$)		Soybean ($kg * ha^{-1}$)		Barley ($kg * ha^{-1}$)		Alfalfa ($kg * ha^{-1}$)		Set Aside ($kg * ha^{-1}$)	
Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral
1,200	600	120	80	800	400	120	80	120	0
800	400	60	40	400	200	30	20		-
400	200	30	20	200	100		-		-
250	0	0	0	150	0		-		-

2,575 simulations (1,500 for Lombardia, 975 for Friuli Venezia Giulia sample area) were run. Simulation were run for a period of 30 years of monoculture. Crop management and

irrigation were set separately for each crop. Each simulation was run with the same combination of crop management, irrigation and animal waste.
Outputs were processed in two steps:

- hierarchical clustering – group average was used to identify the optimal number of clusters; the cut – off point was identified on the dendrogram. Hierarchical clustering was applied because the method evaluates cluster quality based on all similarities between items; soil – climate were divided with the "vegan" package (Oksanen et al., 2013) in R statistical software (R Core Team, 2013) (Fig. 10);
- partitioning around medoids (PAM), Manhattan metric was applied to identify, within each identified cluster, the most representative soil – climate combination (medoid). PAM was applied using "cluster analysis basics and extentions" (Maechler et al., 2013) in R statistical software (R Core Team, 2013).

Figure 10. Hierarchical dendrogram for Friuli Venezia Giulia sample area



The PAM allow to identify 17 medoids: 10 medoids are representative of the 100 soil – climate combinations in Lombardia, 7 medoids are representative of the 65 soil – climate combinations in Friuli Venezia Giulia.

Each medoid was compared with the other soil – climate combinations within each cluster in order to test differences. Normal distribution was tested using Saphiro test and homoscedasticity with Bartlett test. Differences among each cluster and its medoid was tested with the non parametric Kruskal – Wallis test, $\alpha = 0.05$. The R system was used for statistical test (R Core Team, 2013). The following table (Tab.26) reports the number of soil –

climate combinations within each cluster and their P – values. Clusters from 1 to 10 regards soil – climate combinations in Lombardia, clusters from 11 to 17 regards soil – climate combinations in Friuli Venezia Giulia.

Table 26. Clusters, soil – climate combinations and p – values

Cluster	Soil - climate combinations	P- value	Cluster	Soil - climate combinations	P- value
1	10	0.84	10	7	0.79
2	8	0.83	11	8	1.00
3	6	0.70	12	13	0.98
4	6	0.97	13	11	1.00
5	20	0.84	14	12	1.00
6	12	0.76	15	5	1.00
7	5	0.07	16	10	1.00
8	20	1.00	17	5	1.00
9	6	0.71	-	-	-

As for all clusters the null hypothesis has not been rejected, the clusterization allows to run simulations using 17 soil – climate combinations instead of 165 soil – climate combinations.

3.2.5. Regression Lines

The purpose of reducing computational complexity is to run simulations with the strategy described in sections 3.2.1, 3.2.3, 3.2.3, 3.2.4. The simulation outputs have been used to calculate a number of regression lines to calculate N leached, NH_3 emissions and percolated water under different farming conditions.

Organic and mineral fertilization have been plotted against different output values (e.g. N leached, $kg * ha^{-1}$). Regression lines are built using a set of combined organic and mineral N values. Both organic and mineral N values are specific to each crop and covers its nutritional requirements within a wide range. Each organic N value is combined with each mineral N value.

Multiple linear regressions have been calculated for each crop – medoid – management – slurry combination. Management includes the amount of fertilization (both organic and mineral), irrigation type while slurry indicates the type of slurry (section 3.2.1). Mineral and organic fertilization were set with the following values (Tab. 27) for Maize.

Each point of the regression lines is calculated as the average value of a 30 years simulation, discarding the first 10 years. The first 10 years are discarded due to the instability of the system. Regression line for Maize results from 25 points (Organic N and Mineral N combined), while the regression lines for the other crops were calculated with 20 points.

Table 27. Fertilization and animal waste characteristics

Crop	Fertilization		Slurry		
	Organic N	Mineral N	TAN/TKN	C/N	Days to 50% decomposition
Maize	0	0			
	150	75			
	300	150	12.1	69	110
	600	300			
	1200	600			

Typical regression line is:

$$Output = intercept + A * N_{mineral} + B * N_{organic}$$

The values calculated with the multiple regression lines were compared with the values obtained from the simulations run with CropSyst. Simulation were run using 4 soil – climate combinations within a cluster: the medoid and 3 other soil – climate combinations.
Simulations were run with Maize, 4 combinations of organic and mineral fertilization, 1 type of animal waste. Simulations were run for 30 years, first 10 years discarded.
Normal distribution was tested with Saphiro test, homoscedaticy with Bartletts test. Differences among calculated and simulated values were tested with the non parametric Kruskal – Wallis test, $\alpha = 0.05$.
Kruskal – Wallis chi – squared = 0.1875, df = 4, p – value = 0.9959. The R system was used for statistical test (R Core Team, 2013). The null hypothesis has not been rejected.
With the procedures aimed at lowering the computational complexity there were run 248,390 simulations; with the mean values of each simulation a set of 15,368 regression lines were built to calculate N leached, NH_3 emissions and percolated water.
Regression lines were calculated with R statistical software (R core Team, 2013) and "the split – apply – combine Strategy for data analysis" Plyr package (Wickham, 2011), in R statistical software (R Core Team, 2013).

3.3. DSS - AGRONOMIC MODULE

3.3.1. DSS development methodology

The purpose of the Ager SEES Pig project is to design tools aimed at choosing the best technological, environmental and economic solution to manage manure at farm and municipal scale. The developed DSS is an *active DSS*, because it suggests decisions or solutions Haettenschwiler (Haettenschwiler, 1999) and it is model driven, because it emphasizes a model simulation, and knowledge because it is also based on expert knowledge (Power, 2002; Turban and Aronson, 2001). Even if the DSS is model driven with strong modelling capabilities it possess also a developed dialogue component and a database component.

The DSS is intended for farmers, technicians and administrators and it is designed accordingly to their specific needs. The DSS is composed by three modules, the agronomic module, the technological module and the optimizing module (see section 3.3.2). It elaborates agronomic and technological data and calculates the best economic and environment solutions.

The main characteristics of the DSS, (Ruz, 2006; Turban, 1990) are:

- flexibility: user is able to modify a wide number of parameters for both modules. The agronomic module allows users to modify several parameters (see section 3.3.5). In particular the possibility to associate each cadastral units to specific administrative constrains is a features particularly important to administrators: it allows to cope with modifications of the regulatory limits as expected by reconsidering scientific and technical data;
- long life cycle: the wide number of modifiable parameters, a module based on algorithm transformation (technological), a module based on a cropping system simulation model (agronomic) the possibility to expand databases and modifying them grant a long life cycle. In particular the agronomic module allows to associate each cadastral units not only to regulatory limits but also to a farm. A farm it is not a static entity so the user is able to add or remove cadastral units within a 3 km buffer;
- the DSS is easy to use a graphical interface allows user to change several parameters. In particular the agronomic module is based on a graphic WebGIS interface (see section 3.3.5);
- the DSS performs quick calculations and it is not limited by operating system and processor because user does not need to download any kind of software. The optimizing module calculates quickly the best solutions to manage manure. The agronomic module to reduce the needed time to perform a simulation does not include the cropping system simulation, it encloses the manipulated outputs.

The DSS is designed as a “classic DSS” (Salewicz and Nakayama, 2004) with three blocks: database, modelling functions and a user interface.

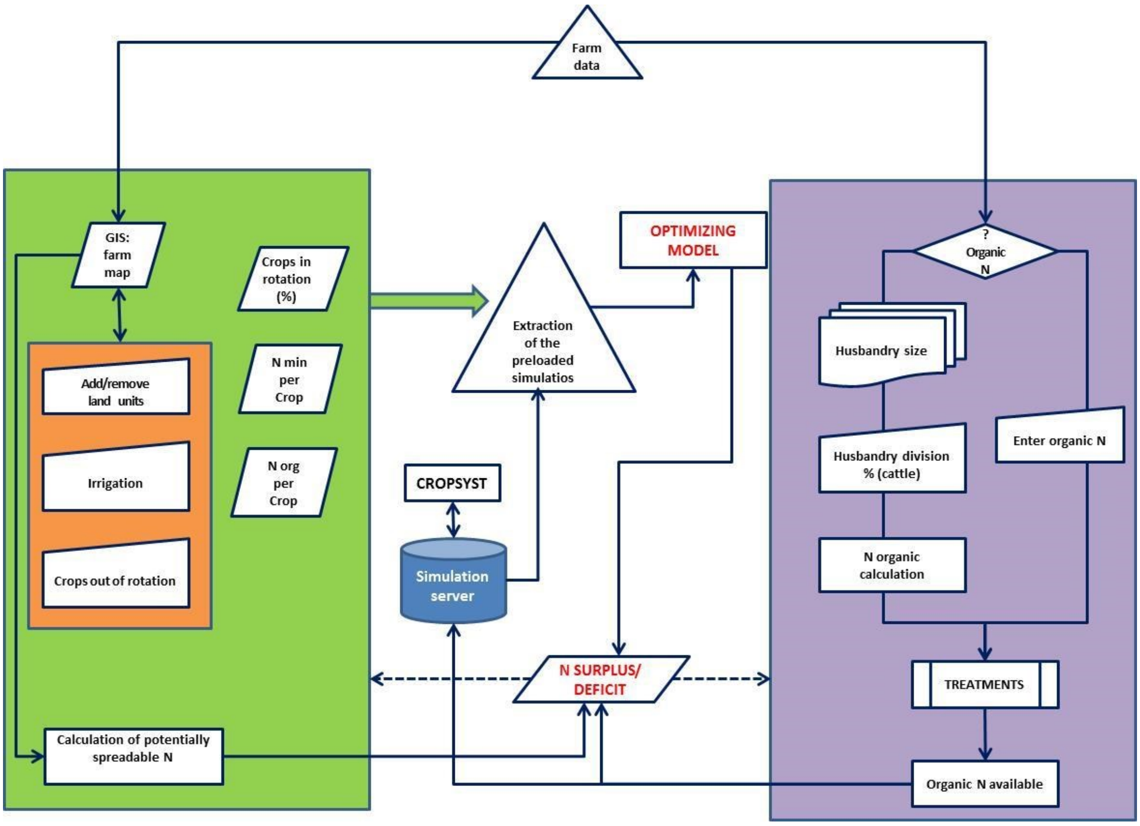
3.3.2. DSS modules

DSS is composed by 3 modules which communicate, transfer and process agronomic and technologic data. Modules are:

- agronomic module – which elaborate agronomic data: crops, mineral and organic fertilization, irrigation, cadastral units;
- technological module – which elaborate technologic data: number of raised animals (swine, cattle, poultry), N from manure, animal waste treatments;
- optimization module – which elaborate the data from both agronomic and technological modules to obtain the best economic and environmental solution. The optimization module has a dual purpose: it calculates if there is a N surplus or deficit considering user's inputs (agronomic and technological) and regulatory limits. The optimization module calculates also the conditions that could suggest a consortium of farms.

The flowchart of the information among the modules is presented in Fig. 11:

Fig. 11. Information flowchart among modules: agronomic module (green block), technological module (violet block), simulation server and optimizing module (central block)



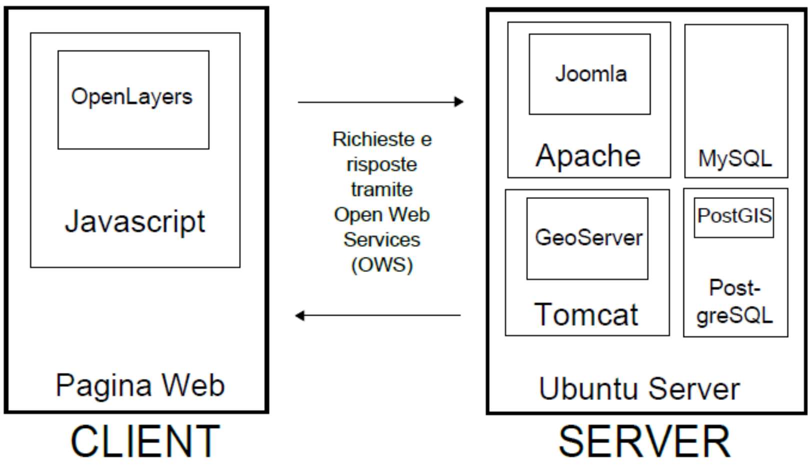
While the agronomic module has been developed in the framework of the doctoral activity, the technological module and the optimization module have been developed by the University of Milano. The DSS has been designed to be used in the entire Po and Veneto basin (Piemonte, Lombardia, Veneto, Friuli Venezia Giulia) working at two levels of detail.

The following sections describe the general system architecture, data modelling, and WebGIS user interface. These sections are related to the agronomic module. The technologic and optimization modules, even if communicating, uses within the DSS different technologies.

3.3.3. System architecture

The system is based on a client – server model using on open source technologies. The server side is based upon Ubuntu server. The web server Apache interacts with Tomcat to support several applications: Joomla (Joomla, 2013), Content Management System (CMS) used to develop web portals with authorization management, Geoserver (Geoserver Development Team, 2013) which is a web application for spatial data visualization and editing which allows to use a wide range of several data sources. The DataBase Management System (DBMS), PostgreSQL (PostegreSQL Global Development Group, 2013), together with spatial extension PostGIS (PostGIS project Team, 2013), has been chosen for spatial data storing and management. MySQL DBMS (MySQL, 2013) is used to support Joomla. On the client side, the CMS Joomla integrates a set of HTML pages which exploit various technologies. The use of Javascript supports an asynchronous interfacing to several data sources by means of libraries such as OpenLayers (OpenLayers, 2013), for vector and raster layers and related event management and jQuery (jQuery, 2013) to deal with graphical and structural elements of the HTML pages. CSM allows to distinguish between public pages, which are fully accessible by any user, and private pages, which are accessible only with authentication. The system architecture is shown in Fig. 12.

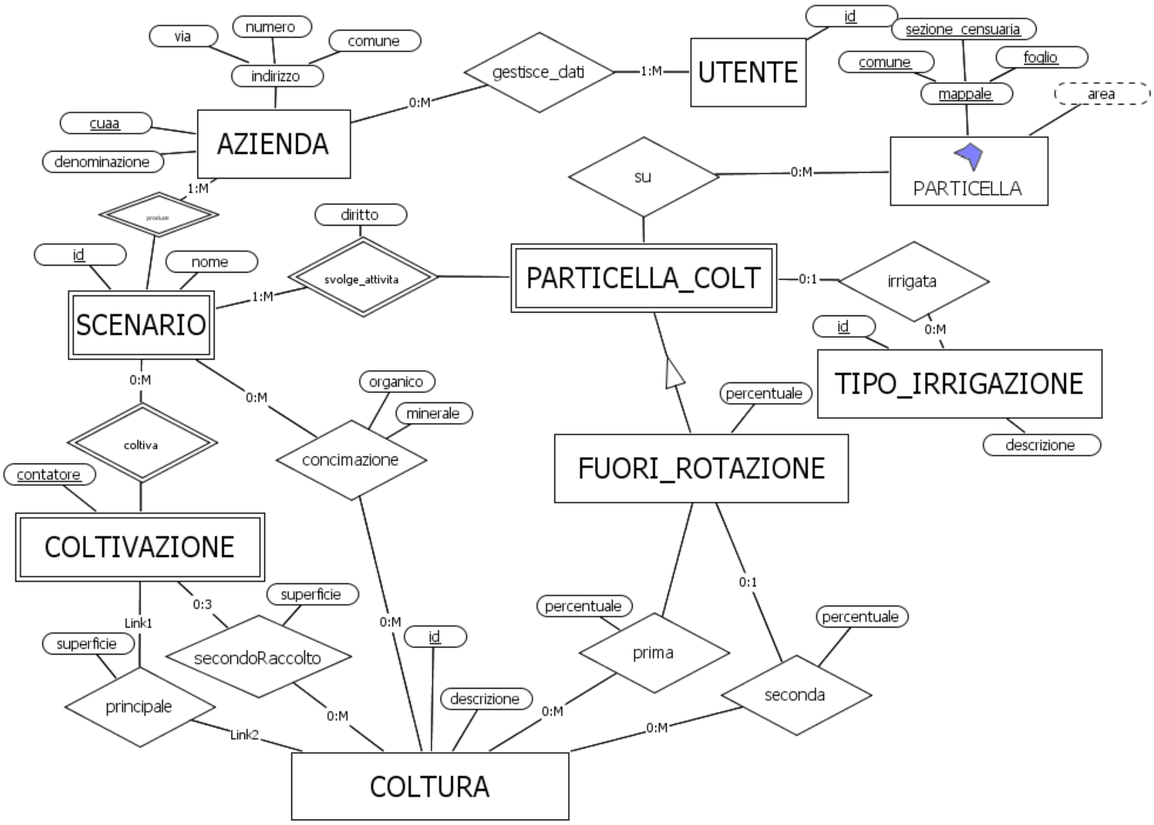
Figure 12. System architecture



3.3.4. Data modelling

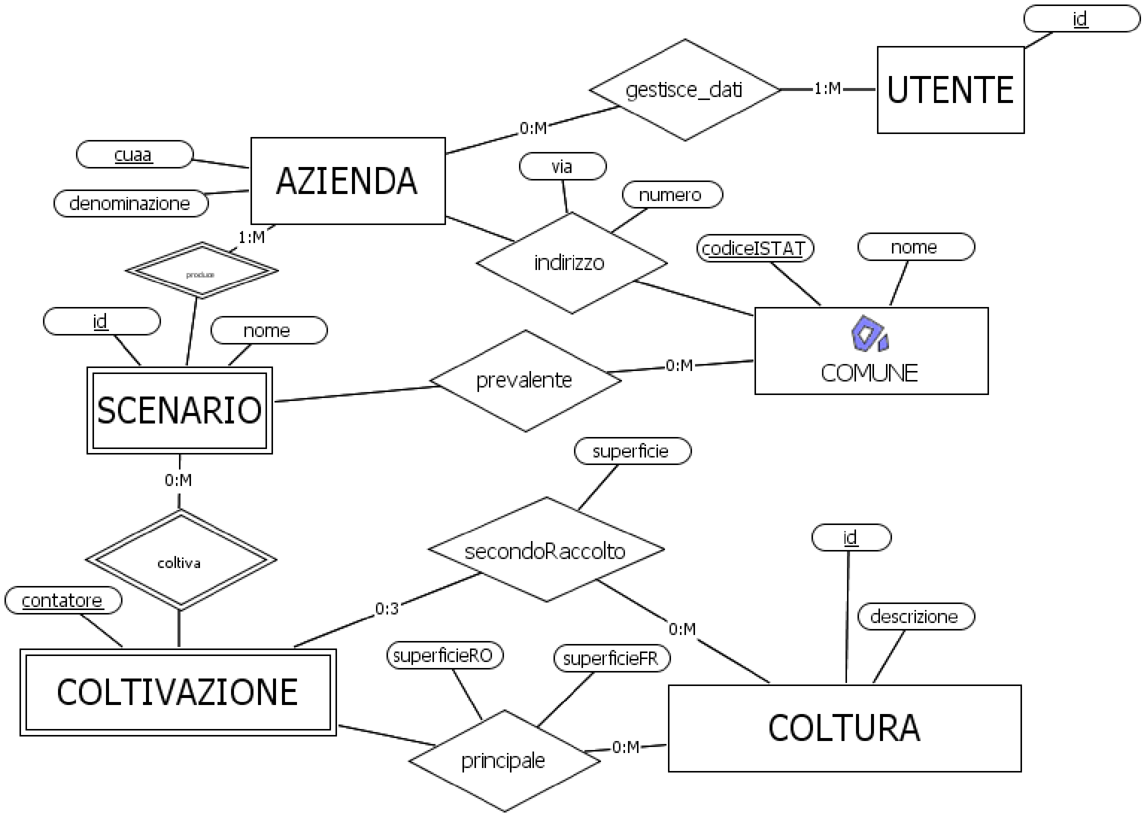
Data are structured in several connected schemas: farm data, agronomic data, technological data and preprocessed and simulation data. Agronomic data are defined with two different schemas: the first one deals with highly detailed data, the second one deals lowly detailed data. The high level of detail is available for the study area municipalities; with this level of detail user is able to run a simulation and obtain outputs for each cadastral unit and at farm level. The conceptual model for agronomic data is shown in Fig. 13.

Figure 13. Conceptual model for agronomic data, at the higher detail level



The low level of detail is available for each municipality where there's at least a pig farm in the Po Veneto basin. User is able to run a simulation and obtain outputs for his farm at municipal level. In fact the low level of detail is based on a reduced data model. Details about cadastral units are unknown so user specify which crops are cultivated associating them to a municipality. The conceptual model for agronomic data outside the study area is shown in Fig. 14.

Figure 14. Conceptual model for agronomic data at the lower detail level



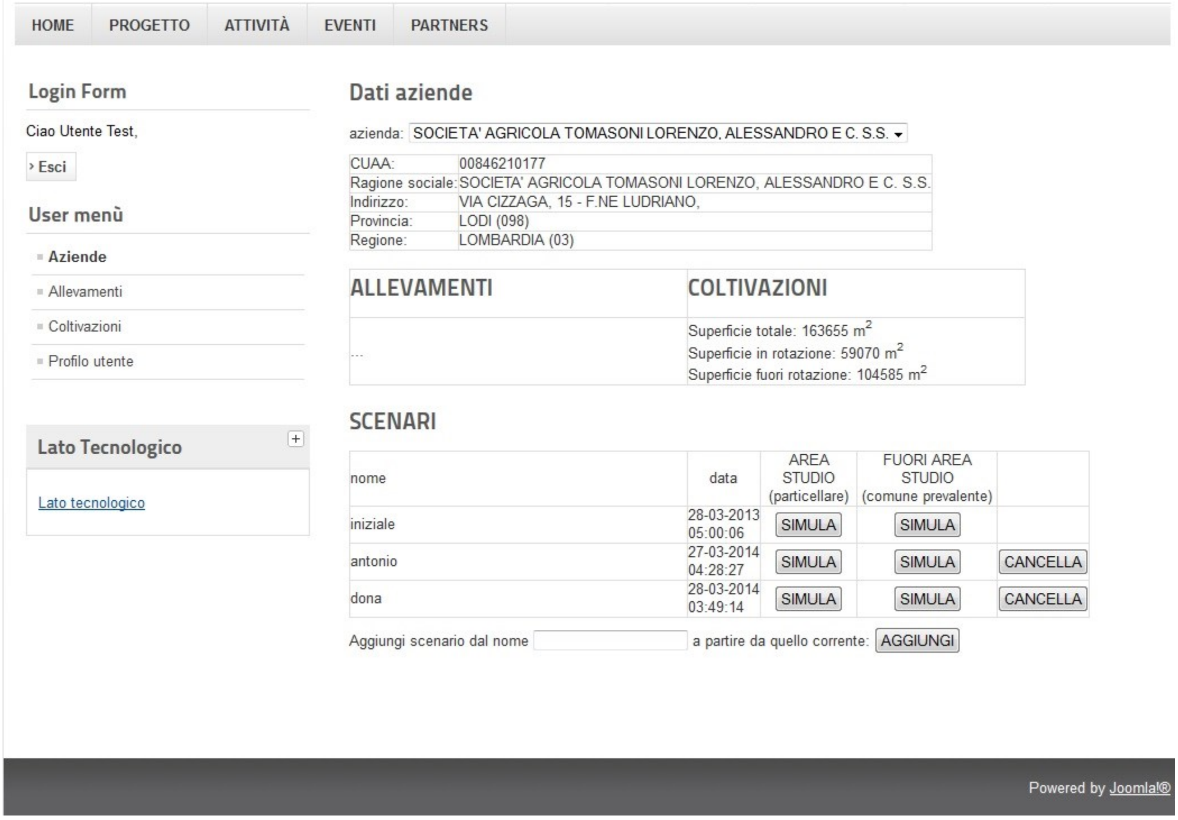
3.3.5. WebGIS user interface – agronomic module

The system is available using a simple web browser. It includes three main sections:

- header: at the top of the page there are the main menu (home, project, activities, events and partners) and, in the public part, project's logo and images;
- login/menu: the login form is on the left of the page. When user is logged it becomes the user menu. It organizes data and functions regarding: farm(s), livestock, crops, user's profile;
- data: the main section is on the right side of the page, including general project data in public pages and personal data in private pages.

User login with is username. After the login the user is enabled to access the information about his farm (CUAA, name, address); the login page also shows information regarding crops (total area, surface area of rotational and non rotational crops – all in m^2) and the number of raised animals (Fig. 15).

Figure 15. Login page – farm data are reported



The login page allows the user to run a simulation under different scenarios, both inside outside the sample area. The Initial Scenario represents the farm's situation at the date of data collection (2012). It is possible to create alternative scenarios to compare different crops and management options. The Initial Scenario and the alternative scenarios are always visible to the user easily allowing their comparison.

The framework considers the farm as a dynamic entity: the user, at high level of detail, can modify cadastral units ownership, adding or removing them. At high level of detail all cadastral units are associated to their specific administrative constrains, according to the current regulations. The user can modify the specific administrative constrains, changing specific attribution of the cadastral units (e.g. NVZs to OZs and vice versa).

The farm page allows to manage agronomic data. Using a WebGIS interface the user can change or specify:

- ownership of cadastral units (Fig. 16);
- irrigation type for each cadastral unit, choosing between three types of irrigation (no irrigation, sprinkler irrigation, surface irrigation Fig.17);
- crops and their area (m^2), as referred to an annual average cropping plan; the user can specify first and second harvest, if any, and their area (Fig.18);
- fertilization, both organic and mineral, for each crop ($kg * ha^{-1}$) (Fig.19);
- associating each cadastral units to specific administrative constrains.

Figure 16. Ownership of cadastral units

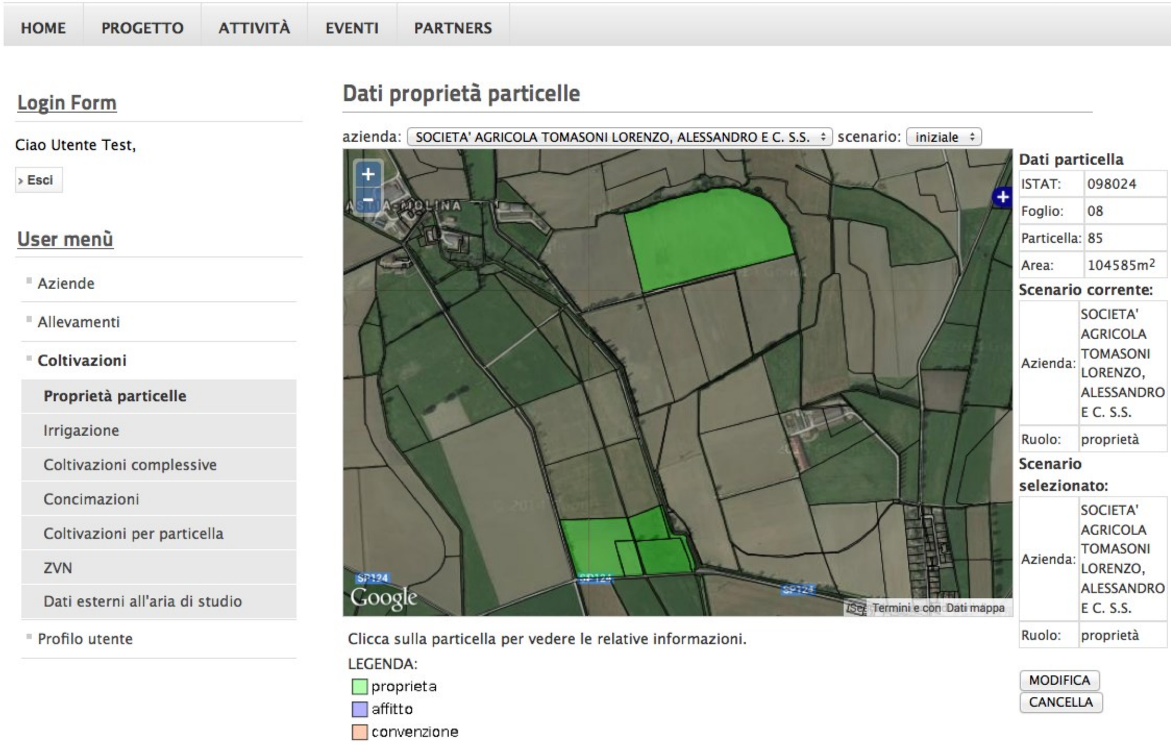


Figure 17. Irrigation type at the cadastral unit level

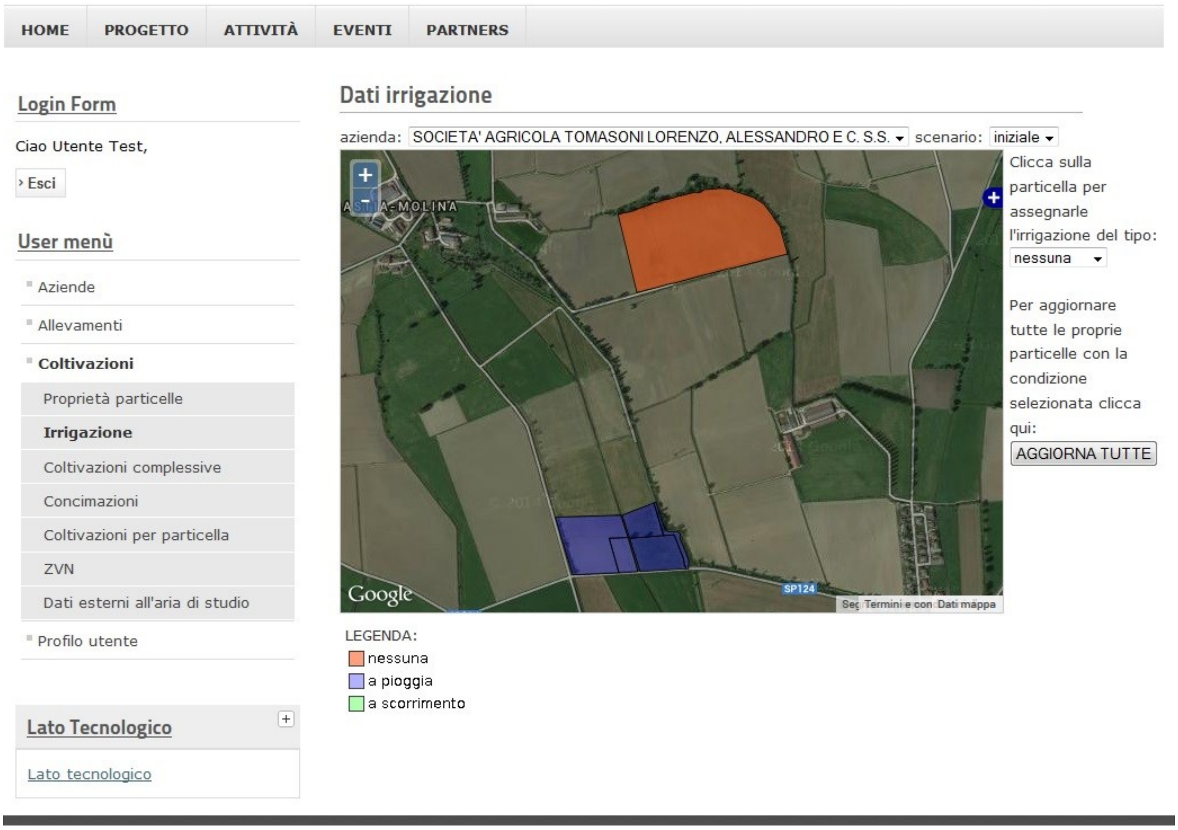
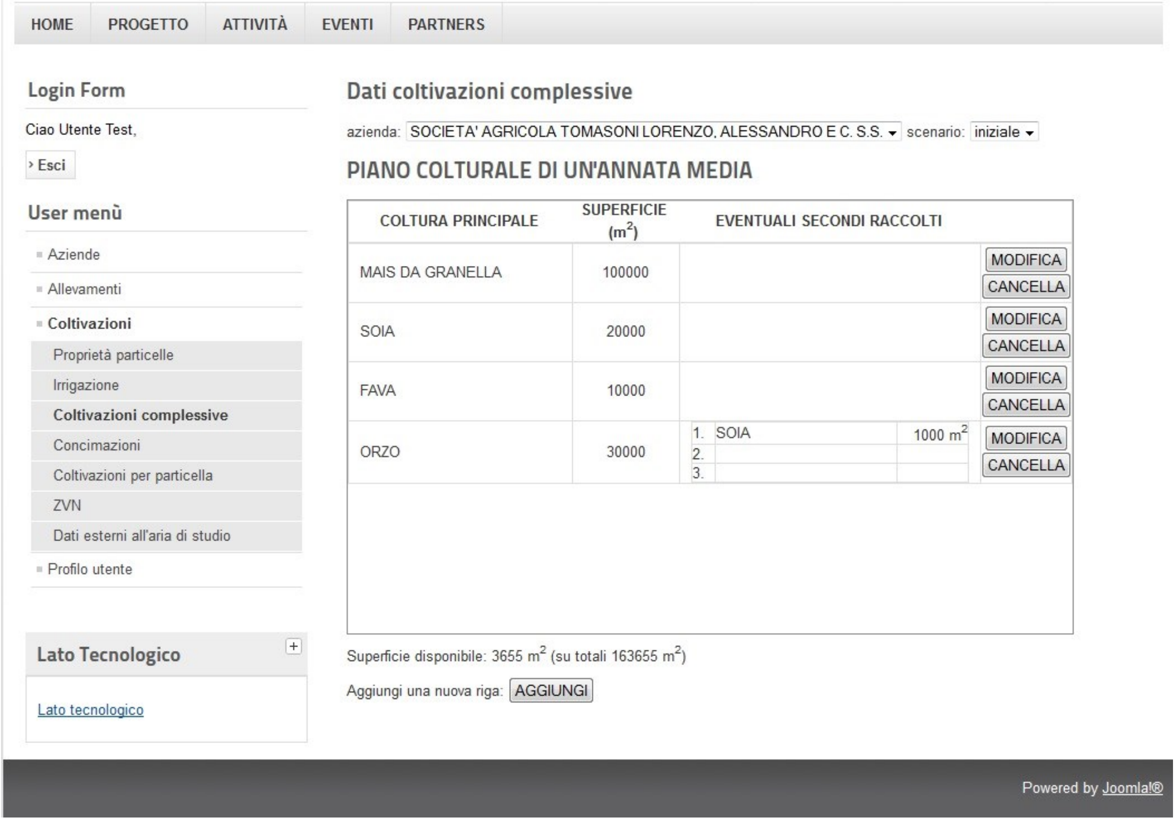


Figure 18. Crops (first, second) and their area



HOME | PROGETTO | ATTIVITÀ | EVENTI | PARTNERS

Login Form

Ciao Utente Test,

› Esci

User menù

- Aziende
- Allevamenti
- Coltivazioni
  - Proprietà particelle
  - Irrigazione
  - Coltivazioni complessive
  - Concimazioni
  - Coltivazioni per particella
  - ZVN
  - Dati esterni all'aria di studio
- Profilo utente

Lato Tecnologico

Lato tecnologico

Dati coltivazioni complessive

azienda: SOCIETA' AGRICOLA TOMASONI LORENZO, ALESSANDRO E C. S.S. scenario: iniziale

PIANO COLTURALE DI UN'ANNATA MEDIA

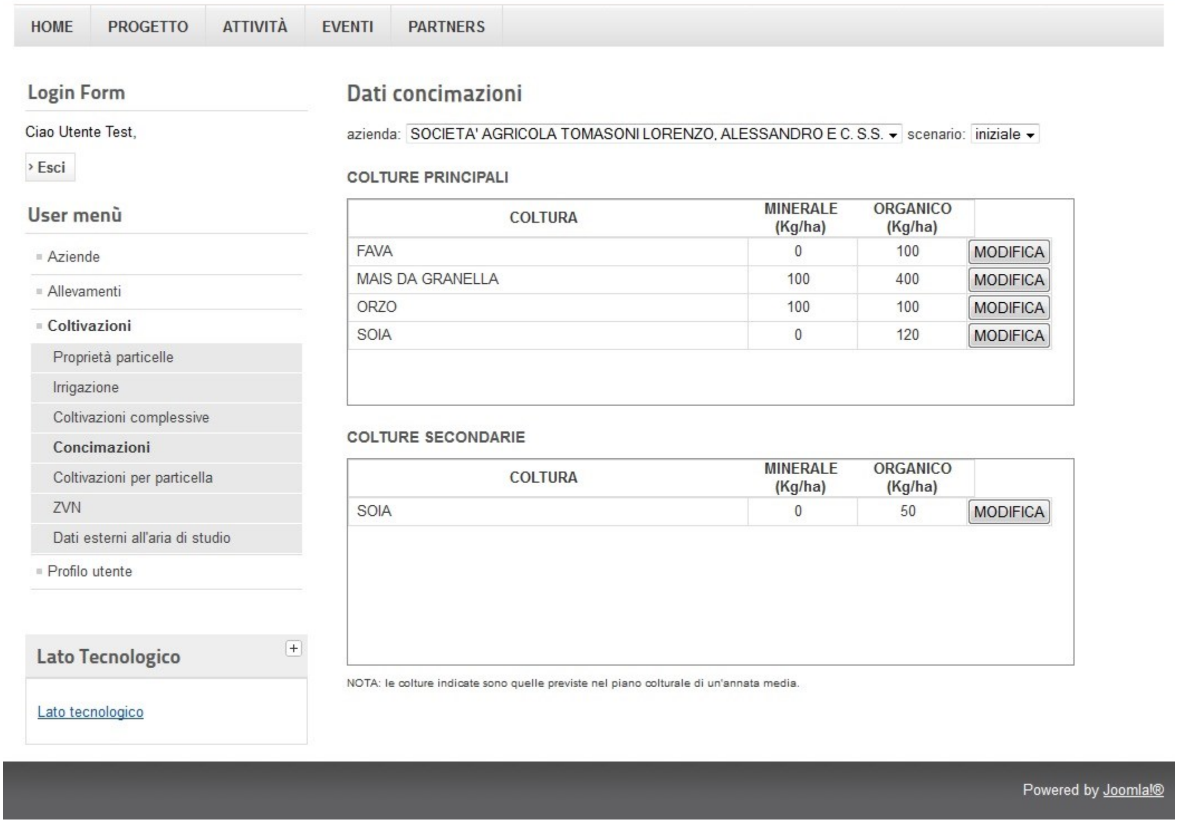
COLTURA PRINCIPALE	SUPERFICIE (m^2)	EVENTUALI SECONDI RACCOLTI	
MAIS DA GRANELLA	100000		MODIFICA CANCELLA
SOIA	20000		MODIFICA CANCELLA
FAVA	10000		MODIFICA CANCELLA
ORZO	30000	1. SOIA 1000 m^2 2. 3.	MODIFICA CANCELLA

Superficie disponibile: 3655 m^2 (su totali 163655 m^2)

Aggiungi una nuova riga: AGGIUNGI

Powered by Joomla!®

Figure 19. Organic and mineral fertilization



HOME | PROGETTO | ATTIVITÀ | EVENTI | PARTNERS

Login Form

Ciao Utente Test,

› Esci

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- Aziende
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  - Concimazioni
  - Coltivazioni per particella
  - ZVN
  - Dati esterni all'aria di studio
- Profilo utente

Lato Tecnologico

Lato tecnologico

Dati concimazioni

azienda: SOCIETA' AGRICOLA TOMASONI LORENZO, ALESSANDRO E C. S.S. scenario: iniziale

COLTURE PRINCIPALI

COLTURA	MINERALE (Kg/ha)	ORGANICO (Kg/ha)	
FAVA	0	100	MODIFICA
MAIS DA GRANELLA	100	400	MODIFICA
ORZO	100	100	MODIFICA
SOIA	0	120	MODIFICA

COLTURE SECONDARIE

COLTURA	MINERALE (Kg/ha)	ORGANICO (Kg/ha)	
SOIA	0	50	MODIFICA

NOTA: le colture indicate sono quelle previste nel piano colturale di un'annata media.

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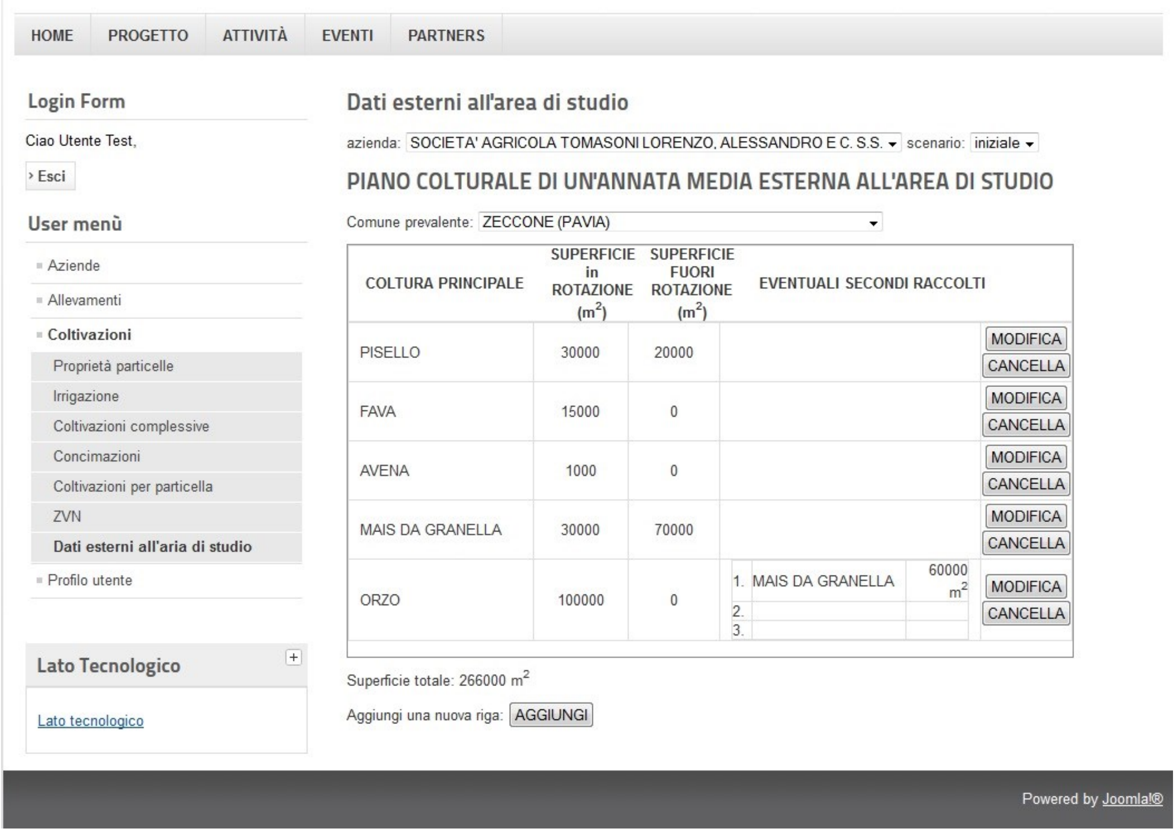
Each cadastral unit is identified by the ISTAT code, census sheet, number, area (m^2), property, (ownership or rent). It is possible to add a cadastral unit within a 3 km buffer from the cadastral unit of each farm.
The user can choose crops among 23 listed crops and specify their area. Only 10 relevant crops have been simulated, while the remainders are managed according to the similarity principle.
The user can choose the amount of organic and mineral fertilizer for each crop ($kg * ha^{-1}$). Except for second crops (see section 3.2.3). the organic fertilization is the same the first crop, the amount of fertilization is fixed to an optimal agronomic value.
For each cadastral unit it is possible to specify:

- percentage of the area in rotation;
- percentage of the area not in rotation and the percentage of the non rotated crops;

The system is supported by a series of controls to prevent errors when data are entered. For instance it is impossible to set crop areas larger than the total farm area, or to set an area dedicated to a second crop larger than the area dedicated to the first crop.
The system controls also the amount of the overall fertilization, considering if cadastral units belongs to NVZs or OZs. If the overall fertilization overcomes the limits imposed by the Directive 91/676/EEC a warning message appears.

The user, whose farm is not located in the municipalities of the sample areas, can run simulations at a lower level of detail., Using a drop down list the user chooses the municipality where his farm is located, then he sets crops, in rotation and not in rotation, second crops, if any and their area (Fig. 20). Outside the study area organic and mineral N are supplied as a single dose, related to the requirements of crops. All crops are simulated always as irrigated but Soybean and Barley are simulated as rainfed.

Figure 20. Data input outside the sample area



3.3.6. Agronomic module simulation

This section reports simulations run with the agronomic module. Two simulations, named Initial Scenario and Scenario 1, have been run in the study area and 2 outside the study area, named Initial Scenario – O.S.A. (outside study area) and Scenario 1 – O.S.A. The Initial Scenario presents a farm with 9 cadastral units with all crops in rotation with surface irrigation. Even Barley is set as irrigated, the agronomic module consider it as not irrigated. Barley is always simulated as not irrigated.

All the cadastral units are located in NVZs (Tab. 28). Each option was set via the WebGIS interface (see section 3.3.5).

Table 28. Agronomic simulation, Initial Scenario – study area

<table>
<tr><th>Cadastral unit</th><th>Area (m^2)</th><th>Vulnerability</th><th>Crops</th><th>Rotation</th><th>Irrigation</th></tr>
<tr><td>1</td><td>8,147</td><td rowspan="9">NVZs</td><td rowspan="9">Maize
Barley
Alfalfa
Feed Crop</td><td rowspan="9">Rotation</td><td rowspan="9">Surface irrigation</td></tr>
<tr><td>2</td><td>8,974</td></tr>
<tr><td>3</td><td>4,902</td></tr>
<tr><td>4</td><td>7,300</td></tr>
<tr><td>5</td><td>5,061</td></tr>
<tr><td>6</td><td>45,025</td></tr>
<tr><td>7</td><td>35,314</td></tr>
<tr><td>8</td><td>40,941</td></tr>
<tr><td>9</td><td>40,317</td></tr>
</table>

Total Area = 195,981 m^2

Each crop area is:
Maize: 137,986 m^2; Barley: 9,000 m^2; Alfalfa: 29,397 m^2; Feed Crop (Cereals and Brassicaceae): 19,598 m^2; Total Area: 195,981 m^2.

N fertilization has been set as follow (Tab. 29); organic N is raw slurry:

Table 29. Crop fertilization $(kg * ha^{-1})$

Maize		Barley		Alfalfa		Feed Crop	
Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral
150	300	100	100	30	120	40	80

Maize: 137,986 m^2, 70.4% of the total area; Barley: 9,000 m^2, 4,6% of the total area; Alfalfa: 29,397 $m^{2,}$ 15% of the total area; Feed Crop: 19.598 m^2, 10% of the total area. The Barley area represents less than 5% of the Total Area so it is not considered to build the rotation. Its area is proportionally redistributed to the other crops (see section 3.2.2).
After the setup has been completed the simulation is ready to run. The inputs acts as coordinates to extract the corresponding set of multiple regression models and the system calculates:

- the Recalculated Area;
- the rotation;
- N leached for each cadastral unit;
- NH_3 losses for each cadastral unit;
- percolated water for each cadastral unit;

The Recalculated Area for each crop is:
Maize: 144,628 m^2 73,8% of the total area; Alfalfa: 30,812 m^2 15,7% of the total area; Feed Crop: 20,541 m^2 10.5% of the total area; Total Area: 195,981 m^2. The sum of the Re-

calculated Areas is equal to the Total Area. The rotation is: Maize 7 years, Alfalfa 2 years, Feed Crop 1 year.
The following table (Table 30) reports N leached, NH_3 and percolated water for each cadastral unit. The values are the same for each cadastral unit. All crops are in rotation, so each cadastral unit is proportionally cultivated with each crop: 73.8% with Maize, 15.7% with Alfalfa and 10.5% with Feed Crop. The N leached, NH_3 and percolated water are calculated as a weighted mean (see section 3.2.2), with the major contribute coming from Maize, which is the most representative crop.

Table 30. Initial Scenario, N leached, NH_3 and percolated water for each cadastral unit

Cadastral unit	Area (m^2)	N leached ($kg*ha^{-1}$)	NH_3 ($kg*ha^{-1}$)	Percolated water (mm)
1	8,147	231	3	268
2	8,974	231	3	268
3	4,902	231	3	268
4	7,300	231	3	268
5	5,061	231	3	268
6	45,025	231	3	268
7	35,314	231	3	268
8	40,941	231	3	268
9	40,317	231	3	268

It is possible to compare different scenarios with different management. A new scenario, Scenario 1, has been set modifying the Initial Scenario. The differences among Scenario 1 and Initial Scenario are the following:

- cadastral unit n. 6: 50% of the area is cultivated with crops in rotation, 50% is cultivated with Maize, not in rotation;
- cadastral unit n. 8: not irrigated.
- cadastral unit n. 9: 100% of the area is cultivated with Alfalfa, not in rotation;

The agronomic module recalculates all the areas according to the user's input (Tab. 31).

Table 31. Scenario 1, areas calculated by the agronomic module – study area

Crop	Total Area (m^2)	Rotation Area (m^2)	Not in Rotation Area (m^2)	Recalculated Area (m^2)
Maize	137,986	115,474	22,513	106,721
Barley	9,000	9,000	-	8,318
F.C.*	19,598	19,598	-	18,113
Alfalfa	29,397	- 10,920	40,317	-

* F.C.: Feed Crop;

A series of controls prevents errors when data are entered. In particular the area has been corrected to respect the total area and area dedicated to the single crop both in rotation and not in rotation. The Rotation Area values are recalculated: Rotation Area + Not in Rotation Area = Total Area (195,981 m^2). The agronomic module suddenly recalculates the rotation area as Recalculated Area. Its sum with Not in Rotation Area = Total Area.
The rotation is: Maize 13 years, Feed Crop 2 years, Barley 1 year. The run simulation returns the following values (Tab. 32):

Table 32. Scenario 1, N leached, NH_3 and percolated water for each cadastral unit

Cadastral unit	Area (m^2)	N leached ($kg*ha^{-1}$)		NH_3 ($kg*ha^{-1}$)		Percolated Water (mm)	
		R.*	N.R.**	R.*	N.R.**	R.*	N.R.**
1	8,147	295		3		252	
2	8,974	295		3		252	
3	4,902	295		3		252	
4	7,300	295		3		252	
5	5,061	295		3		252	
6	45,025	295	335	3	4	252	277
7	35,314	295		3		252	
8	40,941	382		3		202	
9	40,317		11		0		262

* R. = rotation; **N.R. = not in rotation;

A comparison among Initial Scenario and Scenario 1 shows a total different panorama. The overall N leached values in Scenario 1 are higher due to the major contribute of Maize and the contribute of Barley, absent in Initial Scenario.
Cadastral unit 6 shows higher values of N leached, NH_3 emissions and percolated water for Maize, not in rotation, as expected. The N leached, NH_3 emissions and percolated water values obtained for the area whose crops are in rotation are lower, due to the weighted mean among all the crops.
Cadastral unit 8 shows the highest values of N leached than any other cadastral unit. The cadastral unit is not irrigated so the crop did not growth adequately and it is not able to adsorb N, so the leaching of N is greater than any other cadastral unit.
Cadastral unit 9 shows the lowest values of N leached than any other cadastral unit. All the cadastral unit is cultivated with Alfalfa, not in rotation, fertilized with 30 $kg*ha^{-1}$ and 120 $kg*ha^{-1}$.

The Initial Scenario is proposed as base for an agronomic simulation outside the study area, in the municipality of Udine, in the Friuli Venezia Giulia region. This is the Initial Scenario – O.S.A.
The agronomic module recalculates the area for each crop and the rotation. The Recalculated Area for each crop is: Maize: 144,628 m^2 73,8% of the total area; Alfalfa: 30,812 m^2

15,7% of the total area; Feed Crop: 20,541 m^2 10.5% of the total area; Total Area: 195,981 m^2; the rotation is: Maize 7 years, Alfalfa 2 years, Feed Crop 1 year. The agronomic module estimates the N leached, NH_3 and percolated water values at municipality level. N leached: 208 kg*ha^{-1}, NH_3: 12 kg*ha^{-1}, percolated water: 983 mm.
The same scenario is proposed also in another municipality, Fossano in the Piemonte region. This is the Scenario 1 – O.S.A. The agronomic module estimates the N leached, NH_3 and percolated water values at municipality level. N leached: 120 kg*ha^{-1}, NH_3: 12 kg*ha^{-1}, percolated water: 592 mm.
Udine and Fossano have different soil – climate combinations which acts as coordinates to extract the respective set of multiple regression lines.

3.3.7. DSS simulation

The login page allows the user to run a simulation under different scenarios, both inside outside the sample area. The technologic module allows to create alternative scenarios changing the number of raised animals, animal waste storage and wastewater. The DSS is able to assess economic, energetic and environmental effects of the treatments. Each effect is measurable individually as well as the overall "impact".
The DSS elaborates the output on the basis of a pondering system: user specify the priority weight among cost, energy, GHG emissions and NH_3 emissions:

- cost, (relative weight 0 – 1), cost of the treatment or combination of treatments in €;
- energy (relative weight 0 – 1), consumed energy - produced energy (KWh * $year^{-1}$);
- GHG emissions (relative weight 0 – 1), kg * $year^{-1}$;
- NH_3 emissions (relative weight 0 – 1), kg * $year^{-1}$.

The sum of cost, energy, GHG emissions and NH_3 emissions must be 1. This allows the user to evaluate the most sustainable solutions at farm and territorial level as environmental impact and economic efficiency with an objective function.
The farm of the Initial Scenario (see section 3.3.6) has the following herd:

- 130 dairy cows (dairy cows in lactation and not in lactation), weight 600 kg;
- 25 replacement heifers, weight 220 kg;
- 39 replacement heifers, weights 425 kg.

The technological module calculates the amount of animal waste, both manure (m^3) and slurry (m^3), TKN (kg), TAN (kg), DM (kg), volatile solids (VS) (kg), K (kg), P (kg).
The priority weight has been set to obtain a Balanced Scenario, where cost, energy, GHG emissions and NH_3 emissions have the same weight and an Environmental Impact Scenario (E.I.S.) where cost and energy have been set to 0 while GHG and NH_3 have been set both to 0.5 (Table 33).

Table 33. Priority weight setting: Balanced Scenario, E.I.S.

Priority weight	Balanced Scenario	E.I.S.
Cost	0.25	0
Energy	0.25	0
GHG emissions	0.25	0.5
NH_3 emissions	0.25	0.5

The chemical and physical characteristics of animal waste are elaborated with a series of algorithms which allows to obtain the chemical and physical characteristics of animal waste for each treatment or combinations of treatments (see section 3.2.1).
The optimization module elaborates the inputs and returns the rank of treatments, or combinations of treatments, listed in order of effectiveness. According to the priority weight listed below, the thirst three combination of treatments are the following (Tab. 34, Tab.35):

Table 34. Best technologic solutions – Balanced Scenario

Combination of treatments	NH_3 emissions (kg*year^{-1})	GHG (kg*year^{-1})	Energy (KWh*year^{-1})	Cost (€)
Flotation - AD centrifugation NDN – SBR	3780.0	37756.0	-293817.0	68503
Flotation - AD centrifugation NDN	3884.0	37441.0	-294035.0	79272
AD – centrifugation – stripping	5628.0	79273.0	-251350.0	149236

Table 35. Best technologic solutions – E.I.S.

Combination of treatments	NH_3 emissions (kg*year^{-1})	GHG (kg*year^{-1})	Energy (KWh*year^{-1})	Cost (€)
Flotation - AD centrifugation NDN – SBR	3780.0	37756.0	-293817.0	68503
Flotation - AD centrifugation NDN	3884.0	37441.0	-294035.0	79272
Centrifugation – stripping	5003.0	97747.0	121486.0	164761

The DSS is also conceived to calculates the rank of technological solutions for a group of farms. This features is particularly interesting because farmers could assess the consortium option and evaluate cost, energy, NH_3 emissions, and GHG emissions at a higher level than farm.
The N content is not considerate as a variable of the objective function. The eventual excess of N, after a treatment or combination of treatments, assumes its importance for the agronomic module. The N is the link among the agronomic and technological modules. The system is able to calculate the N in excess so user can set a new scenario, via the agronomic or the technological module, to lower its amount.

4 CONCLUSIONS

The doctoral work contributed to the development of a Decision Support System aimed at support farmers, administrators and technicians in choosing the best technological, environmental and economic solutions to manage manure at the farm and regional scale.
In the framework of larger goal the doctoral program mainly focused on the of nitrogen leached from manure, nitrogen emissions (ammonia), percolated water.
Owing to the large number of variables, due to the high level of detail required and the large area involved, computational complexity early resulted a main constraint.
The huge number of simulations required to run all the possible combinations among the involved elements (crops, soils, climate, management practices, fertilization) suggested the opportunity to develop appropriate procedures to reduce their number.
At the level of crops and crop rotations procedures to reduce computational complexity were tested using statistical analysis. Different methods were evaluated to translate a spatial distribution (area) into a temporal sequence (rotation). This issues was previously developed by Muzzolini (2009), who focused combinatorial and computational rules.
The method proposed greatly reduces the number of simulations; as it demonstrated that crop rotations can be built a posteriori by assembling the output resulting from the simulation of single crops.
Also the presence of second harvests greatly increases the number of simulations. Therefore assumptions were done to lower the number of rotations encompassing second harvest. In fact, only 3 combinations of first and second harvest were considered as likely for the study area; moreover fertilization and irrigation for second crops were set at fixed values. These assumptions allow to reduce the number of rotations from 180,075 to 14,683, with a 91.84% break – down.
In order to reduce the computational complexity a cluster analysis of all the soil – climate combinations, identified overlapping soil maps and climate Voronoi polygons was applied. There were have been identified 165 soil – climate combinations, 100 in Lombardia, 65 in Friuli Venezia Giulia.
In the sample areas 2,575 simulations were run and their outputs were processed according to the hierarchical clustering and, afterwards, using partitioning around medoids technique (PAM).
PAM allowed to focus on the most representative soil – climate combination; 17 medoids, (10 for Lombadia and 7 for FVG), were tested using Kruskal – Wallis test to evaluate there's a significant difference between the medoid and the soil – climate combination in each cluster.
As the null hypothesis was not rejected, this method allowed to reduce soil – climate combinations, with a 89.69% break – down.
Assumptions to lower the number of simulation were also applied to waste treatments. Each treatment, or their combinations has been classified by the chemical and physical properties of the manure, slurry, sludge or compost obtained. Different treatments that pro-

duce wastes with similar chemical and physical properties were grouped together. 9 classes for swine wastes and 9 for cattle wastes were obtained.
All the described methods have proven to be effective in reducing the computational complexity, allowing to run a lower number of simulations but maintaining a high level of precision.
The output of the simulations carried out on a limited number of combinations were used to calculate a series of multiple regression lines to calculate the values of nitrogen leached, ammonia gaseous emissions and percolated water under actual conditions of organic and mineral fertilization. The regression lines were loaded into the DSS allowing to calculate output values. Each multiple regression has been calculated considering 20 – 25 points, depending on crop. Each simulation, run for a period of 30 years, represent a point of the regression model.
The number of simulations actually run to cover all the crop – medoids – management – slurry (amount, type) was 248,390 while, without any simplification method, the estimated number of simulation was $9*10^7$ simulations. The break – down is nearly two orders of magnitude.
The methods to reduce computational complexity resulted adequate. The developed meta – model, based on CropSyst, allows to run simulations for the entire Veneto and Po basin, maintaining a high level of detail.
Other works, while presenting a large study area, were focused mainly on one crop (Bocchiola et al., 2013; Sommer et al., 2010), climate change impact on crops (Torriani et al., 2007), evaluate economic and/or environmental impact (Sommer et al., 2010; Bechini et al. 2008). In our work crops, their combinations, first and second harvest, are a primary tools to lower NO_3^- pollution.
The decision support system finally aimed at supporting farmers in searching the most effective management options under both environmental and economic point of view has been developed in a web environment, allowing user to avoid the download of any software, and potential limitation due to operating system and processor, since only a web browser and an internet connection are required. As the cropping system simulation model is not enclosed in the DSS, therefore avoiding software and hardware problems and permitting an expert control over input and simulations output, the tool results extremely robust. The user inputs acts as coordinates to extract the corresponding set of multiple regression models; afterwards the DSS returns values for each cadastral unit of a farm (and their sum), at high level of detail, and at municipal level at low level of detail.
The DSS has a user – friendly interface suited, not only for farmers, but also for technicians and policy makers. The WebGIS interface allows user to easily simulate scenarios with the aim of a map; this feature permits to change crops and their management, as usually done in a farm, but also cadastral units property and regulatory limits; the last option is particularly interesting because it copes with possible regulatory limits modifications as expected by reconsidering scientific and technical data.
The proposed scenarios demonstrates part of the potentiality of the DSS. The proposed scenarios set in the agronomic modules leads to different patterns of N leaching, NH_3

emissions and percolated water. Flexibility, a graphic and intuitive interface, easy set ups and fast answer allows user to compare easily, different management options. The set scenarios in the technological module are compared with a pondering system, specifying the priority weight among cost, energy, GHG emissions and NH_3 emissions.
The DSS allows to set each "feature" of a farm, both agronomic and technologic, in the entire Po and Veneto Basin and the optimization module, basing on the priority weight, lists the best environmental and economic solutions. The DSS considers the whole farm and focuses its attention to manage manure with a full view: environment, costs and also regulatory limits. It also allows to consider the consortium as option, calculating its optimal position and the technology that should be adopted to minimize environmental impact.

LIST OF SYMBOLS AND ABBREVIATIONS

AWC: available water content;

BDN: Banca Dati Nazionale;

C: carbon;

CBPA: codice di buona pratica agricola;

CH_4: methane;

CO_2: carbon dioxide;

COD: chemical oxygen demand;

CoGap: codes of good agriculture practice;

DM: dry matter;

DDSS: dedicated decision support systems;

DSS: decision support systems;

E.I.S.: Environmental Impact Scenario;

$FeCl_3$: ferric chloride;

Fig.: figure;

FVG: Friuli Venezia Giulia;

GAI: green area index;

GDSS: group decision support system;

GHG: greenhouse gases;

H_2S: hydrogen sulphide;

H_2SO_4: sulphuric acid;

HCl: hydrochloric acid;

HI: harvest index;

HNO_3: nitric acid;

IGDS: integrated decision support systems;

K: potassium;

LAI: leaf area index;

LCA: life cycle assessment;

MetHB: methemoglobinemia;

$(NH_4)_2SO_4$: ammonium sulfate;

NH_4^+: ammonium;

NH_4HSO_4: ammonium hydrogen sulfate;

NH_4NO_3: ammonium nitrate;

NO_2^-: nitrites;

NO_3^-: nitrate;

N: nitrogen;

N_2: molecular nitrogen;

NAP: nitrates action programme;

NH_3: ammonia;

NO_2: nitrous dioxide;

N_2O: nitrous oxide;

Ntot: total nitrogen;

NVZs: nitrates vulnerable zones;

O_2: oxygen;

OM: organic matter;

O.S.A.: outside study area;

OZs: ordinary zones;

PM: particulate matter;

PO_4^{3-}: phosphates;

P: phosphorous;

PAM: partitioning around medoids;

SAU: superficie agraria utile (utilized agricultural area);

SIDS: sudden infant death syndrome;

SO_2: sulphur dioxide;

SO_3: sulphur trioxide;

Tab.: table;

TAN: total ammonia nitrogen;

TKN: total Kjeldal nitrogen;

TS: total solids;

TVS: total volatile solids;

VS: volatile solids;

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