Della Torre

Bollettino

della Società Italiana della Scienza del Suolo

Volume 49

No. 1-2 2000

SISS - IUSS

European Soil Bureau
European Commission
JRC - S.A.I.

Proceedings of the International Congress

SOIL VULNERABILITY AND SENSITIVITY

With the contribution of:

Cassa di Risparmio di Firenze

Endorsed by:

Presidenza del Consiglio dei Ministri
Ministero degli Interni
Conferenza Stato-Regioni
Ministero delle Politiche Agricole e Forestali
Ministero dell'Ambiente
Conferenza dei Presidenti delle Regioni e delle Province Autonome
Associazione Nazionale Comuni Italiani
Associazione Nazionale Bonifiche e Irrigazioni
Federazione Nazionale dei Consorzi di Bacino Imbrifero e Montano

Florence, 18-21 October 1999
Salone dei 500, Palazzo Vecchio
Palazzo degli Affari, Piazza Adua 8

PREFACE

The Congress has been organised jointly by the Italian Society of Soil Science (SISS) and the European Soil Bureau of the European Commission (ESB), with the financial contribution of Cassa di Risparmio di Firenze. The purpose was to stimulate the debate about the international and Italian experiences concerning soil vulnerability and sensitivity. Over 200 participants attended the Congress, with 13 oral communications and the exhibition of 20 poster, and this encourages in going ahead with this kind of meetings to increase the knowledge of the soil and the environment.

On the first day, the Congress was hosted at Palazzo Vecchio, in the grandiose Salone dei Cinquecento, whose actual appearance is the work of Giorgio Vasari and his pupils, and dates from the second half of the sixteenth century. The addresses of Paolo Sequi, President of the Italian Society of Soil Science, Sergio Paderi, Town Councillor for the Environment, Jean Meyer-Roux, Vice-president of the Space Applications Institute of the JRC (European Commission), Claudio Del Lungo, Regional Councillor for the Environment, and Fabio Giacomelli, President of FEDERBIM, opened the Congress. Fiorenzo Mancini concluded the opening addresses and chaired the morning session.

The definition of the problem at international level was presented from the point of view of IUSS, OECD, FAO, and ISRIC thanks to Winfried E.H. Blum, Yukio Yokoi, Freddy Nachtergaele and Niels H. Batjes. Invited speakers from SSLRC, INRA, University of Ljubljana, University of Cagliari, ESSC, FSSC and ANBI tried to emphasise the arguments concerning the problem at international level, in relation with the scientific and the normative aspects, and sample case studies from different European organisations have been presented. The contribution of John M. Hollis, Dominique King, Franc Lobnik, Angelo Aru, Josè Luis Rubio, Eric Van Ranst, Anna Maria Martuccelli and their collaborators is acknowledged.

The second day was chaired from Giovanni Fierotti (University of Palermo), and has been devoted to some Italian experiences at different scale of detail, among which:

- the municipal level (Gilmo Vianello, Pier Carlo Tesi, and Francesco Sacchetti);
- the provincial level (Andrea Vitturi and Edoardo Costantini);

- the regional level (Renzo Barberis, Stefano Brenna, Domenico Tosco);
- the watershed level (Roberto Salandin, Costanza Calzolari, Roberto Passino, and Marcello Pagliai);
- and also experiences in parks and natural areas (Gian Tommaso Scarascia Mugnozza and Sergio Paglialunga).

We greatly acknowledge the contribution of all the co-authors and the different speakers that in some cases have kindly replaced the invited speakers. The list is very long, but let us mention Romano Rasio, Amedeo D'Antonio, Furio Dutto, Anna Benedetti, and Aleandro Tinelli.

Pre and post congress scientific excursions have been planned to *Crete Senesi*, *Argille di Volterra*, Military Geographic Office of Florence, and the Natural Park *Migliarino San Rossore Massaciuccoli*. We wish to thank Costanza Calzolari, Marcello Pagliai and collaborators, major general Matteo Facciorusso, and Sergio Maestrelli respectively.

Last but not least, a warm thank to Girolamo Mecella for his valuable support to the organisation, and the staff of the Italian Society of Soil Science and the Experimental Institute for Plant Nutrition that stays behind the scenes, and is the heart of the organisation: Rolando Baroni, Manuela de Pace, Barbara De Rosa, Filippo Ilardi, Grazia La Stella, and Marina Natalini.

Rosa Francaviglia

Patrizia Scandella

Paolo Sequi

SOIL RESILIENCE – THE CAPACITY OF SOIL TO REACT ON STRESS

Winfried E.H. Blum

Institute of Soil Science, Universität für Bodenkultur,
Gregor Mendel-Str. 33, 1180 Vienna, Austria

Sommario. Resilienza del suolo - La capacità di reagire agli stress

La resilienza del suolo può essere definita come "la capacità di un sistema suolo di volgere a un nuovo equilibrio dinamico dopo essere stato perturbato". Stress è definibile come influenza fisica, chimica o biologica sul suolo, generata nella maggioranza dei casi per azione antropogenica, causando varie reazioni nel suolo stesso.

La resilienza si basa su forme differenti di energia come per esempio la forza di gravità, l'energia petrogenica (orogenica) e l'energia solare. Questi tipi di energia sono spiegabili ed esistono pertanto vari esempi di resilienza del suolo dovuti a stress fisico, chimico e biologico, a dimostrare l'importanza di questo nuovo termine nella scienza del suolo, in particolar modo in contesti come "qualità del suolo", "salute del suolo", "uso sostenibile del terreno" e altri simili concetti.

Parole chiave: *resilienza del suolo, stress del suolo, forme di energia nel suolo*

Abstract

Soil resilience can be defined as "the ability of the soil system to return after disturbance to a new dynamic equilibrium". Stress is defined by physical, chemical or biological impacts on soil, mainly induced anthropogenetically, causing soil reactions.

Resilience is based on different forms of energy, such as gravity, petrogenic (orogenic) and solar energy. These are explained and different examples for soil resilience on physical, chemical and biological stress are given, thus highlighting the importance of this new term for soil science, especially in connotation with "soil quality", "soil health", "sustainable land use" and related terms.

Keywords: *soil resilience, soil stress, forms of energy in soil*

Introduction

Only recently the term "resilience" was introduced into soil science, in order to create a common theory that allows to describe and to assess the reaction of soils to a range of impacts, that are mainly caused by human activities.

Soil resilience was defined by Szabolcs (1992) as "tolerance against stress" or "that proportion of the total work of deformation which the body (soil) can level out after the removal of the deforming forces". Another basic definition of soil resilience was given by Blum and Aguilar (1992) as "the ability of the soil system to return after disturbance to a new dynamic equilibrium", see Blum (1994). Ulrich (1987) also used the term "resilience", when discussing the disturbances of terrestrial ecosystems under the aspects of the matter-balance.

Biologists and ecologists have been using this term for a long time in order to describe processes between biota or within biological systems, Peters (1991). But soils are more complex than living organisms and biological systems.

Therefore, in the following, an attempt will be made, to prove whether and to which extent the term "resilience" can be defined for soil systems and if "soil resilience" can be a useful operational approach.

"Soil stress" is defined as physical, chemical or biological impacts on soil, causing soil reactions, mainly induced anthropogenetically.

Energy concept for soil resilience

In view of the fact that soils are even more complex than biological (living) systems, because they consist of living and dead organic and inorganic components with solid, liquid, and gaseous phases at the interface between the lithosphere, hydrophere, biosphere and atmosphere, the question arises: what are the basic characteristics of soil resilience, and which are the forces responsible for the ability of the soil react on stress or more precisely, to return to a new dynamic equilibrium after disturbance?

Three different forms of energy can be distinguished as a possible basis of soil reactions on stress: gravity, petrogenic (orogenic) and solar energy.

Gravity

Gravity determines all kind of transport processes of solid, liquid and gaseous forms of soil materials above and within the soil (soil pore space), including the velocity and the vector of fluxes. In combination with solar energy (wind, rainfall, etc.) gravity is the main determent of transport processes on the soil surface and is therefore a dominant factor in the morphogenesis of landscapes, e.g. through erosion and sedimentation.

Therefore, gravity is an inherent factor in pedogenesis and morphogenesis and shows very little variation over space and time in contrast to other forms of energy, influencing soil processes.

Petrogenic (orogenic) energy

Because of different petrogenetical processes (magmatic, sedimentary and metamorphic), rock parent materials (e.g. granite, gneiss, shales, limestone etc.) and their mineralic constituents (e.g. mica, feldspar, amphibole, calcite, dolomite etc.) contain different forms of energy, depending on their chemical composition and crystal form (crystallinity). This means that energy contained in different minerals is not only based on crystal structure, but also on chemical content, e.g. alkaline, earth alkaline, trace elements and others, which have very different physico-chemical and biological significance.

Through physical, chemical and biological weathering processes, the petrogenic energy pool of soils is constantly lowered, thus increasing the entropy in the system, because the newly formed minerals, like oxides, clay minerals, water soluble salts and others contain less energy than the primary minerals.

These are finite processes, which are terminated when the pool of the primary as well as secondary minerals and ions contained in the rock parent material and the soil is exhausted, see for example "chemical resilience" of soils against acidification.

Because petrogenic energy is an endogenic heritage (orogenesis), it cannot be renewed, except for cases such as volcanic activities, e.g. eruptions and deposition of new primary minerals, earthquakes or other endogenic forces, or transport and sedimentation of new rock and soil materials by water (see river flooding and deposition) and wind. Also, human activities can contribute to new petrogenic energy, e.g. as city rubble (bricks, concrete and other debris), forming new soil parent materials.

Solar energy

In contrast to petrogenic (orogenic) energy, solar energy is constantly renewed, thus driving, together with gravity, all kinds of processes in soils.

Different kinds of solar energy exist, with different time scales and impacts:

- direct energy transfer with short term processes:
  - direct solar radiation, including diffuse radiation by reflection;
  - convection, through air and water masses (temperature, wind, precipitation, etc.);
- indirect energy transfer with short to medium term processes:
  - through energy storage by photosynthesis and later conversion of dead organic matter through biological processes, creating new forms of chemical energy, e.g. CO_2, H_2CO_3, organic acids, or simply heat through biological activity;
  - through fossil energy (coal, oil, gases, mainly used in anthropogenic activities).

All these forms of solar energy are deriving from exogenic sources based on solar radiation. Solar energy is constantly renewed, in contrast to fossil energy. - It can be defined and classified by climatic systems or subsystems.

Solar energy also determines the velocity of physico-chemical (rule of van t'Hoff) and biological reactions or processes. When water is involved, solar energy can even counterbalance gravity, e.g. through capillary rise.

Solar energy has never been constant in space and time and has shown considerable fluctuations in the history of soil formation, e.g. due to the different positioning of the equator in prehistoric times. Therefore, many soil constituents which can be found today do not reflect actual processes, because they developed under different climatic conditions in the past, Blum (1997 a).

Operationalization of soil resilience

In his book “A Critique for Ecology”, R.H. Peters (1991) writes in chapter 4 “Operationalization of terms and concepts”: “The creation of a new scientific theory from the range of available concepts is no easy task. The vague primordia of our ideas must be given form in our thoughts, this form must be interpreted in light of our experience, and then refined to remove incongruous material while preserving some essence of the original meaning. At the end of this process, the concept will be associated with a set of external phenomena and the association likely legitimized with its own term. Only concepts that have gone through this process of operational definition can be used in a theory. - Scientific criticism encourages this operationalization by identifying the present capacities, limitations and roles of existing concepts”.

In the following, an attempt will be made to prove whether and to which extent the term “soil resilience” can be operationalized, describing soil reactions on physical, chemical and biological stress. Whereas in biological systems, gravity and solar energy are the only basis of resilience, in soils, the petrogenic energy concomittantly plays an important role through the pool of chemical elements and the crystal structure of the soil constituents.

Soil **physical** stress can occur through mechanical disturbance, such as compaction, destruction of the soil structure and others. The resilience of soils against physical stress is based on temperature change, e.g. frost (solar energy), swelling and shrinking with water (mainly petrogenic, but also solar energy), and biological activity, e.g. through roots and soil biota (solar energy). Those reactions can be described and analyzed in detail.

Chemically, soil can be stressed through acidification, salinization, alcalinization, pollution by heavy metals and other processes.

A typical example for chemical resilience is the soil buffer capacity against acidification, which can be subdivided into different buffer processes, defined by pH-ranges:

(a) carbonate buffer, based on the dissolution of calcite or dolomite (pH > 7)

$$CaCO_3 + H^+ \Leftrightarrow Ca^{2+} + HCO_3^-$$

$$HCO_3^- + H^+ \Leftrightarrow H_2O + CO_2$$

(b) buffer based on pH-dependent (variable) charges of inorganic and organic surfaces (pH 7 - 5.5):

$(AlOH)_2\,Ca + 2H^+ \Leftrightarrow - (AlOH_2)_2 + Ca^{2+}$

$(COO)_2\,Ca + 2H^+ \Leftrightarrow - (COOH)_2 + Ca^{2+}$

(c) silicate buffer, based on the weathering of silicate minerals (pH 5.5 - 4.5): M = metal ion

$Si - O - M - O - Si - + 2H^+ \rightarrow - (SiOH)_2 + M^{2+}$

(d) oxide and hydroxide buffer, based on the dissolution of Al and Fe-oxides (pH < 4.5):

$Al(OH)_3 + 3H^+ + 3H_2O ⌫ Al(OH_2)_6{}^{3+}$

These examples indicate that through chemical reactions on stress, the petrogenic energy pool is lowered, which is a one-way reaction, thus leading to a constant rise of entropy in the system (Blum, 1998).

Therefore, on the basis of this concept, there are by definition no steady state equilibria in soils, in contrast to biological systems, which are mainly based on gravity and solar energy, and can therefore react more quickly in space and time than soil ecosystems. - There can also be other chemical reactions, which are partly influenced by solar energy, e.g. through evapotranspiration and capillary rise.

Resilience against **biological** stress, sometimes even causing the local or regional extinction of soil biota, is mainly based on solar energy (direct/indirect) but also on petrogenic energy (chemical and crystal structure of soil constituents). However, the main energy form behind biological resilience is solar energy through radiation and photosynthesis as the nutritional basis of soil biota.

Conclusions

Resilience is an inherent character of soil, explaining all kinds of soil reactions on stress. Resilience differs from one soil unit to the other because it depends not only on the individual mineral and organic/biotic soil constituents, but also on site or micro-site conditions, e.g. topography, climate, hydrology, solar radiation, and others.

Resilience can be measured on an operational basis, using specific methodological approaches of soil physics, soil chemistry including mineralogy, soil biology including microbiology, or a combination of these.

Resilience is therefore a term which fits well into the actual international discussion about "soil quality", "soil health", "sustainable land use", and related terms, Blum (1997 a and b); Greenland and Szabolcs, 1992.

References

BLUM W.E.H., AGUILAR SANTELISES A. (1992). A concept of sustainability and resilience based on soil functions - The role of ISSS in promoting sustainable land use. In: *Soil resilience and sustainable land use*, Proceedings of a Symposium held in Budapest, 28 September, 1992, ed. by D.J. Greenland and I. Szabolcs (ed.), C A B International, Wallingford, England.

BLUM W.E.H. (1994). *Soil Resilience - General Approaches and Definition. - Transactions 15th World Congress of Soil Science*, Vol. 2a, 233-237, Acapulco, Mexico.

BLUM W.E.H. (1997 a). Soil as an open, complex system of biotic and abiotic interactions - *Energy concept. Mittlg. Österr. Bodenkundl. Ges.* 55, 13-15, Wien, Austria

BLUM W.E.H. (1997 b). Basic Concepts: Degradation, Resilience and Rehabilitation, in: Lal, R., W.E.H. Blum, C. Valentin and B.A. Stewart (Eds.): *Methods for Assessment of Soil Degradation*, 1-16, CRC Press, Boca Raton.

BLUM W.E.H. (1998). Soil Resilience – A Concept for Describing Soil Reaction on Stress. – in J. Blahovec (Ed.): "*Flow and Deformation in Biology and Environment*", Proceedings of the International Conference, pp. 17-10, Prague (Czech Republic), September 14-16, 1998.

GREENLAND D.J., SZABOLCS I. (ed.) (1992). *Soil resilience and sustainable land use*, Proceedings of a Symposium held in Budapest, 28 September, 1992, C A B International, Wallingford, England.

PETERS R.H. (1991). *A critique for ecology*. - Cambridge University Press.

SZABOLCS I. (1992). Concept of soil resilience. In: *Soil resilience and sustainable land use*, Proceedings of a Symposium held in Budapest, 28 September, 1992, ed. by D.J. Greenland and I. Szabolcs, C A B International Wallingford, England.

ULRICH B. (1987). Stability, elasticity and resilience of terrestrial ecosystems under the aspect of the matter balance. - *Ecol. Studies* (Springer) 61, 11-49.

MEASURING THE ENVIRONMENTAL IMPACTS OF AGRICULTURE - OECD AGRI-ENVIRONMENTAL INDICATORS: SOIL RELATED ISSUES

Yukio Yokoi

Policies and Environment Division, Directorate for Food, Agriculture and Fisheries
Organisation for Economic Co-operation and Development
OECD, 2 Rue Andre-Pascal, 75775 Paris CEDEX 16, France

Introduction

What are the environmental benefits and costs of agriculture? What is the relationship between government policy, agriculture and the environment? What are the underlying causes and effects of agriculture's impact on the environment? It is evident from a wide range of activities now underway nationally and internationally, that a major effort is taking place to provide analysis and develop a set of agri-environmental indicators to help answer and respond to these type of questions. At the meeting of OECD Agricultural Ministers in 1998, Ministers requested OECD to foster sustainable development through analysing and measuring the effects on the environment of agricultural and agri-environmental policies and trade measures.

This paper introduces the current OECD work on the development of the agri-environmental indicators, including indicators of soil quality, focusing on risk of erosions, off-farm sediment flows and soil management.

1. Why and How Measure Impacts of Agriculture

To encourage a sustainable agriculture, it will be necessary to provide analysis, measurement and responses to assist in this decision-making process. The analysis of sustainable agriculture, especially the environmental dimension, involves answering a number of key questions (Pearce, 1999):

• What are the external benefits and costs of agriculture and how much is society prepared to pay to meet environmental objectives, taking into account the trade-offs between these objectives and that agriculture also meets economic and social goals, such as through producing food and creating jobs?

• What is the relationship between government policy and agriculture and the consequences for achieving sustainable agriculture, especially the production and trade distortions created by production linked subsidies, recognising that markets can help reduce negative environmental impacts but may fail to take account of the non-market effects of farming on the environment?

• What are the underlying causes and effects of agriculture's impact on the environment, not only, for example, nitrogen runoff and water pollution, but why nitrogen runoff occurs in the first place?

In order to help select and develop appropriate indicators to answer these questions, work undertaken by OECD on agri-environmental indicators, has suggested that they should possess a number of attributes (OECD, 1997). This implies that indicators must be:

• ***policy-relevant***, that is they should be demand (issue) rather than supply (data) driven, and address the key environmental issues faced by governments and other stakeholders in the agriculture sector;

• ***analytically sound***, based on sound science, but recognising that their development involves successive stages of improvement;

• ***easy to interpret*** and communicate essential information to policy makers; and,

• ***measurable***, that is feasible in terms of current or planned data availability and cost effective in terms of data collection, processing and dissemination.

To help improve information on the current impacts and trends in the environmental effects of agriculture, the OECD is developing a set of agri-environmental indicators within the ***Driving Force–State–Response (DSR) framework***. This framework addresses a set of questions related to the linkages between causes, effects and actions:

• What is causing environmental conditions in agriculture to change, for example, changes in farm chemical input use (***Driving forces***)?

• What are the effects of agriculture on the environment, for example, the impacts on soil, water, air, and natural habitats (***State***)?

• What actions are being taken to respond to the changes in the state of the environment, for example, by farmers, consumers, the food industry and governments, such as promoting sustainable agriculture by community based approaches (***Responses***)?

The DSR framework has helped facilitate the process in OECD of arriving at a consensus on a set of preferred indicators. The framework recognises explicitly that agrienvironmental interactions and linkages are complex and multifaceted, and provides a structure within which individual indicators can be placed in context (Moxey, 1999). As with any classification system, the boundaries between driving forces, states and responses may be unclear in some cases. However, the value of the DSR lies not so much in the precise categorisation of individual indicators, but rather in the provision of a common framework within which indicators can be presented and debated.

Within the context of the DSR framework and building on previous OECD work on indicators (OECD, 1997; 1999), this has led to considerable progress in both the identification and specification of policy-relevant indicators. In summary, the indicators are being developed to cover primary agriculture's:

• use of natural resources and farm inputs: nutrients, pesticides, water and land;

• environmental impact on: soil and water quality, land conservation; greenhouse gas emissions, biodiversity, wildlife habitats and landscape; and,

• interaction between environmental, economic and social factors, such as farm management practices; farm financial resources; and rural viability.

It is against this background that OECD is developing a number of indicators related to soil quality and management issues.

2. Soil related indicators

1) Policy and Environmental Issues

The key policy objective for the soil quality and management in agriculture is to optimise the appropriate functioning of soils as a limited resource for sustainable agricultural production, in ways that are environmentally sound. The limitations on the availability of soil resources to provide safe, nutritious food for an expanding world population is a critical issue when considering global food security. High quality soils are rare and at risk of degradation and loss through, for example, urbanisation. There is a need to know which soils are where, their condition, and the results of policy measures to restore or maintain soil quality.

The soil quality issues are of importance to policy makers because some aspects of soil degradation are only slowly reversible or irreversible, although the relative importance of each issue varies between countries. It should be noted that farm management decisions are influenced by different government policy actions, such as environmental regulations, agricultural support measures and investments in research, education and extension services. Those management decisions will eventually affect environment including soil quality. In this sense, the information on soil and land management practices which are currently undertaken is also important, providing the future projection of soil quality.

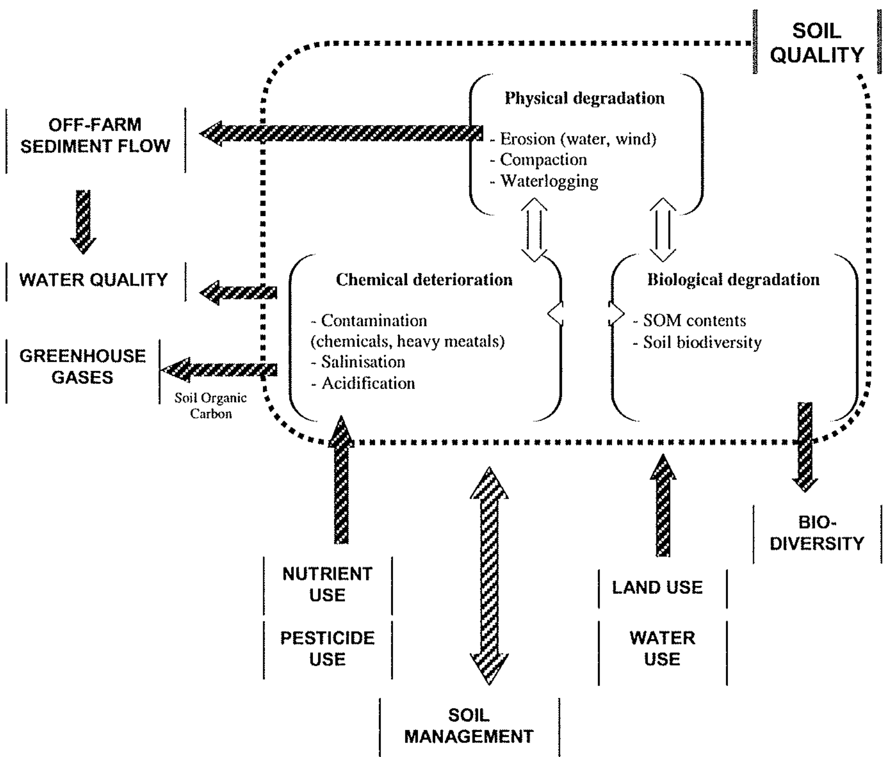
Soil quality can be degraded through three processes: physical, chemical and biological degradation. The main potential adverse impacts from agricultural activities on soil quality include soil erosion, organic matter loss and the loss of soil biodiversity. Other impacts are important in some regions and for certain countries. These include soil contamination from the use of farm chemicals (including heavy metals), soil compaction (and structural decline), acidification, salinisation and waterlogging. The soil degradation may reduce production, lead to products of poor quality, attract the question of safety, and cause problems in farming operations. While these negative consequences directly affect financial balance of farming, the off-farm effects related to soil and land management can be significant, which could be problems to broader population or society. Soil sediment flow from farm land affects various parts of the environment in the downstream, for example rivers and lakes, wildlife habitats and built-up areas. Due to the proximity of agricultural land to rivers, lakes and other aquatic environments the delivery of soil sediment into the aquatic environment tends to be high. Some estimates suggest more than 60 per cent of the soil erosion loss from agricultural land is delivered into aquatic environments (Castro and Reckendorf, 1995). Erosion can damage aquatic environments by impairing water storage capacity in rivers, lakes and reservoirs increasing flooding and damaging water systems.

Among the various soil degradation processes, soil erosion is a key policy issue, for many OECD countries, while issues such as soil compaction, salinisation and waterlogging are relevant only to specific regions in certain OECD countries. Soil erosion and associated off-farm sediment flow are particularly important for the areas with heavy rainfall after long dry seasons during which vegetation does not grow enough to cover soil surface. Accordingly, producing indicators of the physical processes of quality degradation through water and wind erosion are considered to be a priority. An assessment of erosion needs to consider both the physical potential for erosion and the erosion rates resulting from different management choices.

Appropriate soil management practices help to reduce the negative effects which would take place otherwise. Soil management encompass the range of decisions farmers make, including when and how to till the soil, how much crop residue to keep on the soil surface, whether to clear land or leave it in rangeland or woodland, whether to construct terraces and others. Reduced tillage and no-till will generally improve soil structure through reduced compaction. Other methods to improve soil structure involve crop rotation with forage grasses and/or legumes, and the application of manure. Reduced tillage and no-till also results in greater soil cover. Winter cover crops provide protection from soil erosion over winter and add organic matter to the soil when they are ploughed under in the spring.

Figure 1 shows the linkages between these Soil Quality issues and the other areas covered in the OECD Agri-environmental indicators.

Figure 1. Soil Quality and Other Agri-environmental Indicator Areas.



Source: OECD secretariat

2) Selected Indicators

The three indicator areas, namely, soil erosion, off-farm sediment flow and soil management will be discussed in the following paragraphs which are covered by OECD agri-environmental indicator work and of particular relevance to soil issues.

Water erosion indicator and ***wind erosion indicator*** are defined as the agricultural area subject to water/wind erosion, that is the area for which there is a risk of degradation by water/wind erosion above a certain reference level. For water erosion, estimation is made with the so-called Universal Soil Loss Equation (USLE), used extensively in many countries, although the USLE is usually adapted to suit local conditions.

Off-farm sediment flow indicator is identified which is linked to soil erosion but from different aspects, which is defined as "the quantity of soil sediments delivered to off-farm areas from agricultural soil erosion". Here, key policy issue is to maintain and enhance the function or role of agriculture to regulate soil and water flow through appropriate agricultural land use and management practices. This indicator is to focus on the control of negative effects to off-farm areas caused by sediment flow rather than on resource degradation in farming areas. The need for this indicator comes from the recognition that some agricultural management practices have important roles contributing to downstream off-farm areas. Substantial change in these management practices or agricultural activities may lead to negative environmental effect on those areas.

The OECD agri-environmental indicators include those which look at management aspects. The indicator on ***farm management standards*** is defined as national and sub-national environmental farm management standards. The indicator is an inventory of environmental farm management standards, regulations, codes of good agricultural practice etc., established by public agencies, as well as those standards defined by voluntary groups, professional farm organisations, self-generated standards by the agro-food industry, etc. It also shows the management area addressed by the standard (whole farm, nutrients, pesticides, soil, water, etc.). Data are compiled from records of government agencies, professional organisations, industry, farm surveys, etc.

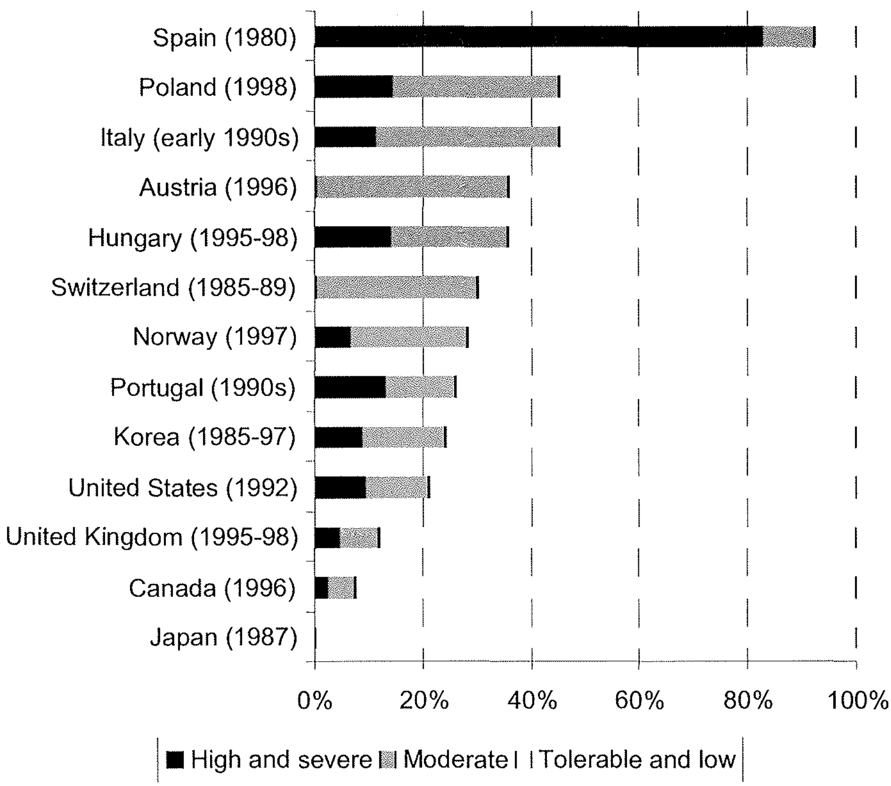
As one of the indicators for farm management practices, the ***soil cover indicator*** is defined as number of days in a year that the soil is covered with vegetation. The indicator is calculated from agricultural census data showing the period during any one year when the soil has a vegetative cover.

Plant and crop residue cover protects soils from erosion, reduces runoff of nutrients and pesticides and provides habitat for biodiversity. The greater the cumulative soil cover, the greater the protection from soil erosion, compaction and runoff, and the greater the contribution to biodiversity.

3) Recent Trends

The work is still at the early stage of data collection and the provisional result of analysis will be presented, which is based on the questionnaire responses from OECD member countries but yet to be validated. As there seem to be inconsistency in term so calculation method and definition for key terms being used, care should be taken when the results are interpreted. In general, therefore, trends within countries over time series should be emphasised rather than comparison between countries.

Figure 2. The percentage of agricultural land area affected by water erosion in selected OECD countries: 1990s.



Source: OECD (2000, forthcoming).
Notes: The criteria for each risk categories differ among countries (See Table 1).

The extent of the ***water erosion*** of soil across OECD countries reveals that a small number of countries are experiencing widespread problems of high and severe water erosion. However, for some countries, more than 10 per cent of agricultural land is in this class, in particular, large part of farm land is severely affected in Spain (Figure 2). It should be noted that there is a wide difference of risk class categories between countries (Table 1), although whether same definition should be used only for simple comparison purpose could be controversial. Trends in water erosion over the past ten years show a reduction from higher/moderate classes into tolerable or low classes of water erosion (Figure 3). The reduction in water erosion largely reflects a combination of the adoption of conservation/no tillage, less intensive crop production and the removal of marginal land from production in some areas.

Table 1.

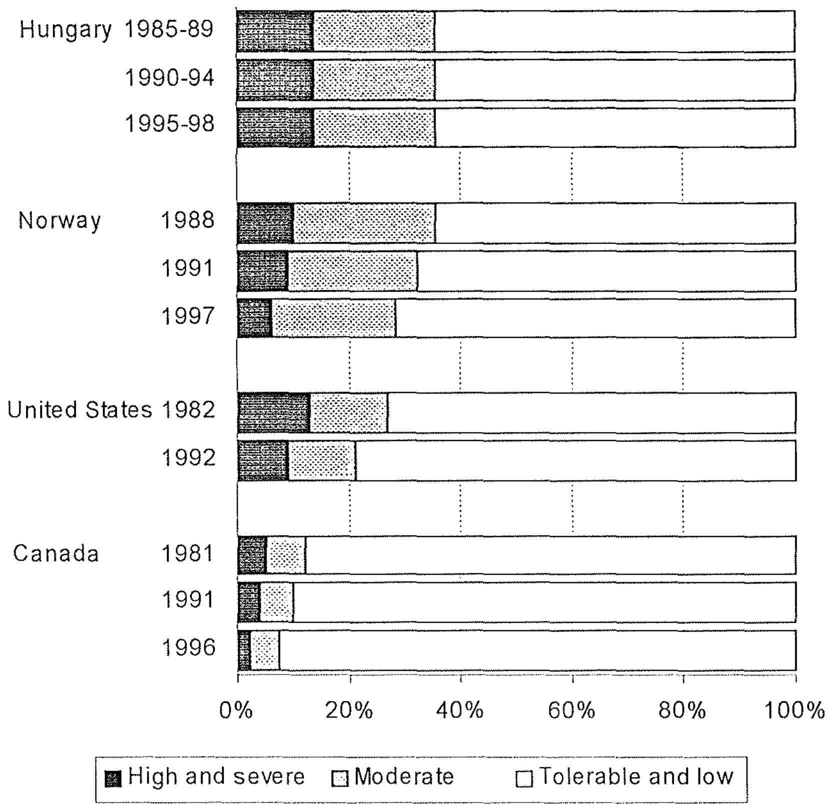
Risk class categories of water erosion.

Countries	High and severe	Moderate	Tolerable and low
Canada, Hungary, Japan, Korea, Norway, Spain	> 22 t/ha/yr	11-22 t/ha/yr	< 11 t/ha/yr
Poland		> 10 t/ha/yr	< 10 t/ha/yr
Austria	> 20 t/ha/yr	6-20 t/ha/yr	< 6 t/ha/yr
Switzerland		> 6 t/ha/yr	< 6 t/ha/yr
United States	> T	T - 2T	< T
United Kingdom	High and very high	Moderate	Very small and small

Notes: T value for the United States is the level of erosion believed tolerable on different soils to maintain productivity.

Soil degradation is considered to be one of the most important threats to the agricultural industry in Canada over the long term even though the share of affected area seems relatively small. Recent preliminary research on national trends in soil quality in Canada, indicate that soil quality will continue to decline in areas of intensive cropping and marginal land where soil conservation practices are not used, although there are important differences at a regional level (AAFC, 1999).

Figure 3. Changes in agricultural land area affected by water erosion.



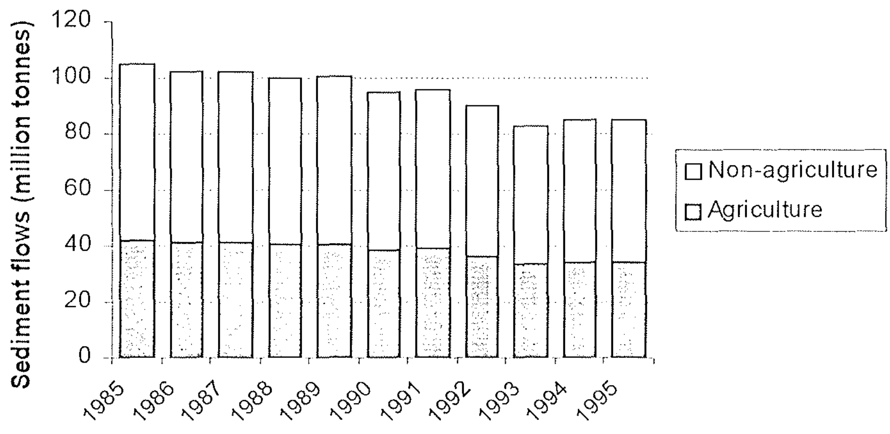
Source: OECD (2000, forthcoming)
Notes: See Table 1 for risk class categories of water erosion.

Southern European countries reported that erosion is an important problem. The problem of soil degradation could be aggravated by a combination of unfavourable natural conditions including the high proportion of steep land, heavy rainfall in autumn and winter when land cover is reduced, a thin topsoil layer. Loss of soil productivity in the eroded areas is a major problem, as is sedimentary deposition downstream, with erosion triggering sometimes irreversible degradation and desertification.

In Portugal, soil conservation policy has not been closely integrated with agricultural policy in the past, but recent developments have aimed to strengthen soil conservation programmes. These include reforestation programmes and schemes to control forest fires, specific agriculture programmes including encouragement to replace arable crops by permanent crops and pasture, information and training campaigns to improve soil tillage practices, and the development of irrigation in order to permit more intensive agriculture and reduce the total area cultivated.

In Italy, the cost to society of sediment yield from agricultural land to off-farm areas is perceived high, particularly in terms of stream degradation and disturbance to wildlife habitat, as well as direct costs for deposit dredging and water storage loss of reservoirs. The trends show ***off-farm sediment flows*** from agriculture as well as total national sediment flows has declined in the past decade (Figure 4). Many other countries, where few data available on sediment flows with time series, reported the situation related to sedimentation in rivers and lakes, while some implied difficulty of aggregation to have national data. Another problem reported is difficulty to disaggregate the measured sediment into agriculture-origin sedimentation and non-agriculture-origin. For this indicator, further attempts are needed to examine the feasibility of the methods and to collect the relevant data.

Figure 4. Share of agriculture in sediment flows (Italy).



Source: OECD (2000, forthcoming)

Environmental conditions and farming systems vary within and across OECD countries and, consequently, optimal farm management practices and environmental farm management standards also vary. ***Farm management standards*** are often developed at the sub-national level resulting in great variations even within a country. In federal states such as Canada, the nature of environmental farm management standards, regulations and codes of practice vary by province and across commodity groups. Voluntary codes of practice are generally used for soil management (Table 2).

Table 2.

Environmental farm management standards in selected OECD countries.

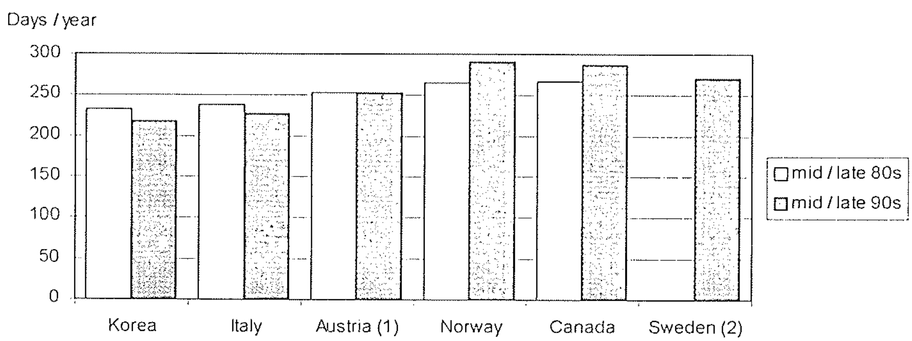
	Farm management area					
	Whole farm	**Nutrients**	**Pesticides**	**Soil**	**Water**	**Other**
Number of OECD countries with						
a) compulsory standards	1	6	5	3	3	1
b) regulations	2	7	6	5	4	4
c) voluntary codes of practice	8	8	7	7	4	4
d) other	3	1	3	1	0	0

Notes: The table shows the farm management areas addressed by environmental farm management standards in selected OECD countries.

Source: OECD Agri-environmental Indicator Questionnaire, 1999.

Many OECD countries have policy initiatives to increase ***soil cover***, but only a few OECD countries calculate the annual soil cover area (Figure 5). The number of days when soil is covered exceeds 250 days/year and has increased in Austria, Canada, Norway and Sweden, while the decrease of soil cover in Korea and Italy implies possible increase of risk in erosion and off-farm sediment flow. National attempts for the development of management practice indicators include the one made by Switzerland, which has developed an index to measure winter soil cover, and the results from the pilot project show that soil cover has increased. Canada uses an index of bare-soil days to estimate the number of days in a year that soil is bare under specific cropping and tillage practices (AAFC, 1999).

Figure 5. The number of days in a year that the soil is covered with vegetation.



Source: OECD (2000, forthcoming)

Notes: 1. Data refer to 1994 and 1997.

2. Data is not available for mid late 80s.

Table 3.

Land and soil management practices in Canada.

	1991	1996
Reduced tillage practices	percentage of planted area	
Tillage retaining most crop residues on soil surface	24	31
No tillage prior to seeding	7	16
Other land and soil management practices[1]	percentage of farms	
Crop rotation	37	57
Permanent grass cover	..	29
Winter cover crops for spring plough-down	9	3
Contour cultivation	9	5
Strip-cropping	8	4
Grassed waterways	11	9
Windbreaks or shelterbelts	..	13

Notes: (1) Percentages may exceed 100 where more than one practice is used on the same crop area.

Source: AAFC, 1999: Historical Overview of Canadian Agriculture (1996 Census), Statistics Canada 1997; Agricultural Profiles of Canada, Statistics Canada.

Table 4.

Environmental Land Management Practices in the United States.

	1985-1989		1990-1994		
Management practice	Years	Area in hectares	Years	Area in hectares	Percentage Change
Conservation Tillage	1989	23 310	1990-94	24 144	4
Zero Tillage	1989	5 706	1990-94	11 283	98
Crop Rotation	n.a.	n.a.	1990-92, 1994	54 226	n.a.
Winter Cover Crops	1985-89	58	1990-94	53	-9
Contour Cultivation	1987	12 726	1992	12 611	-1
Grassed Waterways	1988-89	79	1990-94	86	9
Strip-cropping	1988-89	53	1990-94	42	-21
Windbreaks	1988-89	243	1990-94	91	-63
Grass Cover Establishment	1988-89	2 609	1990-94	643	-75
Grazing Land Protection	1988-89	1 492	1990-94	1 395	-7
Terraces and Diversions	1988-89	405	1990-94	282	-30

Notes: n.a.: not available.

Source: OECD Agricultural Environment Indicators Questionnaire 1999, see also USDA, 1997.

Sustainable land management practices are promoted in most OECD countries, while the type and implementation vary country by country. For certain OECD countries the crop area under environmental land management practices has increased significantly and in Norway and Switzerland, for example, these practices are now used in over 70 per cent of the crop area. The studies in Canada and the United States showed the change in adopting different land management practices (Table 3; Table 4).

4) Further Work

Further work on soil related indicators could focus on the development of indicators for soil biodiversity, soil organic matter, inherent soil quality and economic valuation of soil quality.

Soil biodiversity indicators involve the use of living organisms, or of products from living organisms, as a measure of soil quality. This indicator could reflect the combined effects of many factors, that would otherwise be too difficult, costly or time consuming to measures while it may not provide a clear cause and effect relationship in explaining soil quality without additional information.

Soil organic matter indicator would serve to help analyse the impacts of soil conservation programmes. Soils with adequate amounts of organic matter have good aggregation and tilth, permit water and air infiltration, are resistant to erosion, and help provide favourable biological habitats.

A key aspect to further development of soil quality indicators will be to determine the proportion or area of the land where current land use exceeds the assessed capability of the land. In this context, an indicator of ***inherent soil quality*** could be developed, which reveals agricultural areas where there is a mismatch between the soil capability and the actual or impending land use.

Economic valuation of soil quality would allow for the analysis of relationships between agricultural land degradation, farm productibity and profitability. To support economy-wide assessments that are firmly based on the current activities and decisions of farmers there is a need to improve the information on land degradation and the environment, and develop links between that information, agricultural activities and farm management practices. Economic analysis could provide estimates of the on- and off- farm costs of soil degradation and the costs of maintaining soil quality.

3. Future Challenges

The development of environmental indicators is relatively recent compared to work on economic and social indicators. But whereas the latter is often concerned with the monetary measurement of human phenomena, environmental indicators aim to capture the relationship between the biophysical "natural" environment and human activities, usually measured in physical terms. This, in part, explains why environmental and sustainable agriculture indicators present a considerable challenge in the future.

Some of the ***key future challenges in indicator development*** relate to spatial scales; temporal dimensions; analysis of linkages between the different dimensions of sustainable agriculture; and, the valuation of the environmental costs and benefits of agricultural activity.

The ***spatial scales*** to measure agricultural environmental indicators varies from the field, farm, watershed, through to the ecozone and national levels. The capability to develop and measure indicators for a range of spatial scales is constrained by: the ability to extrapolate data from the field/farm level to higher levels; the trade-offs that occur with gains in coverage at higher levels but loss of the detail/variation at lower scales; and that information at different scales may require different indicators depending on the use, and users, of the information (McRae *et al.*, 1995). From the OECD perspective data need to be captured at as detailed a level as possible then aggregated to the national level with some expression of the variation around the national average indicator value.

The variations in the ***temporal dimensions*** of different environmental effects of agriculture range from the short term, such as the impact on wildlife from pesticide use; medium term, for example depletion of groundwater reserves; and to the long term, which may involve decades in the case of soil erosion. The impacts on the environment from agricultural policies, economic and societal pressures may also have different time lags and consequences. While this problem is not uncommon to socio-economic indicators, there is nonetheless an important difference, as a key focus of sustainable development is intergenerational concerns. Most indicators, however, use a time series approach showing current trends, which presents a key challenge for indicator construction in terms of the current-future trade-off.

The sustainable development concept emphasises ***the links between the economic, social and environmental dimensions*** (Rennings and Wiggering, 1997). Balancing economic imperatives (e.g. food production), with environmental impacts (e.g. conserving landscapes) and social concerns (e.g. preserving rural communities), requires some means of weighing up these impacts and concerns, such as through the use of cost-benefit frameworks. Use of a cost-benefit framework highlights the need to develop indicators that use a ***common monetary unit*** rather than physical measures, so that trade-offs and priorities can be more easily gauged by policy makers and the public.

As the challenges to indicator development are overcome and more indicators become operational they will enrich the information base for policy decision makers with an interest in agri-environmental issues. It is clear, however, that there is a gap between the current development of agri-environmental indicators (indicator supply) and expectations for indicator delivery by policy makers and other stakeholders (indicator demand). These indicators are essential to make well-informed policy choices and without them there is a risk of making short-sighted and flawed decisions (Ervin, 1995).

As national and international efforts advance to establish agri-environmental indicators they will need to command broad consensus in terms of their feasibility and policy relevance. Also it will be important that the indicators are valuable in interpreting trends in environmental conditions in agriculture and agricultural sustainability, are based on a consistent methodology to enhance their utility for international comparison, and are transparent so that all "stakeholders" can understand the indicators and the policy implications based on them.

This paper draws from materials provided in the forthcoming (2000) OECD publication: *Environmental Indicators for Agriculture, Volume 3: Methods and Results.*

Any remaining errors in the paper are the responsibility of the author, and the views expressed do not necessarily reflect those of the OECD or its member countries. For further information regarding the OECD work on agri-environmental indicators, contact the Author: Tel: (33 1).45.24.89.55; Fax: (33 1).44.30.61.02; E-mail: yukio.yokoi@oecd.org

References

Agriculture and Agri-Food Canada (AAFC) (1999). Farm Resource Management Indicator: Soil Cover and Land Management Component. Technical Report, Report No. 18, Ottawa.

CASTRO J., RECKENDORT F. (1995). Effects of Sediment on the Aquatic Environment. RCA III, Working Paper No.6, Natural Resources Conservation Service, US Department of Agriculture, Washington, D.C.

ERVIN D., BATIE S., LIVINGSTON M. (1995). Developing Indicators For Environmental Sustainability: The Nuts and Bolts: Introduction and Symposium Summary. In: *Developing Indicators For Environmental Sustainability: The Nuts and Bolts.* (Ed. S. Batie) Special Report (SR) 89: 1-7, Proceedings of the Resource Policy Consortium Symposium, Washington, D.C.

McRAE T. *et al.*, (1995). Role and Nature of Environmental Indicators in Canadian Agricultural Policy Development.

In: *Developing Indicators For Environmental Sustainability: The Nuts and Bolts.* (Ed. S. Batie) Special Report (SR) 89: 117-142, Proceedings of the Resource Policy Consortium Symposium, Washington, D.C.

MOXEY A. (1999). Cross-cutting issues in developing agri-environmental indicators. In: *Environmental Indicators for Agriculture, Volume 2: Issues and Design.* OECD, 1999, Paris.

OECD (1997). *Environmental Indicators for Agriculture*, Paris.

OECD (1999). *Environmental Indicators for Agriculture, Volume 2: Issues and Design*, Paris.

OECD 2000 (forthcoming). *Environmental Indicators for Agriculture, Volume 3: Methods and Results*, Paris.

PEARCE D. (1999). Measuring Sustainable Development: Implications for Agri-environmental Indicators. In: *Environmental Indicators for Agriculture, Volume 2: Issues and Design.* OECD, 1999, Paris.

RENNINGS K., WIGGERING H. (1997). Steps Towards Indicators of Sustainable Development: Linking Economic and Ecological Concepts, *Ecological Economics*, Vol. 20, 1: 2536.

Soil Vulnerability Evaluation and Location Fragility Assessment

Freddy O. Nachtergaele

Technical Officer Land Classification
Soil Resources, Management and Conservation Service
Land and Water Development Division FAO
Viale delle Terme di Caracalla - 00100 Rome - Italy

Abstract

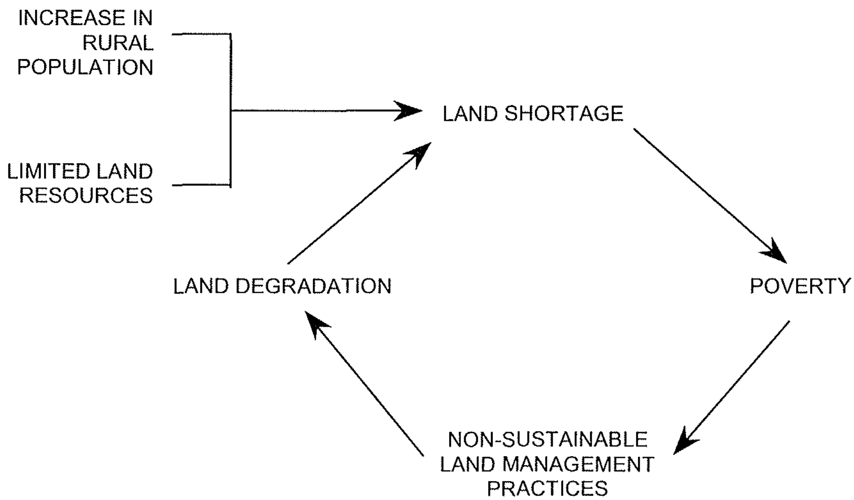
Although the subject of this paper was originally to deal exclusively with soil vulnerability, it has evolved into an argument for expanding the concept into a more holistic approach of so-called location fragility, while at the same time clearly identifying human nature rather than nature itself, as the driving force of natural disasters in general, and location vulnerability, in particular. The central argument is illustrated with an analysis of a number of global datasets which indicate a strong link between the actual status of soil degradation and population pressure, as well as with inherent biophysical fragility. Local vulnerability is further illustrated with the special case of vulnerabilities of deltas for projected sea level rise. Methodology developments and FAO programmes concerned with combatting land degradation are briefly discussed in an Annex.

1. Introduction

It is perhaps taken for granted, but deserves to be stressed from the beginning, that the main underlying concern for soil vulnerability is the risk of chronic or irreversible loss of economic productive capacity as a consequence of resource degradation, whether or not the land is deemed to be vulnerable. A particular concern for FAO in this respect is that poor rural communities, particularly in countries in development, may be unable to respond adequately to the (population) pressures they face, while often having only limited access to institutional and infrastuctural support, and consequently engage in agricultural production practices that exacerbate the degradation process. This in turn reduces the production potential and generates even more pressure to further deplete natural resource stocks and hence perpetuate the "cycle of poverty". This is illustrated in Figure 1 (FAO/UNDP/UNEP, 1994).

Figure 1

Causal nexus between land, population, poverty and degradation.
Source: FAO, UNDP and UNEP, 1994



2. Definitions of land, vulnerability and vulnerable land

There is an extensive literature on lands variously described as fragile, marginal, vulnerable, problem, and more- or less favoured. Early writers (Dent, 1990) focused on purely biophysical aspects of vulnerability including steep slopes, arid and semi-arid lands with highly variable rainfall patterns, areas that are poorly drained, too cold, or are of low inherent fertility. More recent contributions have recognized that a major development preoccupation is not with the biophysical characteristics of lands as such, but the susceptibility of different types of land to biophysical degradation on a temporary or long term basis, as a consequence of human activity. From an agricultural point of view, "Vulnerability" implies a mismatch between human use and biophysical conditions (Turner and Benjamin, 1994). Appropriately matching the use of land with its capacity, underscores the FAO's approach to land evaluation (FAO, 1976) the first guiding principle of which requires that "land suitability is assessed and classified in relation to particular land uses. Thus a sloping moderately watered hillside, with light-to-medium textured soils could be extremely fragile under one use, but under another, based on better adapted technologies and management practices, could be quite productive even over the long term.

It can not be emphasized enough that fragile land often implies inappropriate technology including unadapted amount, mix and timing of input use as compared to the resource's capacity/capability.

Some definitions of *fragile land* follow:

"*Fragility refers to the sensitivity of land to biophysical deterioration under common agricultural, silvicultural and pastoral systems and management practices*" (Turner and Benjamin, 1994)

"*Fragile lands are ...those that are so sensitive to biophysical degradation that common uses cannot be sustained and the land does not readily recover*" (Turner and Benjamin, 1994)

"*Fragile land is land sensitive to land degradation as a result of inappropriate human intervention*" (TAC, 1996)

Land itself is open to various definitions and is generally interpreted as comprising the soil, the terrain and the land cover. FAO's framework for land Evaluation (FAO, 1976) however provides a more encompassing definition in which land comprises "*The physical environment, including climate, relief, soils, hydrology, and vegetation to the extent that these influence potentials for land use*".

Most other definitions, in particular the ones given before on "fragile lands", leave ambiguity as to the inclusion of climate. (It is highly unlikely that climate can be "degraded" on the spot). Even the FAO definition fails to capture the importance of the specific land location as a determining factor: the accessibility of infrastructure and markets, and the incidence and severity of pests and diseases that have an impact on the land and its use.

Therefore, it may be preferable to reserve the word "land" as a shorthand descriptor of the prevailing range of biophysical attributes of a given location that circumscribe the biophysical potential of that location for specific economic uses. (Wood *et al.*, 1999).

In any particular location biophysical and socio-economic factors interact in ways that can alter the physical production capacity of the land. Hence location rather than land should become the central issue, as we are concerned with the location at which human welfare and its supporting natural resource base may be at risk, regardless that be as a consequence of biophysical or socio-economic factors.

Another consideration in this respect is the fact that land and land use may change in time and therefore the "common practices" or the "inappropriate human interventions" as used in the definitions given above, could well evolve so as to reduce and perhaps negate resource degradation. This mitigation can be brought about by induced innovation (Boserup, 1965 and 1981), formal scientific research and development of "win-win" approaches, market integration, investment and participatory land use planning approaches (FAO, 1998).

Based on these considerations, Wood *et al.* (1999) conclude that the generally accepted concept of land fragility (and in the present context the even narrower concept of soil vulnerability) is only of limited use, if adapted local development policies are to be developed. The same authors prefer therefore the concept of location rather than land wherein:

"The capacity of a location to support a specific economic activity depends on both biophysical factors such as climate, terrain, soil, hydrology, land cover, and fauna, as well as socio-economic factors such as demography, income and technology constraints, physical and institutional infrastructure and market integration. It is recognized that the nature of the activity, as well as human-induced and natural changes in these location-related factors, can bring about positive or negative changes in the location's capacity to support this (or another) activity over time."

3. Human-induced Causes of Location Vulnerability

It is important to underline the three main causes of location vulnerability to natural disasters in general.

The first and foremost may well be the close link between demographic growth rate and poverty, resulting in an accelerated urbanisation process particularly in countries in development: in 2015 the world's population will be urbanized for 54 % against 45 % in 1995 and only 38% in 1975 according to UN's estimates (UN, 1996). This is the more worrying in that the majority of this urban expansion goes on completely without being regulated or planned. Very seldom are inundation or landslide risks taken into account when urban expansion takes place. According to the International Red Cross (1995), 40 out of the 50 cities with greatest expansion rates are *located* in zones with a high seismic risk. Moreover, because the major city-expansion takes place in poorer countries, the new constructions are often of low quality and highly vulnerable. The same source estimates that 20% of the present world population lives in shantytowns.

The second cause of enhanced vulnerability to natural disasters can be directly linked to the unadapted use of the biophysical land resource with consequent disastrous off-site effects. The accelerated deforestation and expansion of the road networks covering soils increasingly with cement rather than with vegetation, has an exponential effect on the inundation risk as both result in less water storage in forests and in soils leading to enhanced run-off. A remarkable measure, worth serious consideration in the developed world, was taken by the Chinese Government after severe floods had hit the country in the summer of 1998, when the Government decided to forbid any further development and deforestation of the watershed of the Yang-Tse (Le Monde, 10-9-1998).

The third cause is the poor or inexistant prevention policy undertaken by most governments. Indeed the World Bank estimates that it is possible to reduce the cost of natural disasters by 280 thousand million dollars a year simply by investing one seventh of that amount in preventive measures, notably adapted seismic and enforcing already existing regulation for urban expansion.

The above analysis would tend to confirm from another angle that “so called natural disasters are perhaps not so natural” (extract from Koffi Anan’s closing speech of the UN decade of disaster prevention, Geneva, 5th of June 1999).

4. Location vulnerability assessment at a global scale

4.1 The link between land degradation, population pressure and physical factors.

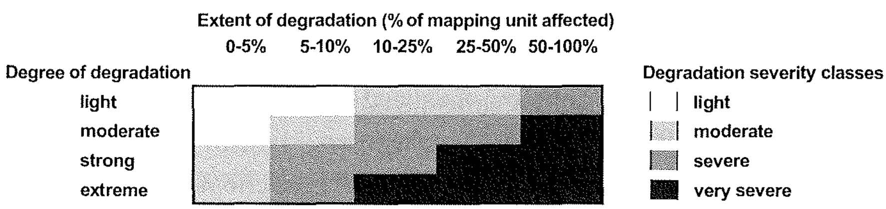
In order to illustrate location vulnerability at a global scale, and its relation with increasing population pressure and biophysical characteristics, a rather unorthodox analysis was attempted using global datasets such as: the soil and terrain resource as given in the digital soil map of the world (FAO, 1995), the status of human induced land degradation assessment (Oldeman *et al.*, 1991) and a global population dataset (Tobler *et al.*, 1995). The results presented here are provisional and are to be published later (Bot, Nachtergaele and Young, 2000).

In the late 1980s, UNEP and ISRIC undertook a global inventory of the status of human-induced land degradation (Oldeman *et al.*, 1990 and 1991). The Global Assessment of Soil Degradation (GLASOD) approach involved a structured recording of severity and nature of land degradation throughout the world. Expert information was integrated into standardized regional topographic base maps that contained only country boundaries, major cities and hydrological features. Results were published in a 1:10 million scale map in which the relative extent (infrequent, common, frequent, very frequent and dominant) and degree (none, light, moderate, strong and extreme) of soil degradation is depicted according to type (water erosion, wind erosion, chemical deterioration (salinization, acidification, pollution) and physical deterioration (sealing, crusting and compaction of the topsoil, sodication, waterlogging and aridification) and cause (agriculture, deforestation, overexploitation of vegetative cover for domestic use, overgrazing, (bio)industry). The map also indicates the location of stable land, which may be those lands where human intervention is minimal due to low population densities, or regions where soil improvement or protection programmes have been succesfully implemented, and "wastelands", which are defined as terrains without appreciable vegetative cover or agricultural potential (Oldeman *et al.*, 1991). The degree of soil degradation is estimated in relation to changes in agricultural suitability, in relation to declined productivity and in some cases in relation to its biotic functions.

In this paper an inventory is made of the soil degradation severity, which is calculated according to a combination of the degree of soil degradation and its spatial occurrence within individual mapping units (% of the area affected). Severity can thus be seen as an indicator of the overall seriousness of degradation. With four categories for the degree, and five categories for the extent, twenty combinations are possible. These combinations have been grouped into four severity classes (light, moderate, severe and very severe). A very severe degraded area can mean that either extreme degradation is occuring in only 10-25% of the map unit, or that moderate degradation affects 50-100% of the map unit.

Figure 2.

Degradation severity classes. *Source: Oldeman et al., 1991.*



Only one part of each mapping unit is actually affected by land degradation. However, it is not known which part of the mapping units is degraded, and which is not. It can be discussed that using severity as an indicator an exaggerated impression of the estimated extent of degradation is provided. On the other hand, taking only into account the estimated actual degraded area (Table 1) an underestimation of the problem area will be the result, because it does not adequately consider the area surrounding the degraded site. As it is not exactly known where the degradation occurs, it will not be possible to use the degree of land degradation as the variable to determine correlations between population densities, erosion risks and land degradation data.

Table 1.

Degree of soil degradation (% of total area)

	None	Light	Moderate	Strong	Extreme
Africa	83	6	6	4	0.2
Asia	82	7	5	3	~0
Australasia	88	11	0.5	0.2	~0
Europe	77	6	15	1	0.3
North America	93	1	5	1	0
South America	86	6	6	1	0
World	85	6	7	2	~0

Source: World Atlas of Desertification. UNEP.1992

Table A1 (Annex I) provides an extract of a country summary for Subsaharan Africa, and area shares in each of GLASOD's four degradation severity classes, along with the dominant cause and type of degradation. Given the expected importance of spatial variation of population density as a factor influencing degradation, it was considered useful to examine the spatial correspondence between that variable and the GLASOD degradation severity index. Table A1 therefore, also contains an estimate of the average population density (Tobler *et al.* 1995) in the areas corresponding to each land degradation severity class. Table 2 provides an overview of the area extent of each of the degradation severity classes and the population density by region for the whole world.

Table 2 and Table A1 suggest a clear relationship between the two variables, which is visualized in Figure 3. In most countries higher population densities are associated with areas adjudged to be more intensely degraded. However, for some countries one may suspect out-migration from, and even abandonment of, degraded lands and, hence, a possible decrease in population densities in the worst affected areas, which seems to be the case in the Far East. In other cases, such as that of the Machakos district in Kenya (Tiffen *et al.* 1994), there are circumstances in which increased population pressure and high levels of degradation have induced actions that lead to successful land rehabilitation.

Table 2.

Land degradation severity and population density by region. (Population density in number of inhabitants per km^2)

	None		Light		Moderate		Severe		Very Severe	
	%	Population density	%	Population density	%	Population density	%	Population density	%	Population density
Sub-Saharan Africa	33	8	24	20	16	29	15	34	12	50
North Africa & Near East	30	2	18	22	17	34	30	15	5	22
South East Asia	1	121	17	31	33	65	37	134	13	163
Far East	29	115	8	100	27	68	28	121	9	90
North Asia, east of Urals	53	4	14	11	12	10	17	19	4	20
Australia & Pacific	41	2	16	3	40	1	3	1	0	NA
South & Central America	23	10	27	13	23	15	22	28	5	58
Europe	10	31	20	75	22	112	37	101	12	86
North America	56	5	15	23	15	25	15	21	0	NA

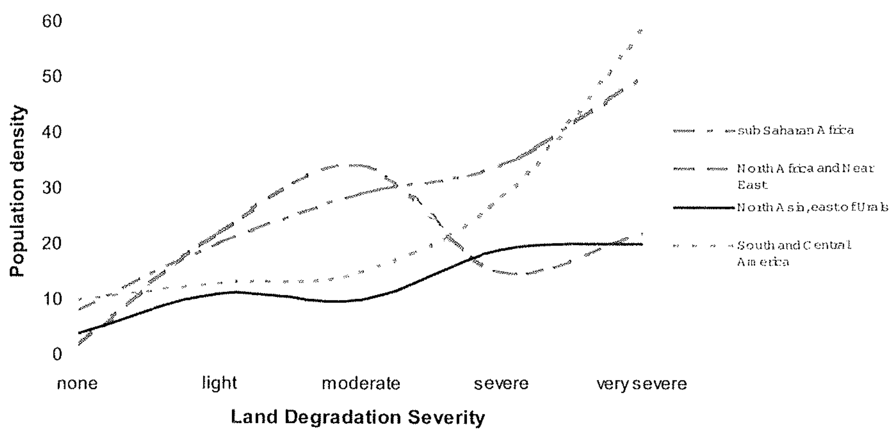
NA = not applicable

A global analysis of land degradation (Bot, Nachtergaele and Young, 2000) does indicate that the severest assessments of degradation are associated with very high population densities in hilly countries (Burundi, Rwanda, Thailand, Vietnam, Haiti, Bosnia Herzegovina), while other cases are associated with higher deforestation rates in the more humid countries such as Togo, Malaysia, Honduras, Costa Rica, Cuba and the small island states in the Caribbean, sometimes associated with higher population density (Togo, Cuba and Costa Rica), and in other cases not (Malaysia and Honduras).

A parallel analysis of the suspected causes of land degradation worldwide indicate that overgrazing appears to be a major cause of severe land degradation in most of the dryland countries such as Libya, Tunisia, Iran, Iraq and Syria, and occurs in areas where too many heads are being grazed or where the unadapted sort of animals are being used. (Bio)industrial activities are the main cause of moderate to severe degradation in some of the European countries, like Belgium, Lithuania, Luxembourg, The Netherlands, Norway and Sweden, leading to forms of pollution such as the accumulation of urban and industrial wastes, the excessive use of pesticides and acidification by airborne pollutants. Such causes are associated with intensive agricultural, industrial and urban land uses. The dominant degradation type is closely associated with prevailing climatic conditions, with water erosion and nutrient depletion dominating in the more humid tropical countries, and wind erosion and physical deterioration prevailing in drier areas.

Figure 3

Population density in relation to land degradation severity



As (annual) cropping is often blamed as the cause of land degradation the information on human-induced land degradation due to agricultural activities has been specifically looked into in the study. Agricultural activities that lead to degradation encompass all aspects of improper agricultural land management. They include a wide variety of mismanagement types which result in various forms of degradation. Among these are the absence of anti-erosion measures, the insufficient or excessive use of fertilizers, the shortening of fallow periods without compensated use of (in)organic fertilizers, the improperly timed use of heavy machinery, and the improper use of irrigation water and poor drainage leading to problems such as salinization. Severely degraded land due to agricultural activities covers an area of almost 12.5 million square kilometres globally, which is 35% of the total severely degraded land. (Severely degraded is defined as those areas with severe and very severe degradation). Table 3 gives an overview per region of the area extent.

Table 3

Human-induced severe and very severe land degradation due to agricultural activities

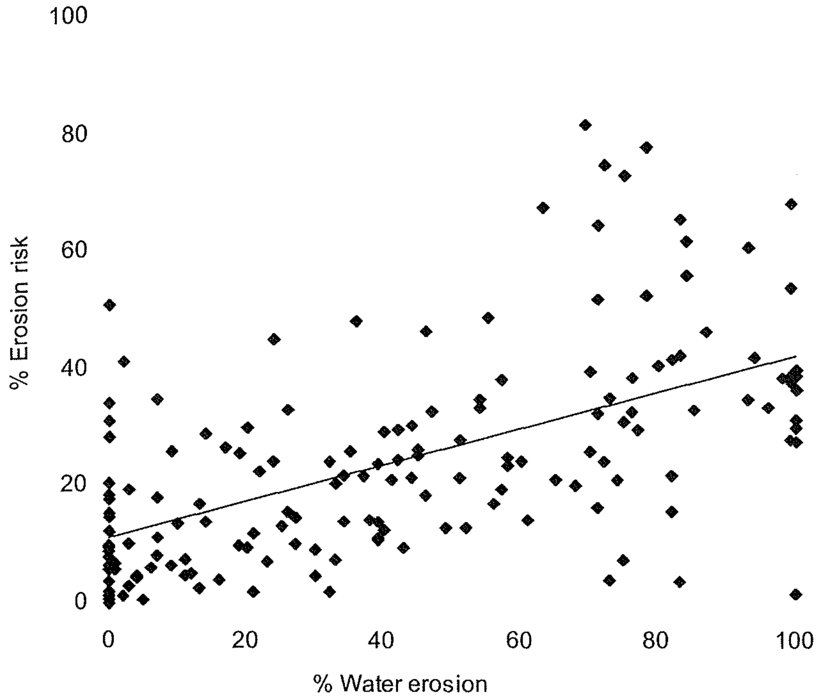
Region	Area extent ('000 km^2)	% of severely degraded land
Sub-Saharan Africa	2046	27
North-Africa/NearEast East	759	27
North Asia, east of Urals	1180	27
Asia and Pacific	3506	42
South / Central America	1795	32
North America	2427	77
Europe	726	23
World	12439	35

It would be feasible to explore further whether the inclusion of other variables such as livestock density (Wint and Rogers 1998; Kruska *et al.* 1995) would provide greater (explanatory) insights into the GLASOD degradation severity classes, although it would be difficult to assume that these were indeed fully independent, given the "expert"way in which the GLASOD data were compiled.

Another approach is to establish whether the susceptibility of a soil to degradation, as assessed by an interpretation of its physical, chemical, and biological properties, is a useful predictor of actual degradation. Figure 3 shows the relationship between national aggregates of the GLASOD ("actual") land degradation severity status when due to water erosion and a determined water erosion risk ("potential") indicator . The latter is based on the percentage of land having very steep slopes (>30%) and land with moderate slope (8-30%) and texturally different top- and sub-soils. Again, there appears to be evidence of a linear relationship between these two factors on a country basis, suggesting, perhaps not remarkably, that soil and terrain indicators merit inclusion as important explanatory variables in predicting likely degradation rates.

Figure 4

FCC (potential) and GLASOD (actual) indicators of land degradation.



Both the above analysis show that when land degradation is defined as a decline in soil quality or reduction in its capacity to support human life in a broader context soil and terrain factors cause degradation, but that population pressure is at least an as important indicator.This re-inforces the need for an holistic, location-specific approach.

There is scope to further investigate the fact that in some cases the percentage of actual degraded land is much higher or much lower than potentially at risk. Generally, the countries with more actual degradation than erosion risk have high population densities in their severely degraded areas and the countries with low degradation have low densities or no severe degradation at all.

While there is clearly some scope for improved prediction of land degradation, there are still many problems in the measurement of actual degradation, be it nutrient depletion (Smaling 1993) or net topsoil loss (Stocking 1986), and even more controversy about interpreting the economic and social impact of that degradation (see, for example, Pimentel *et al.* 1995, and the response by Crosson, 1995 and the estimates of FAO/UNDP/UNEP, 1994). Despite the high political profile attached to actions for mitigating the negative impacts of development on the environment, suprisingly little attention has been paid to the systematic measurement, compilation, and interpretation of data that could better inform national governments and transnational institutions about the appropriate type and scale of potential interventions. Finally a link with economic factors rather than population alone is highly recommended. Initial work using the GLASOD results was undertaken in this respect by Cuffaro (1998).

Specific FAO work related to mapping land degradation and formulating methodologies for assessment and providing remedies are given in Annex II.

4.2 Location and the possible effect of sea level rise

To further illustrate location vulnerability as distinct from soil vulnerability and a function of time and its effect on agriculture, attention is drawn to the work of Gommes *et al* (1998) in which a method was proposed to determine the potential effect of sea level rise on agriculture and estimate it at a global scale.

It is generally accepted that in the worst case scenario, global mean sea-level is expected to rise 95 cm by the year 2100, with large local differences due to tides, wind and atmospheric pressure patterns, changes in ocean circulation, vertical movements of continents etc.; the most likely value is in the range from 38 to 55 cm (Warrick *et al*, 1996). The relative change of sea and land is the main factor: some areas may experience sea level drop in cases where land is rising faster than sea level.

Contrary to a common assertion according to which "it is estimated that 50-70% of the global human population lives in the coastal zone" (IPCC 1996b, p. 294), the population is rather land-bound, as illustrated in Table 4 below. The densities given are approximate in that they are based on an assumed total length of the coastline of 100,000 km and on "large, round" continents. Global population density is about 39 persons/km2. In spite of the gross approximations involved in the last column of Table 4, it is clear that population densities are far higher along the coasts than inland. Small (personal communication) indicates the percentages to be 37% within 100 km, and 66% within 400 km.

Table 4

Distribution of world population as a function of the distance from the nearest coastline. Based on the digital vector map by Tobler *et al.* (1995 and 1997), roughly 1:5 M scale, population standardized to 1994.

Distance from the coast (km)	Population (million)	Accumulated population (million)	Accumulated percentage	Approximate density (persons/sq.km)
Up to 30	1147	1147	20.6	382
>30 to 60	480	1627	29.2	160
>60 to 90	327	1954	35.0	
>90 to 120	251	2205	39.5	
Beyond 120	33395	5567	100	

There are, of course, large local differences. For instance, Sestini (1992; quoted by Zwick 1997), writes that:

"the importance of the Mediterranean seafront in relation to the rest of the country varies; as an example, it is relatively less so in Spain, France and Turkey than in Italy, Greece, Albania, Algeria, Israel. In Greece as much as 90% of the population lives within 50 km of the coast and all major industrial centres are coast-related as well as much of agriculture. In Egypt, the Nile delta north of Cairo represents 2.3% of the area of the country, but contains 46% of its total cultivated surface and 50% of its population; the [altitude] belt 0-3 m harbours about 20 % of the population (with Alexandria 3.5 million, and Port Said 450.000 inhabitants), 40% of industry, 80% of port facilities, 60% of fish production."

It is also well known that most of the current largest urban concentrations are on the seacoasts (Engelman 1997). The population in the world's 15 largest cities is projected to be 223 million in the year 2000. It appears that overall urban population trends are not so obvious. While most coastal megacities do grow in size, their share of the total population often remains stable (1%, from 1950 to 2015, for Calcutta and Shanghai), and sometimes decreases (from 7% to 6% for New York over the same period). Also, the percentage of the urban population living in megacities often decreases (New York: 12% to 7% between 1950 and 2015; Cairo: 35% to 32%; Rio de Janeiro: 14% to 6%; Calcutta: 7% to 4%; Beijing: 6% to 2%; Jakarta: 15% to 10%, etc.), which points to the growth of other urban areas.

Also noteworthy is the fact that many cities suffer land subsidence due to groundwater withdrawal (Nicholls and Leatherman, 1995).

This, of course, may be compounded by sea-level rise, the more so since current rates of subsidence may exceed the rate of sea-level rise between now and 2100.

In order to evaluate the exposure of countries to sea level rise, Gommes *et al* (1998) proposed an Insularity Index defined as the ratio between the length of the coastline (km) and the total land area (km^2) that it encloses:

$$\text{Insularity Index} = \frac{\text{Coastline (km)}}{\text{Land area (km}^2\text{)}}$$

In order to assess the combined effect of insularity and population, a very simple "vulnerability index" (or VI), is defined as the product of the Insularity Index and population density:

Vulnerability Index = Insularity Index **x** population density

Table 5 illustrates the wide variations in both indices and the various protection costs involved.

Table 5

Some typical values of Insularity Index, Vulnerability Index (VI) and protection costs. Data from Factbook (1997), UN 1996a UN 1997, median population scenario, as well as CZMS (1990) for the protection costs.

Country	Insularity Index	Vulnerability Index	Protection cost (% GDP)
Libya	0.0010	0.0030	0.08
Zaire	0.000016	0.031	0.12
United States	0.0022	0.063	0.02
Sweden	0.0078	0.17	0.14
Nicaragua	0.0076	0.24	0.35
Belgium	0.0021	0.70	0.01
Italy	0.026	4.9	0.04
Netherlands	0.013	5.0	0.03
Greece	0.10	8.3	0.10
United Kingdom	0.051	12	0.02
Jamaica	0.028	21	0.19
Mauritius	0.096	52	0.15
Anguilla	0.67	77	10
Gaza strip	0.11	230	NA
Singapore	0.31	1700	0.05
Tokelau	10.1	1500	11
Maldives	2.1	1800	34
Monaco	2.2	36000	0.13

Small islands and low-lying coastal areas have received much attention in the literature, including the IPCC assessments in the recent years. Deltas fall into the same category of areas very vulnerable to sea level rise. But unlike deltas and other coastal areas, small islands have no hinterland to move to in the case of loss of land. In addition, their land resources are very limited.

According to Nicholls and Leatherman (1995), a 1m SLR would affect 6 million people in Egypt, with 12% to 15% of agricultural land lost, 13 million in Bangladesh, with 16% of national rice production lost, and 72 million in China and "tens of thousands" of hectares of agricultural land.

More than direct land loss due to seas rising, indirect factors are generally listed as the main difficulties associated with SLR. These include erosion patterns and damage to coastal infrastructure, salinization of wells, sub-optimal functioning of the sewerage systems of coastal cities with resulting health impacts (WHO 1996, chapter 7), loss of littoral ecosystems and loss of biotic resources.

Deltas pose a set of more specific problems, as they are the areas where sea and land most closely interact: their average elevation is usually very low, to the extent that tidal effects can be felt for several tens of km, and in some cases hundreds, inland. Note that the deltas in closed seas, such as the Nile and Danube, do not normally suffer the same difficulties. This land/sea interaction results in very complex agricultural systems, where irrigation and rain-fed agriculture may be practised in alternate seasons, with attention to irrigation water quality (salinity) and to the washing out of salts by rains before planting crops.

The Mekong delta provides a clear example of this complexity (see, for example, Jelgersma *et al.*, 1993). Siltation is usually very active during certain seasons of the year: deposition in the Mekong Delta continues to extend the Ca Mau peninsula to the south and west at a rate of 150 m/year in some places (Fedra *et al.*, 1991). The delta, therefore, is as much the result of conditions upstream as the result of local or coastal interactions. Sea-level rise, therefore, cannot be examined without some sound assumptions about climate and rainfall changes in the river catchment as a whole.

Contrary to many other "normal" coasts, deltas are difficult and expensive to protect, due to the very dissected nature of the coastline. A measure of the difficulty is provided by the "multiplier" used by CZMS (1990) to evaluate protection costs. Multipliers for deltas usually vary from 6 to 8, but may reach higher values for the Magdalena (10.4, Venezuela), Orinoco (11.3), Parana (26.7), Mekong (9.8) or Ganges-Brahmaputra-Mahanadi (7.5).

CZMS (1990) stresses that the multiplier may be affected by large errors (100%), but the parameter gives at least a crude measure of the level of intricacy of the coastline in deltas.

Although deltas tend to be densely populated, it is not really relevant to assess exactly how many people live in them [6]. Due to their very high productivity (generally fertile soils, water availability, multiple cropping, especially in tropical areas) they produce significantly more food than the local consumption. In Vietnam, for instance, 50% of national rice production comes from the Mekong delta in the south, while 20% is produced in the Red River delta near Hanoi. Although much of this production is for export, a disaster in the deltas would have profound effects on the whole country. This indicates a fragile situation in which any major disturbance would result in economic and possibly political shock waves well beyond the delta proper.

In coastal areas, and particularly deltas, we thus have to take into account: projected SLR, modified ocean circulation patterns as they affect the building and erosion of the coast, climate change in the catchment basin and change of the coastal climate, and changes in the frequency of extreme events. In addition the erosion rates and risks in the uplands are also a factor. This also constitutes a major difference with small islands where remote land-based changes are likely to be of less importance.

It is therefore concluded that changes in deltas and small islands could have repercussions over large areas. Given the populations potentially involved, this is more likely to seriously affect the major deltas, such as the Ganges-Brahmaputra, Mekong and Nile. In both the cases of deltas and small islands, a likely scenario could be outmigration when disasters due to SLR reach levels or frequencies considered unacceptable. It is at such thresholds that maximum damage and loss of life could be expected.

5. Conclusions and Recommendations

• The notion of soil vulnerability is of little use for practical policy- and development planning. It is therefore recommended to broaden the scope of the definition to "location vulnerability" assessment, which would take into account the biophysical factors as well as the socio-economic ones including the anticipated changes.

• Location vulnerability cannot be expressed in absolute terms as it is often the result of a mismatch between the potentials/capabilities of the location and the (mis)use that is made of it by humans. It is recommended therefore to use a holistic, participatory and multidisciplinary approach in planning the future use of lands.

• The analysis of global datasets on land degradation status do indicate a statistically significant correlation with socio-economic as well as with biophysical factors. It is recommended that these datasets are refined and a systematic effort is undertaken to improve on them, particular those data concerned with land use.

• Potential sea level rise due to climatic change has been predicted to have particularly a strong impact on small islands but even more so on delta areas. It is recommended to carry out feasibility studies on protective measures in the major delta areas.

Acknowledgement

Many of the ideas developed in this article were arrived at in collaboration with others during the last two years, and published in various forms elsewhere. I gratefully acknowledge the contribution of Stanley Wood (IFPRI), Alexandra Bot, Jacques du Guerny and Rene Gommes (FAO) whose ideas are, I hope faithfully, reflected. The input of my colleagues in AGL involved with land degradation and soil conservation, are gratefully acknowledged. Last but not least, the efforts of other international organizations such as UNEP and ISRIC in this respect deserve to be acknowledged and to receive continued support.

Bibliography

BOSERUP E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure.* London: Allen and Unwin.

BOSERUP E. (1981). *Population and technological change: A study of long-term trends.* Chicago, Il: The University of Chicago Press.

BOT A.J., F.O. NACHTERGAELE, A.YOUNG (2000). Physical resource potentials and constraints at regional and country level. *FAO World Soil Resources Report* (in preparation).

CROSSON P. (1995). Soil erosion estimates and costs. *Science* 269: 461- 463.

CUFFARO N. (1997). Population Growth and Agriculture in Poor Countries. Areview of theoretical issues and empirical evidence. *World Development* Vol 25 no 7 pp 1151-1163

CZMS (Coastal Zones Management System) (1990). Strategies for adaption to sea level rise. Published for IPCC, Geneva by Ministry of Transport, Public works and Water Management, The Hague, The Netherlands. 122 pp.

DENT F.J. (1990). Problem soils of asia and the Pacific. Report on the expert consultation of the Asian Network on problem soils. Bangkok. August-September 1989. RAPA, Bangkok.

FEDRA K., L. WINKELBAUER, V.R. PANTALU (1991). Expert system for environmental screening. An application for the lower Mekong basin. IIASA Report RR 91 – 19, Laxenburg, Austria. 169 pp.

FAO (1976). A framework for land evaluation. *FAO Soils Bulletin* No 32 . Rome.

FAO (1995). The digital soil map of the world and derived soil properties (Version 3.5). FAO Land and Water Digital Media Series #1. CD-ROM, FAO Rome.

FAO (1996). Land husbandry – components and strategy. *FAO Soils Bulletin* No 70. Rome.

FAO, UNDP and UNEP (1994). Land degradation in South Asia: its severity, causes and effects upon the people. *World Soil Resources Reports* No. 78. 100 pp. FAO, Rome.

GOMMES R., J. du GUERNY, F.O. NACHTERGAELE, R. BRINKMAN (1998). Potential impact of sea-level rise on population and agriculture. HYPERLINK http://www.fao.org/ http://www.fao.org/

IPCC (1996). Climate Change 1995, the science of climate change. Contribution of Working Group I to the second assessment report of the Intergovernmental Panel of Climatic Change. Edited by J.T. Houghton, L.G. Meira Filho, B. Callander, N.Harris, A. Kattenberg and K. Maskell. xii + 572 pp.

JELGERSMA S., M. VANDERZIJP, R. BRINKMAN (1993). Sealevel rise and the coastal lowlands in the developing world. *J. Coastal Res.* 9 (4): 958-972.

KRUSKA R.L., B.D. PERRY, R.S. REID (1995). Recent Progress in the development of decision support systems for improved animal health. In *Proceedings of the Africa GIS '95 Meeting: Integrated GIS Useful for Sustainable Management of Natural Resources in Africa.* Abidjan.

NICHOLLS R.J., S.P. LEATHERMAN (1995). Global Sea Level rise p 92 –123 in: Strepek and Smith (1995).

OLDEMAN L.R., R.T.A. HAKKELING, W.G. SOMBROEK (1990). World Map of the status of human-induced land degradation. An Explanatory note. Global Assessment of soil degradation (GLASOD), UNEP, Nairobi, Kenya.

OLDEMAN L.R., R.T.A. HAKKELING, W.G. SOMBROEK (1991). World map of the status of human-induced soil degradation. UNEP, Nairobi.

PIMENTEL D. *et al.* (1976). Environmental and economic costs of soil erosion and conservation benefits. *Science* 194 (149).

SMALING E. (1993). An Agro-ecological framework for integrated nutrient management with special reference to Kenya. PhD Thesis, Wageningen university. the Netherlands.

STOCKING M. (1986). *The cost of soil erosion in Zimbabwe in terms of loss of three major nutrients.* FAO, Rome.

TAC (Technical Advisory Committee) Secretariat and FAO 1996: Report on the study of CGIAR research priorities for marginal land: Agenda Item 3. Report presented at the Seventy-First Meeting of the International Livestock Research Institute. Addis Abeba, Ethiopia.

TOBLER W. *et al.* (1995). The global demographic project. Technical Report No TR 95-6 Santa Barbara University of California. Santa Barbara, USA.

TURNER H.B.L., P.A. BENJAMIN (1994). Fragile lands: Identification and use for agriculture. Chapter 5 in: *Agricultural Environment and health: Sustainable development in the 21st century.* ed. V. Ruttan, 104-45. Minnesota of University. Minnesota Press.

WARRICK R.A., C. LE PROVOST, M.F. MEIER, J. OERLEMANS, P.J. WOODWORTH (1996). Changes in Sea Level. Chapter 7, p. 362-405 in IPCC 1996.

WHO (1996). *Climatic change and human health.* Edited by A.J. Mc Michael, a. Haines R. slooff and S. Kovats. WHO, Geneva. 296 pp.

WINT W., D. ROGERS (1998). Predictions of cattle density. Cultivation Levels and Fgarming Systems in Kenya. AGA Consultants report. FAO, Rome.

WOOD S., SEBASTIAN K., NACHTERGAELE F.O., NIELSEN D., DAI A. (1999). Spatial aspects of the design and targeting of agricultural development strategies. Environment and Production Technology Division Discussion Paper # 44.IFPRI, Washington, D.C.

Table A1 Land degradation: severity of humun-induced degradation for Sub-Saharan Africa.

	Total area	None		Light		Moderate		Severe		Very severe		Cause	Type
	km²	km²	%	km²	%	km²	%	km²	%	km²	%		
Angola	1243	759.0	61	193.0	16	121.0	10	65.0	5	105.0	8	D	W
Benin	112	0.0	NA	61.0	54	28.0	25	11.0	10	12.0	11	D	W
Botswana	599	183.0	31	267.0	44	80.0	13	25.0	4	44.0	7	O	N
Burkina Faso	274	0.0	0	59.0	21	59.0	21	36.0	3	120.0	44	O,D,A	W
Burundi	28	2.0	7	0.0	0	5.0	17	0.0	0	21.0	76	A	W
Cameroon	475	188.0	40	25.0	5	85.0	18	68.0	14	109.0	23	A,O,D	W
Central af	622	273.0	44	321.0	51	17.0	3	2.0	4	9.0	2	D	W
Chad	1282	510.0	40	381.0	30	85.0	7	289.0	23	17.0	1	O	N,W,P
Congo D.R.	2337	767.0	33	1210.0	52	185.0	8	152.0	7	23.0	1	D	W,C
Congo Republic	342	268.0	78	42.0	12	24.0	7	2.0	1	6.0	2	D	C
Djibouti	23	0.0	0	0.0	0	23.0	100	0.0	0	0.0	0	O	N
Equatorial Guinea	28	22.0	79	6.0	21	0.0	0	0.0	0	0.0	0	D	C
Eritrea	93.5	13.1	14	0.0	0	21.2	22.7	51.6	55	7.6	8	O	W,N
Ethiopia	1104	53.0	4	125.0	10	700.0	57	97.0	8	244.0	20	O	W
Gabon	267	217.0	81	8.0	3	24.0	9	18.0	7	0.0	0	D	C
The Gambia	11	0.0	0	6.0	53	5.0	47	0.0	0	0.0	0	D	W
Ghana	238	14.0	6	60.0	25	142.0	60	7.0	3	15.0	6	D	W
Guinea	255	0.0	0	200.0	78	45.0	18	10.0	4	0.0	0	D	W
Guinea Bissau	36	0.0	0	9.0	24	27.0	76	0.0	0	0.0	0	D,A	W,C
Ivory Coast	322	9.0	3	255.0	79	46.0	14	0.0	0	12.0	4	D	W,C
Kenya	580	38.0	7	237.0	41	128.0	22	111.0	19	66.0	11	O	W
Lesotho	31	0.0	0	0.0	0	0.0	0	23.0	75	8.0	25	O	W
Liberia	111	44.0	40	55.0	49	0.0	0	12.0	11	0.0	0	D	C
Madagascar	593	0.0	0	27.0	5	147.0	25	286.0	48	133.0	22	A	W
Malawi	95	37.0	39	3.0	3	55.0	58	0.0	0	0.0	0	A	W
Mali	1235	567.0	46	218.0	18	84.0	7	165.0	13	201.0	16	O	W,N
Mauritania	1030	764.0	74	0.0	0	0.0	0	182.0	18	84.0	8	O	N
Mozambique	784	244.0	31	228.0	29	312.0	39	0.0	0	0.0	0	A,D	W
Namibia	823	467.0	57	97.0	12	70.0	9	174.0	21	15.0	2	O	W
Niger	1184	642.0	54	9.0	1	0.0	0	330.0	28	203.0	17	O	N
Nigeria	921	27.0	3	349.0	38	39.0	4	248.0	27	258.0	28	D,O	W
Rwanda	26	0.0	0	0.0	0	7.0	28	0.0	0	19.0	71	A,D	W
Senegal	196	0.0	0	77.0	39	50.0	25	27.0	14	42.0	22	D,O,A	W,C
Sierra	73	0.0	0	35.0	48	10.0	14	28.0	39	0.0	0	D	W,C
Somalia	628	145.5	23	60.5	9.6	328.9	52	0.0	0	93.2	15	O,A	W
Southafrica	1181	263.0	22	98.0	8	60.0	5	219.0	19	541.0	46	O	W,N
Sudan	2501	1163.0	46	326.0	13	263.0	11	366.0	15	383.0	15	O	W,N
Swaziland	17	0.0	0	0.0	0	17.0	100	0.0	0	0.0	0	A	W
Tanzania	937	114.0	12	289.0	31	295.0	31	228.0	24	11.0	1	A,O	W
Togo	57	0.0	0	14.0	24	12.0	22	17.0	30	14.0	24	D,A	W
Uganda	235	9.0	4	2.0	1	101.0	43	96.0	41	27.0	12	O,D,A	W
Zambia	752	135.0	18	157.0	21	334.0	44	126.0	17	0.0	0	D	W
Zimbabwe	390	34.0	9	205.0	53	151.0	39	0.0	0	0.0	0	A,O	W
Total	24,072	7813.0	33	5654.0	24	3836.0	16	3420.0	15	2742.0	12		

NA: not applicable A: agriculture O: overgrazing D: deforestation W: water erosion N: wind erosion C: chemical deterioration P: physical deterioration

Annex 2

Methodology development and FAO Programmes in Land Degradation Mapping and Assessment

In 1979 FAO developed a provisional methodology for assessment and mapping of land degradation. FAO also developed in 1984 a provisional methodology for assessment and mapping of desertification. The degradation methodology was included in the agro-ecological zones approach and used to estimate the population supporting capacity of the land (FAO, 1984). Although not directly associated with the preparation of the Global assessment of human induced degradation (UNEP/ISRIC, 1991), FAO supported the more detailed follow-up study of Soil Degradation in Asia (ASSOD, Lynden, 1997) carried out by national institutes in the region (UNEP/ISRIC/FAO, 1997). At the same time guidelines for erosion mapping at more detailed scales were developed (FAO/UNEP, 1998) and applied in Mediterranean countries.

Together with ISRIC, and with Dutch Government funding, FAO also undertook a study of soil vulnerability in Eastern Europe (SOVEUR) under which a geographic database will be established for 13 countries in the region at an equivalent scale of 1:2.5 Million. The activities of this project and the methodological aspects in determining the vulnerability of soils to selected categories of polluants will be treated in a separate paper in the present International Conference (Batjes, 1999). FAO is also actively involved in a project dealing with the rehabilitation of polluted soils in Romania and recently organized an International Workshop on the rehabilitation and management of polluted soils in which it was decided to explore the possibility of establishing a network on "Protection of soil quality in East and Central Europe" gathering initially six countries (Rumania, Poland, Bulgaria, Czech Republic, Slovak Republic and Lithuania).

Apart from the numerous publications on soil conservation and management (FAO, 1996) FAO strongly supports the World Overview of Conservation Approaches and Technologies (WOCAT) and published the initial results of this initiative on CD-ROM (FAO, 1998).

As far as mapping and assessment of land degradation is concerned, this resulted in a manual that successfully links three basic cartographic approaches: The Soil and Terrain database (SOTER, UNEP/ISRIC/ FAO/ISSS, 1993); the ASSOD and SOVEUR results in terms of types and causes of land degradation; and the WOCAT methodology, providing the possible remedies. The final draft of this manual is now ready (FAO/ISRIC, 1999) and will continue to be tested first in southern Africa, then elsewhere.

Soil Degradation Status and Vulnerability Mapping in Central and Eastern Europe: the SOVEUR Project

Niels H. Batjes

International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands

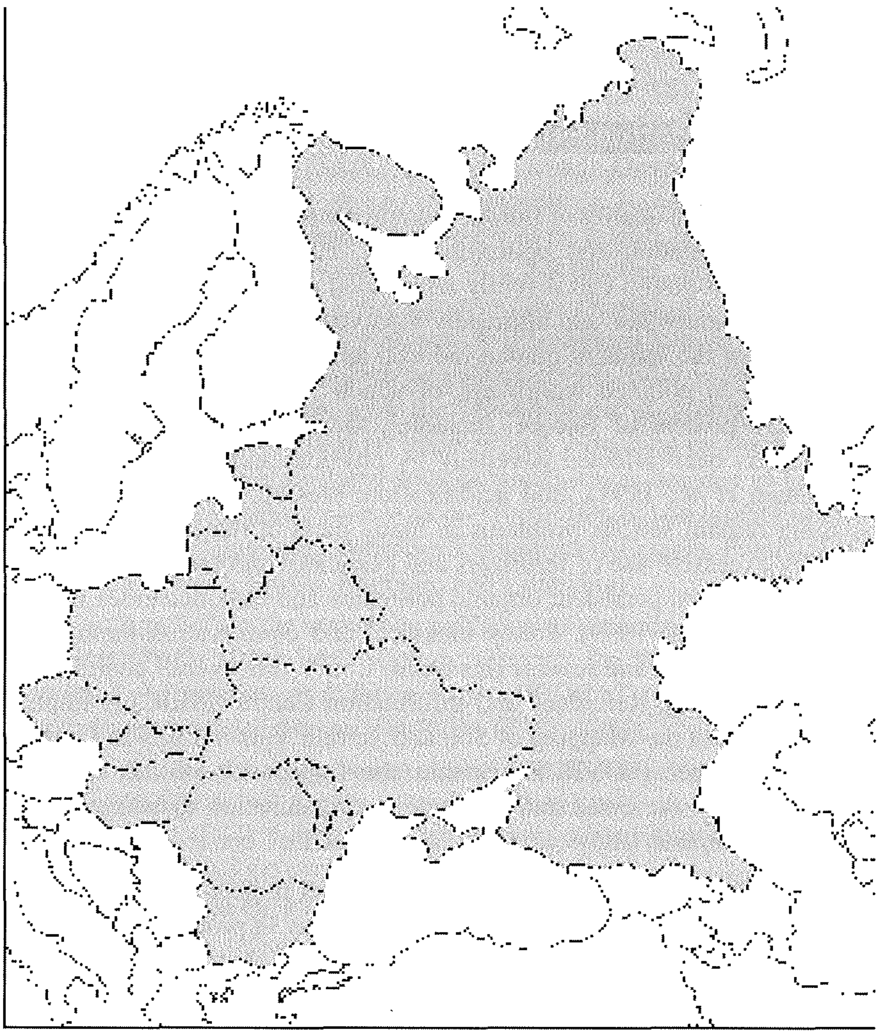
1. Introduction

The quality of Europe's environment has deteriorated as a result of land degradation and pollution (EEA, 1999; Stanners and Bourdeau, 1995). Soil pollution can severely affect food production, the quality of surface and groundwater, and ultimately biodiversity and human health. An earlier study of the status of human-induced land degradation showed 22 x 10^6 ha have been polluted worldwide, of which 19 x 10^6 ha occur in Europe. About 30 percent of Europe, including the European part of the former USSR, has been affected adversely by physical and chemical degradation (Oldeman *et al.*, 1991). Soil acidification, erosion, salinisation and waterlogging remain serious problems in many parts of the region. Pollution of land by excessive use of fertilizers and pesticides and by contaminants such as heavy metals, persistent organic pollutants and radionulceides is also widespread (UNEP, 1999). Policy measures and conservation methodologies are needed to halt and reverse this trend. It is in this overall context that the International Soil Reference and Information Centre (ISRIC) is implementing the project on 'Mapping of Soil and Terrain Vulnerability in Central and Eastern Europe' (SOVEUR), within the framework of the Cooperative Programme of the Food and Agriculture Organization (FAO) and Netherlands Government (Project GCP/RER/007/NET).

The ultimate aims of the SOVEUR project are to strengthen regional awareness of the significant role soils play in protecting food and water supplies, and to demonstrate the need for environmental protection (Batjes and Bridges, 1997). This has been achieved by: (1) developing a soil and terrain digital database, (2) mapping the current status of soil degradation, and (3) preparing maps showing the vulnerability of soils to selected categories of pollutants at a scale of 1:2,500,000. The SOVEUR project area encompasses 13 countries in Central and Eastern Europe, including Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, Russian Federation (west of the Urals), Slovakia, and the Ukraine, and covers about 18.98 x 10^6 km^2 (Fig. 1).

Figure 1

Location of SOVEUR project area in Central and Eastern Europe



Following a brief discussion of SOVEUR project implementation, the methodologies used for the various project activities are presented. Subsequently, general observations are made about the preliminary results, pending their definitive evaluation during the concluding regional workshop, the anticipated distribution of the final project outputs, and scope for follow-up studies at more detailed scales.

2. SOVEUR project implementation

2.1. Background

From the mid eighties ISRIC has been involved in various projects related to soil degradation, contamination and soil pollution. Essentially, the work started with the development of a 1:10 million scale, expert-judgement based map of the Global Status of Human-Induced Soil Degradation (GLASOD, see Oldeman *et al.*, 1991). This was followed by a more detailed study, at the scale of 1:5 million, of the status of soil degradation for South East Asia (Van Lynden and Oldeman, 1997), and by a review of the current situation in Western Europe concerning human-induced soil degradation and soil protection (Van Lynden, 1995). Model-based studies, focussing on the impact of water erosion on food production, were prepared within the framework of UNEP's Pilot Global Environment Outlook Project (Batjes, 1996; Mantel and Van Engelen, 1999; Mantel *et al.*, 1996). Other studies have developed scenarios for the possible increase in organic carbon sequestered in the soil, upon introduction of improved management practices on the agricultural lands and reclamation of the GLASOD-degraded lands (Batjes, 1999a). Further ISRIC participates in the World Overview of Conservation Approaches and Technologies, which aims to make an overview of activities undertaken to reduce soil degradation in the world (WOCAT, 1998).

In 1991, ISRIC organized an international workshop for the Chemical Time Bombs project to assess the feasibility and desirability of implementing a project on 'soil vulnerability mapping in Europe' (Batjes and Bridges, 1991). The presently discussed SOVEUR project is a sequel to this initial workshop, and related work on updating the information on world soil resources, and their degradation status, in a digital soil and terrain database (Batjes *et al.*, 1993; Oldeman *et al.*, 1991; Van Lynden and Oldeman, 1997). Actual SOVEUR project implementation by ISRIC started in early 1997, upon signing of a Contractual Services Agreement with FAO.

2.2.Project implementation

Methodologies for the three project activities enumerated in the introduction were prepared for discussion during an international workshop, attended by representatives from ESB, FAO, INRA, ISRIC, and the 13 participating countries (Batjes and Bridges, 1997). Following the plenary sessions where each country presented a synopsis of its information, discussion groups explored the main issues of soil degradation and pollution of regional concern which were mappable at the scale of 1:2.5 million. The availability, accessibility and comparability of the primary and secondary data required were explored with a view to assess the possibility of model development and the preparation of soil vulnerability maps. On reaching a consensus upon methodological issues, work plans for the implementation phase were developed and agreed upon with the national collaborators. Participants realised that, in order to achieve the project goals successfully, full collaboration of all parties concerned with respect to the sharing of data and information would be essential. Nonetheless some data proved to be unavailable, or unaccessible, within the constraints of time and finances of the SOVEUR project. Other materials were made available in a range of 'alternative' formats, often necessitating time-consuming data harmonization efforts prior to their inclusion in the common database for Central and Eastern Europe. Issues of data acquisition, quality control, data sharing, and model uncertainty of relevance to SOVEUR project implementation have been discussed elsewhere (Batjes, 1999c).

3. Methodological aspects

3.1. Development of a soil and terrain database

The first stage in the SOVEUR project encompassed the development of a digital soil and terrain database using the internationally endorsed SOTER approach (Van Engelen and Wen, 1995). This methodology uses physiography as the main entry for subdividing terrain units, the basic map units, into terrain components and soil components. Land areas showing a distinctive, and often repetitive, pattern of landform, parent material, surface form, slope and soils are mapped as SOTER units. These are identified by unique labels on the map. In the database, each SOTER unit is characterized further by its geometric data (i.e., location and topology) and attribute data (e.g., soil characteristics).

The soil and terrain attribute data are stored in 5 digital files (Fig. 2):

(1) The *terrain unit* table lists the main, unique, features of a SOTER unit.

(2) The *terrain component* table specifies the attribute data by terrain component (with a maximum of 3), as well as its relative extent in the corresponding terrain unit.

(3) The *soil component* table specifies the relative area of the individual soil components (with a recommended maximum of 6) within a SOTER unit as well as its overall position within a terrain component. Each soil component is characterized by one soil profile, which is considered to be representative for the area under consideration.

(4) The *profile* table lists selected, common attributes for the representative profile(s).

(5) The *horizon* table holds morphological, chemical and physical data by individual horizon, within a given soil profile.

Figure 2

SOTER units (SU) as shown on the geometric database (map) and as characterized in the attribute database (Source: Batjes and Van Engelen, 1997)

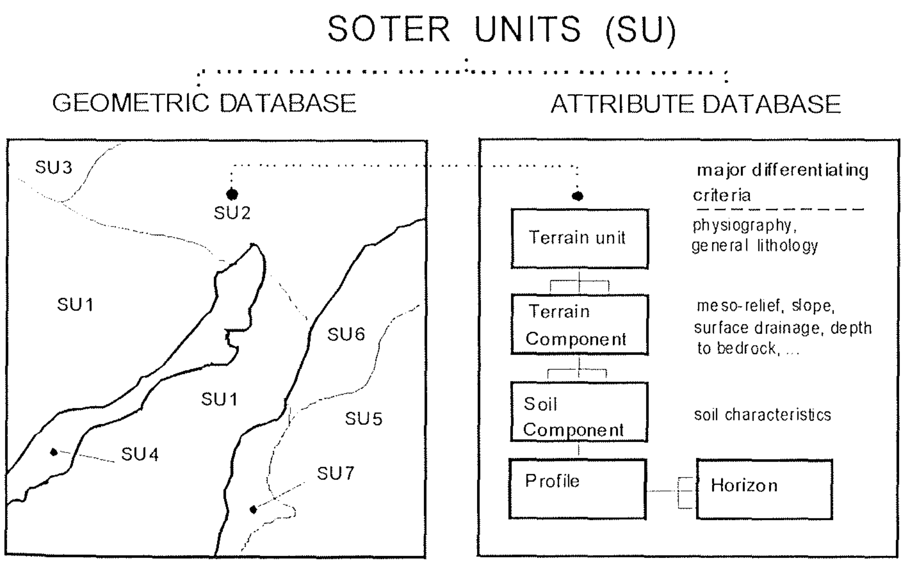


Table 1 lists he attributes that can be accommodated in each SOTER file. Besides the above described set of 5 files, there are 4 additional files for characterization of various source materials. These include the name of the source map (i.e., *map_ID*), and the name of the national laboratory (i.e., *lab_ID*) where the soil samples were analysed. The unique laboratory number, in turn provides the logical link to the type of analytical methods used, and to a brief description of each uniquely coded analytical method (see Batjes and Van Engelen, 1997).

Table 1.

Non-spatial attributes of a SOTER unit (as used for the 1:2,500,000 scale SOVEUR Project)

TERRAIN UNIT		TERRAIN COMPONENT		SOIL COMPONENT	
1 *SOTER unit_ID*	[1]	8 *SOTER unit_ID*	[14]	19 *SOTER unit_ID*	[33]
2 year of data collection	[2]	9 *terrain component number*	[15]	20 *terrain component number*	[34]
3 *map_ID*	[3]	10 prop. of TC in SOTER unit	[16]	21 *soil component number*	[35]
4 major landform	[8]	11 dominant slope	[9]	22 prop. of SC in SOTER unit	[36]
5 regional slope	[9]	12 local surface form	[22]	23 *profile_ID*	[37]
6 hypsometry	[10]	13 depth to bedrock	[27]	24 position in terrain component	[39]
7 general lithology	[12]	14 parent material	[25]	25 surface rockiness	[40]
		15 surface drainage	[28]	26 surface stoniness	[41]
		16 depth to groundwater	[29]	27 rootable depth	[46]
		17 frequency of flooding	[30]		
		18 duration of flooding	[31]		
PROFILE		**HORIZON**		***Horizon** (continued)*	
28 *profile_ID*	[48]	40 *profile_ID*	[63]	57 electrical conductivity	[92]
29 *profile database_ID*	[49]	41 *horizon number*	[64]	58 exch. Ca^{2+}	[93]
30 latitude	[50]	42 upper depth	[--]	59 exch. Mg^{2+}	[94]
31 longitude	[51]	43 lower depth	[68]	60 exch. Na^{+}	[95]
32 elevation	[52]	44 diagnostic horizon	[65]	61 exch. K^{+}	[96]
33 sampling date	[53]	45 diagnostic property	[66]	62 exch Al^{3+}	[97]
34 *lab_ID*	[54]	46 horizon designation	[67]	63 exch. acidity ($H^{+}+Al^{3+}$)	[98]
35 drainage	[55]	47 moist colour	[70]	64 CEC soil	[99]
36 infiltration rate	[56]	48 dry colour	[71]	65 total org. carbon	[102]
37 FAO classification (1988)	[58]	49 type of structure	[74]	66 total nitrogen	[103]
38 FAO phase (1988)	[62]	50 abundance of coarse fragments	[75]	67 total carbonate equiv.	[100]
39 national classification	[60]	51 total sand	[82]	68 gypsum content	[101]
		52 silt	[83]	69 bulk density	[86]
		53 clay	[84]	70 soil water held at pF1.7	[87]
		54 particle size class (USDA)	[85]	71 soil water held at pF2.0	[87]
		55 pH H_2O	[90]	72 soil water held at pF2.5	[87]
		56 pH KCl	[91]	73 soil water held at pF3.7	[87]
				74 soil water held at pF4.2	[87]

Note: Numbers to the left refer to those as used for the SOVEUR project (see Batjes and Van Engelen, 1997), while those in brackets (e.g., [12]), refer to the original item number in the SOTER Procedures Manual (Van Engelen and Wen, 1995). *Primary keys* shown are in italics.

3.2. Mapping of soil degradation status

The spatial SOTER database — with its unique 'delineations' consisting of uniform areas in terms of landform, surficial lithology and soil units — , has been used as a geographic basis for an expert-based assessment of the status of soil degradation, with special focus on pollution. In a general sense, soil degradation can be described as the deterioration of soil quality, or 'the partial or entire loss of one or more functions of the soil' (Blum, 1988). The qualitative approach, developed for the SOVEUR project (Van Lynden, 1997), is largely derived from the original GLASOD methodology (Oldeman *et al.*, 1991).

The methodology makes a distinction between soil degradation status, rate and risk. The status reflects the current degree and extent of a particular type of soil degradation, while the rate indicates the relative decrease or increase (trend) of degradation over the last 5 to 10 years (in so far as leading to the present status of degradation). The rate of degradation, as indicated on the status map, gives an indication of the danger of further deterioration. However, it does not consider areas that are appear to be stable at present, yet may be at risk from degradation in the future upon a change in land use, for example.

Table 2 serves to illustrate the type of information can be shown on the map of soil degradation status. The types of degradation considered on the map, annex database, include: soil pollution, for example by heavy metals, pesticides and other contaminants; water erosion; wind erosion; chemical deterioration (other than by pollution); physical deterioration, such as caused by compaction, sealing and crusting, or subsidence of organic soils. Finally, there is a category of land that appears to be 'stable' or without 'apparent degradation'. In each case, the relative extent of each type of degradation within a map unit is given, together with information on the inferred degree of the soil degradation process, and inferred impact of this process on the various soil functions. Main causative factors of soil degradation are also indicated, using broad categories commensurate with the 1:2,500,000 scale of mapping adopted for the SOVEUR project. When appropriate, local sources of soil pollution have been shown as point sources using their geographical coordinates. Full details on the methodology, including the differentiating criteria, may be found in Van Lynden (1997).

Table 2.

Matrix table showing the type of information shown on the soil degradation status map for the SOVEUR area

Poly-ID	Degradation type		*Pollution only: specific substance*	Extent	Degree	Impact	Cause	Rate	Remarks
378-XX	1	Wt		30%	2	B3	a	1	Some improvement due to conservation measures
	2	Cpp	PCB	25%	1	I2	a	-2	Effects on ground- and surface water
	3	Wt/Cpp		15%					NB: Enhanced downstream effect of Cpp due to erosion
	4	Sn		30%					
379-XX	1	Cpa	NO_X, SO_2	40%	3	E2	i	-2	Mainly atmospheric deposition
	2	Pc		30%	M	A3	a	-1	Frequent use of heavy machinery
	3	Wo		30%	L	A2	i,f	-2	Construction activities
380-XX	1	Wt		40%	M	A3	a	1	Conservation measures having positive effect
	2	Cn		30%	M	B2	a	-1	
	3	Wt/Cn		20%	E	B3	a	-1	Degree and Impact higher than for individual types!
	4	Cph	Cd, Pb	*l*	4	H2,P3	i	-2	local : 50° 30' 20" N, 20° 00' 15' 'E
	5	Sh		10%					Successful conservation and rehabilitation measures

Notes: For each polygon (Poly-ID) shown on the map, the data base specifies the types of degradation that occur together with aggregated information on their relative extent, degree, impact, cause and rate (see Van Lynden, 1997). Abbreviations used in the table are: Cp: soil pollution; Cpp: by pesticides and other contaminants; Cpa: via soil acidification; Cph: by heavy metals. Cn: chemical deterioration, fertility decline and reduced organic matter content. W: water erosion; Wt: loss of topsoil by sheet/surface wash; Wo: off-site effects of water erosion in upstream areas. P: Physical deterioration; Pc: compaction. S: stable land without apparent degradation; Sh: stable under human influence. W: Wasteland. The letter *l*, under extent, refers to marked local points of soil pollution as identified by their geographic coordinates.

3.3. Soil vulnerability mapping

The third and last activity in the SOVEUR project concerns the development of simple procedures for mapping the vulnerability of soils to selected categories of pollutants, using the methodological framework of Batjes (1997a). A preceding workshop defined soil vulnerability as the 'capability for the soil system to be harmed in one or more of its ecological functions' (Batjes and Bridges, 1993). These functions include production of humus, filtering, storage, buffering and transformations of heavy metals, persistent organic chemicals and other harmful substances. In addition, the protective role of soil and conservation of its genetic reserve of flora and fauna are significant issues (Blum, 1990).

Each soil is a chemically and biologically complex medium comprising weathered and newly formed mineral fragments, organic matter in various stages of decomposition, (micro)organisms, and solutes and gases in its pores. Soils in Central and Eastern Europe are diverse, ranging from shallow and stony Leptosols to poorly drained Histosols rich in organic matter. Depending on their inherent properties, such as content of clay, organic matter and calcium carbonate and cation exchange capacity, as well as their water regimes, each soil will react in different ways to similar pollution and environmental changes. Thus regional differences in static and dynamic soil properties — both horizontally and vertically — will largely control a soil's capacity to control movement of pollutants. As such, each soil may be viewed as a chromatographic column, or system of 'geochemical barriers', with respect to contaminant behaviour (Glazovskaya, 1991).

Each polygon on the SOTER map has been described in terms of its main component soils (see Fig. 1 and Table 1), using regionally representative soil profiles characterized at the soil unit level of the Revised Legend (FAO, 1988), and their relative extent. As most profile descriptions have been obtained from routine type of soil surveys, complete horizon data sets are not always available for all the considered attributes. Consequently, the number of observations for each of these attributes will vary between soil units, and with the depth range considered. The Revised Legend code has been used to aggregate the available soil profile data and to link derived interpretations of soil properties, such as median soil pH, organic matter content and cation exchange capacity, with the polygons demarcated on the SOTER map (Batjes, 1999b). The usefulness of soil classes as carriers of soil information, for a range of environmental applications, is well documented (Batjes, 1997b; Bouma *et al.*, 1998a; FAO, 1995; Le Bas *et al.*, 1998).

Table 3.

Important soil capacity-controlling properties for heavy metals and persistent organic chemicals.

Capacity controlling property	Possible detrimental environmental effects
Cation- or anion exchange capacity (CEC resp. AEC)	Soil having a low CEC or AEC has a low capacity to retain cations, such as heavy metals, or anions, such as Arsenicum and organic anions, by sorption. The size of CEC and AEC mainly depends on clay content and type, organic matter content and type, and soil pH.
Soil reaction (pH)	A decrease in soil pH (generally) increases heavy-metal solubility, decreases CEC, and alters microbial composition and activity.
Redox potential (Eh)	A decrease in redox potential (more reducing moisture conditions), dissolves iron and manganeseoxides, which mobilizes oxide-sorbed toxic chemicals. Increasing redox potential mobilizes heavy metals by dissolving metal sulfides.
Organic matter content/quality (OM)	Decreasing OM content reduces CEC, soil pH buffering capacity, the sorption capacity for toxic organic compounds, soil water-holding capacity, alters physical structure (e.g., increases soil erodibility and compaction hazard), and decreases microbial activity.
Soil structure	Altering soil structure can reduce drainage and thereby increase redox potential (more oxidizing conditions), increase soil erodibility, affect the rate of chemical release to drainage water, and alter soil pH.
Salinity	Increasing salinity solubilizes toxic chemicals by altering the ion-exchange equilibrium, increasing soluble complexation, and decreasing chemical thermodynamic activities in solution. Further, it can decrease microbial activity.
Microbial activity	Altering microbial activity and population ecology can reduce toxic degradation of organics (increase in toxic build-up), and alter redox potential and pH.

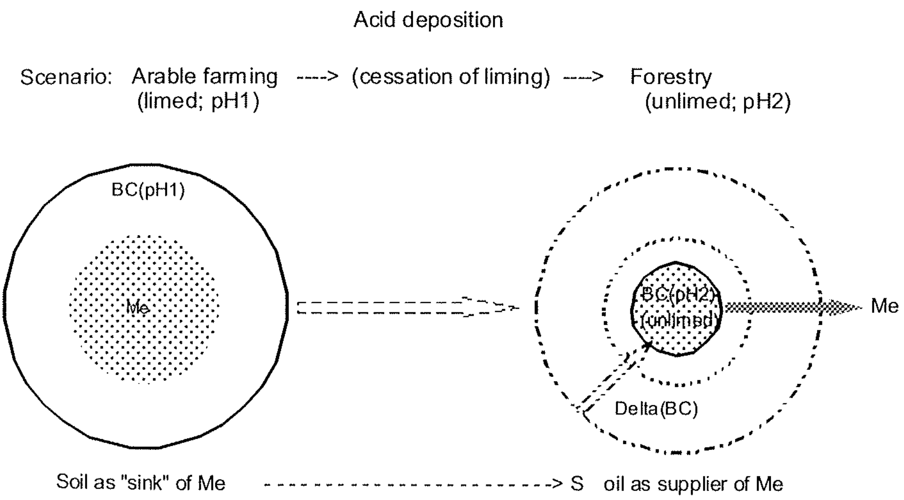
Source: Hesterberg *et al.* (1992)

Table 3 lists seven important 'capacity controlling properties' affecting soil buffering and maximum retention capacity for heavy metals and persistent organic chemicals. Depending on the chemicals and environmental processes under consideration the soil factors must be given different weightings. This can be done with matrices, showing the main processes that affect the mobility and speciation of a chemical in relation to possible changes in the environmental conditions (Blume and Brümmer, 1987a; Blume and Brümmer, 1987b; Cindery *et al.*, 1998; Fränzle, 1987; Stolpe *et al.*, 1998). This means that several soil vulnerability maps, each corresponding to a well defined pollution scenario, can be compiled from the same digital base maps and set of derived soil attributes.

Any environmental change that alters the 'capacity controlling properties' will subsequently affect the maximum 'sink capacity', either favourably or unfavourably. Important processes (triggers) influencing a soil's capacity to hold, or release, various contaminants and pollutants include: acid precipitation; liming of agricultural land; eutrophication; salinisation; water erosion; and, changes in climate, hydrological conditions and land use (Hesterberg *et al.*, 1992). The scenario depicted in Figure 3 illustrates that with progressing acidification there may be a time when the critical load for a heavy metal is exceeded, turning the soil in to a supplier rather than a sink for this potentially harmful metal.

Figure 3

Schematic representation of the effect of cessation of liming, associated with a shift from arable cultivation to forestry, and acid deposition on the buffering capacity of the soil, and subsequent mobilization of heavy metals (Me). (pH1 ≈ 6.5; pH2 << pH1); BC is the buffering capacity with BC(pH1)>BC(pH2); Modified after Stigliani (1988).



A 'strong delayed response' may be observed in soils which can store large amounts of potentially mobilizable chemical compounds; these sudden occurrences of pollution are the 'chemical time bombs' (Stigliani, 1988; Stigliani, 1991). Alternatively, so-called 'weak rapid responses' or 'whimpers' occur where compounds are easily lost in continual small amounts. They are (shortly) delayed responses with as yet no trigger effect. These are not 'chemical time bombs' (CTB) but rather what the participants of the initial SOVEUR workshop termed 'more or less' polluted areas. The location, and type, of these 'polluted' areas are shown on the soil degradation status map for the SOVEUR area (see Van Lynden, 1997), in so far as current data availability permits. The assessment of soil vulnerability forms the first stage in identifying areas considered at risk from 'delayed pollution' (see Batjes, 1997a).

In the CTB-sense, the most vulnerable soils are those with high but finite capacities for storage of potentially harmful and mobilizable chemicals (Batjes and Bridges, 1993; Stigliani, 1991). In addition, 'time-delayed' and then 'sudden' non-linear releases of pollutants are important. Consequently, the chemicals of concern with respect to CTB-occurrences are the long-lived species most resistant to chemical decomposition, especially heavy metals and persistent organic-chemicals.

3.4. Areas at risk

The concept of 'chemical time bomb' stresses:

(1) the (changing) capacity of the soil reservoir to hold or release contaminants, and

(2) a trigger system.

The severity, nature and timing of the impacts resulting from CTBs will vary with (Batjes and Bridges, 1993):

(1) the degree of *loading* of the soil with a particular chemical;

(2) the capacity or *propensity* of the soil to retain this chemical;

(3) the type (and intensity) of the environmental and socio-economic *triggers*;

(4) the *sensitivity* of individual soils to the respective triggers.

(5) the *targets* affected by the released pollutants.

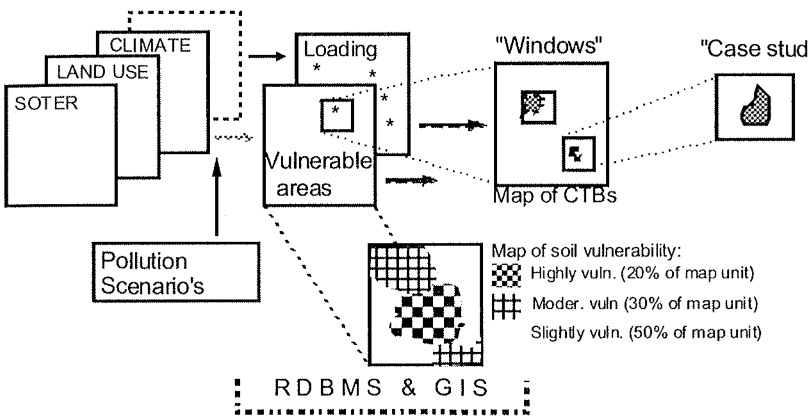
The combined interpretation of items (2), (3) and (4) will permit mapping of the *relative* vulnerability of soils to a pre-defined pollution scenario. In a Geographic Information System (GIS), the 'vulnerability map' can be overlaid onto a map of current or anticipated future (accumulated) loadings (1) to show where 'chemical time bombs' are prone to occur.

Depending on the sources and types of pollution, different scales of mapping and modelling approaches are needed. At the observation level adopted for the SOVEUR project, it is possible to map soils considered at risk from to diffuse sources of pollution, including acid deposition, heavy metals, and persistent agro-chemicals. More detailed studies are required to determine CTBs associated with point-source pollution, such as mine spoilings and waste dumps. Exploratory analyses at the (sub)continental level, can provide the basis for identifying areas at risk where more detailed studies of soil pollution would be useful. These can then be used for identification of hot-spots, for case studies and remediation at the local level.

Figure 4

Schematic GIS procedure for mapping vulnerable soils and areas prone to Chemical Time Bombs (CTBs)

Scale: ≈1:2.5 M ≈1:250,000 ≈1:25,000



Modelling approach:	macro-scale descriptive model; regional applicability;	meso-scale ——— micro-scale from empirical to mechanisitic models; local applicability (initially);
Purpose:	awareness increasing.	prediction and remedial action.

4. Results and conclusions

Working at the scale of 1:2.5 million is an excellent exercise for integrating data and expertise from a range of countries. The SOVEUR project thus plays a significant role in enhancing scientific cooperation on issues of soil degradation and pollution, within Central and Eastern Europe.

Quality control is a major issue in spatial and point data handling, particularly when disparate sources are used; some of the 'best' available data may be patchy and of uncertain quality. Uncertainties related to model and data errors are prone to be significant at the considered scale of 1:2,500,000 (Loague and Corwin, 1996; Prieler *et al.*, 1996). Generally, the various types of uncertainties are difficult to evaluate and they will vary amongst the various data sets and models used (Batjes, 1999c; Leemans and van den Born, 1994; Pan *et al.*, 1995). As such, results will mainly be applicable to large areas as a whole, increasing awareness of (adverse) effects of human intervention on the quality of soil resources in Central and Eastern Europe.

A harmonized SOTER and soil degradation status database, with associated a series of derived thematic maps, has been prepared for the 13 countries of the SOVEUR area. The assessment of the vulnerability of soils to cadmium mobilization, as inducible by acid deposition, has been the first 'vulnerability' mapping exercise in accordance with the recommendations of the SOVEUR implementation workshop. These products will first be presented and discussed during a concluding workshop in Busteni, Romania (26-30 October 1999). During this venue, any remaining cross-border correlation issues will have to be resolved in consultation with representatives of the national institutes concerned, and the maps of soil degradation status and vulnerability may be fine-tuned. Additional maps of soil vulnerability can easily be generated at this stage, using available 'parametric overviews of derived soil properties' combined with specialist knowledge of contaminant behaviour.

Following the Busteni workshop, the SOVEUR-derived databases, project reports, and a selection of thematic maps will be finalized. Subsequently, it is the intention that these project results will be made available on a low-cost CD-ROM, possibly in FAO's Digital Land and Water Media Series, so that they may become accessible to an as wide range of users as possible.

In the first instance, the 'awareness-increasing' products should be of interest to planners, policy-makers, and civil servants of the Governments of the participating countries, as well as international organizations such as FAO, UNEP and the European Union. In addition, there is an important role in education as currently the soil is not seen as deserving protection from degradation and pollution by many authorities. Further, natural and social scientists will have access to a suite of up-to-date soil and terrain data for a range of environmental studies at the observational level. For the future, however, more detailed systems may need to be developed, especially for the smaller countries, to allow more detailed studies at the regional or national level (see Fig. 4). Technical, policy and legal aspects of chemical time bombs, with emphasis on the institutional action required in Eastern Europe, have been discussed elsewhere (Appelgren and Burchi, 1993).

Integration with a soil monitoring system will permit analysis of changes in the driving-forces of soil processes in relation to toxicant (im)mobilization, thereby providing a better scientific basis for model development, evaluation, and risk assessment (see GTOS, 1995; Van Duijvenbooden, 1998; Varallyay, 1993). This information can then be translated into possible management options for land use planners. Concerted action is also needed at the pan-European level on sampling methods, analytical methods, methods for harmonizing disparate data sets, model approaches, and ultimately on how to link information obtained at different scales (Bouwman, 1999; Cramer and Fischer, 1997; Goodchild, 1994; Kirkby *et al.*, 1996).

The scope for identifying areas considered most at risk from remobilization of selected types of contaminants will strongly depend on the availability of, and unrestricted access to, auxiliary databases of the main socio-economic and bio-physical driving forces of global change. For example, access will be needed to up-to-date geographic databases specifying accumulated pollutant loads as well as the type and intensity of the environmental triggers which may lead to toxicant mobilization in Central and Eastern Europe in the next decades. Information on principal land use changes and environmental changes anticipated in the region over the next 25-50 years will also be needed for scenario formulation (see Bouma *et al.*, 1998b; Hesterberg *et al.*, 1992; UNEP, 1999). The acquisition of these often access-restricted data bases is beyond the resources of the SOVEUR project. Issues of data accessibility, copyright and legal responsibility are likely to become of increasing importance in the near future (e.g., Jones and Buckley, 1997), and there is a pressing need to clarify the current situation in many of these areas (see Naff, 1999; Webster, 1997).

The trans-boundary nature of effects associated with diffuse-pollution, such as acidification, deposition of heavy metal dust and radio-nucleides, requires further development and implementation of international agreements on control measures and remediation strategies.

Acknowledgements:

The project on 'Soil Vulnerability Mapping in Central and Eastern Europe' (SOVEUR) is being implemented by the International Soil Reference and Information Centre (ISRIC), within the Food and Agriculture Organization (FAO) and Netherlands Government Cooperative Programme (Project: GCP/RER/007/NET), with the cooperation of specialist institutes from Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, Russia Federation (west of the Urals), Slovakia, and the Ukraine.

References

APPELGREN B.G., BURCHI S. (1993). Technical, policy and legal aspects of chemical time bombs with emphasis on the institutional action required in Eastern Europe. *Land Degradation and Development*, 4, 437-440.

BATJES N.H. (1996). Global assessment of land vulnerability to water erosion on a ½ by ½ grid. *Land Degradation and Development*, 7, 353-365.

BATJES N.H. (1997a). Methodological framework for assessment and mapping of the vulnerability of soils to diffuse pollution at a continental level (SOVEUR project), Report 97/07, pp. 34. International Soil Reference and Information Centre (ISRIC), Wageningen.

BATJES N.H. (1997b). A world data set of derived soil properties by FAO-UNESCO soil unit for global modelling. *Soil Use and Management*, 13, 9-16.

BATJES N.H. (1999a). Management options for reducing CO_2 concentrations in the atmosphere by increasing carbon sequestration in the soil, NRP Report No. 410-200-031, pp. 114. Dutch National Research Programme on Global Air Pollution and Climate Change, Bilthoven.

BATJES N.H. (1999b). Soil data derived from SOTER for environmental studies in Central and Eastern Europe (SO-VEUR Project; Version 1.0), Report 99/02, pp. 30. International Soil Reference and Information Centre, Wageningen.

BATJES N.H. (1999c). Soil vulnerability mapping in Central and Eastern Europe: Issues of data acquisition, quality control and sharing. In: *Data Sharing for International Water Resource Management: Eastern Europe, Russia and the CIS*, NATO Science Series 2: Environmental Security (Vol. 61). (Ed. by T. Naff), pp. 187-206. Kluwer Academic Publishers, Dordrecht.

BATJES N.H., BRIDGES E.M. (1991). Mapping of soil and terrain vulnerability to specified chemical compounds in Europe at a scale of 1:5 M, Proceedings of an international workshop (Wageningen, 20-23 March 1991), pp. 177. International Soil Reference and Information Centre (ISRIC), Wageningen.

BATJES N.H., BRIDGES E.M. (1993). Soil vulnerability to pollution in Europe. *Soil Use and Management*, 9, 25-29.

BATJES N.H., BRIDGES E.M. (1997). Implementation of a Soil Degradation and Vulnerability Database for Central and Eastern Europe, Proceedings of an international workshop (Wageningen, 1-3 October 1997), pp. iv + 81. ISRIC, Wageningen.

BATJES N.H., VAN ENGELEN V.W.P. (1997). Guidelines for the compilation of a 1:2,500,000 SOTER database (SO-VEUR Project), Report 97/06, pp. 58. ISRIC, Wageningen.

BATJES N.H., VAN ENGELEN V.W.P., OLDEMAN L.R. (1993). Proposed assessment of the vulnerability of European soils to chemical pollution using a SOTER-shell approach. *Land Degradation & Rehabilitation*, 4, 223-231.

BLUM W.E.H. (1988). Problems of soil conservation, Nature and Environment No 40. Council of Europe, Strasbourg.

BLUM W.E.H. (1990). Soil pollution by heavy metals: Causes, processes, impacts and need for future action, Report Men 6(90)4. Council of Europe, Strasbourg.

BLUME H.-P., BRÜMMER G. (1987a). Predicting the behaviour of heavy metals in soils using simple field methods (in German). *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft*, 53, 111-117.

BLUME H.-P., BRÜMMER, G. (1987b). Predicting the behaviour of pesticides in soils with simple field methods (in German). *Landwirtschaft Forschung*, 40, 41-50.

BOUMA J., BATJES N.H., GROOT J.J.R. (1998a). Exploring land quality effects on world food supply. *Geoderma*, 86, 43-59.

BOUMA J., VARALLYAY G., BATJES N.H. (1998b). Principal land use changes anticipated in Europe. *Agriculture, Ecosystems and Environment*, 67, 103-119.

BOUWMAN A.F. (1999). *Approaches to Scaling of Trace Gas Fluxes in Ecosystems*. Elsevier, Amsterdam.

CINDERY S., CAMBRIDGE H.M., HERRERA R., HICKS W.K., KUYLENSTIERNA J.C.I., MURRAY F., OLBRICH K. (1998). Global assessment of ecosystem sensitivity to acidic deposition, pp. 19. Stockholm

Environmental Institute, York.

CRAMER W., FISCHER A. (1997). Data requirements for global terrestrial ecosystem modelling. In: *Global Change and Terrestrial Ecosystems*, (Ed. by B. Walker and W. Steffen), pp. 529-565. Cambridge University Press, Cambridge.

EEA (1999). *Europe's Environment: The Second Assessment.* Office for Official Publications of the European Communities and Elsevier Science Ltd., Oxford, 292 pp.

FAO (1988). *FAO-Unesco Soil Map of the World, Revised Legend* (with corrections and updates). ISRIC, Wageningen, 140 pp.

FAO (1995). *Digital Soil Map of the World and Derived Soil Properties, Land and Water Digital Media Series 1.* Food and Agriculture Organization of the United Nations, FAO.

FRÄNZLE O. (1987). Sensitivity of European soils related to pollutants. In: *Scientific basis for soil protection in the European Community*, (Ed. by H. Barth and P. L'Hermite), pp. 123-145. Elsevier Applied Science, London.

GLAZOVSKAYA M.A. (1991). Methodological guidelines for forecasting the geochemical susceptibility of soils to technogenic pollution, Tech. Pap. 22, pp. 40. CTB-ISRIC, Wageningen.

GOODCHILD M.F. (1994). Sharing imperfect data. In: *Proceedings UNEP and IUFPRO international workshop in co-operation with FAO in developing large environmental databases for sustainable development*, (Ed. by A. Singh), pp. 102-110. UNEP/GRID, Sioux falls.

GTOS (1995). Global Terrestrial Observing System GTOS - Turning a sound concept into practical reality, UNEP/EAP.TR.95-08, pp. 97. ICSU / UNEP / FAO / UNESCO / WMO, Nairobi.

HESTERBERG D., STIGLIANI W.M., IMESON A.C. (1992). Chemical time bombs: Linkages to scenarios of socio-economic development, Executive Report 20. International Institute for Applied Systems Analysis, Laxenburg.

JONES R.J.A., BUCKLEY B. (1997). European soil database information access and data distribution procedures. European Soil Bureau, Space Application Institute, Directorate General Joint Research Centre, Ispra.

KIRKBY M.J., IMESON A.C., BERGKAMP G., CAMMERAAT L.H. (1996). Scaling up processes and models from the field plot to the watershed and regional areas. *Journal of Soil and Water Conservation*, 51, 391-396.

LE BAS C., KING D., JAMAGNE M., DAROUSSIN J. (1998). The European Soil Information System. In: *Land Information Systems: Developments for Planning the Sustainable Use of Land Resources*, (Ed. by H.J. Heineke, W. Eckelmann, A.J. Thomasson, R.J.A. Jones, L. Montanarella and B. Buckley), pp. 33-42. The European Soil Bureau, Joint Research Centre, Ispra.

LEEMANS R., van den BORN G.J. (1994). Determining the potential distribution of vegetation, crops and agricultural productivity. *Water, Air, and Soil Pollution*, 76, 133-161.

LOAGUE K., CORWIN, D.L. (1996). Uncertainty in regional-scale assessments of non-point source pollutants. In: *Application of GIS to modelling of non-point source pollutants in the vadose zone*, (Ed. by D.L. Corwin and K. Loague), pp. 131-152. Soil Science Society of America Inc., Madison.

MANTEL S., VAN ENGELEN V.W.P. (1999). Assessment of the impact of water erosion on productivity of maize in Kenya: an integrated modelling approach. *Land Degradation and Development*, (in press).

MANTEL S., VAN ENGELEN V.W.P., BATJES N.H. (1996). Impact of water erosion on food productivity: A test case from Uruguay. In: *Report of the UNEP/RIVM/PE Workshop on Global and Regional Modelling of Food Production and Land Use and the Long-term Impact of Degradation of Land and Water Resources (20-22 May 1996; RIVM, Bilthoven), Environment Information and Assessment Meeting Report 2*, pp. v39-v42. UNEP/WAU/RIVM, Bilthoven.

NAFF T. (1999). Data Sharing for International Water Resource Management: Eastern Europe, Russia and the CIS, *NATO Science Series 2: Environmental Security* (Vol. 61), pp. 187-206. Kluwer Academic Publishers, Dordrecht.

OLDEMAN L.R., HAKKELING R.T.A., SOMBROEK W.G. (1991). World Map of the Status of Human-Induced Soil Degradation: An explanatory Note (rev. ed.), pp. 35 (with maps). UNEP & ISRIC, Wageningen.

PAN Y., MCGUIRE A.D., KICKLIGHTER D.W., MELLILO J.M. (1995). The importance of climate and soils for estimates of net primary production: a sensitivity analysis with the terrestrial ecosystem model. *Global Change Biology*, 2, 5-23.

PRIELER S., SMAL H., OLDENDRYNSKI K., ANDERBERG S. (1996). Cadmium, zinc and lead load to agricultural land in the Upper Oder and Elbe Basin during the period 1955-1994, Working Paper 96/30, pp. 21. International Institute for Applied Systems Analysis, Laxenburg.

STANNERS D., BOURDEAU P. (1995). *Europe's Environment: The Dobris Assessment.* Office for Official Publications of the European Communities, Luxembourg.

STIGLIANI W.M. (1988). Changes in valued "capacities"of soils and sediments as indicators of non-linear and time-delayed environmental effects. *Environmental Monitoring and Assessment*, 10, 245-307.

STIGLIANI W.M. (1991). Chemical Time Bombs: definition, concepts and examples, Executive Report No. 16. International Institute for Applied Systems Analysis (IIASA), Laxenburg.

STOLPE N.B., KUZILA M.S., SHEA P.J. (1998). Importance of soil map detail in predicting pesticide mobility in terrace soils. *Soil Science*, 163, 394-403.

UNEP (1999). *Global Environmental Outlook 2000.* United Nations Environment Programme, Nairobi.

VAN DUIJVENBOODEN W. (1998). Soil monitoring systems and their suitability for predicting delayed effects of soil pollutants. *Agriculture, Ecosystems and Environment*, 67, 189-196.

VAN ENGELEN V.W.P., WEN T.T. (1995). Global and National Soils and Terrain Digital Databases (SOTER): Procedures Manual, (*Published also as FAO World Soil Resources Report No. 74*), pp. 115. UNEP, IUSS, ISRIC, FAO, Wageningen.

VAN LYNDEN G.W.J. (1995). European soil resources, Nature and Environment No. 71. Council of Europe Press, Strasbourg.

VAN LYNDEN G.W.J. (1997). Guidelines for the assessment of soil degradation in Central and Eastern Europe (SOVEUR Project), Report 97/08b (rev. ed.), pp. 20. International Soil Reference and Information Centre (ISRIC), Wageningen.

VAN LYNDEN G.W.J., OLDEMAN L.R. (1997). The Assessment of the Status of Human-induced Soil Degradation in South and Southeast Asia, pp. 32 (with maps). UNEP, FAO, ISRIC, Wageningen.

VARALLYAY G. (1993). International Workshop on Harmonization of Soil Conservation Monitoring Systems (FAO/ECE working party on relations between Agriculture and the Environment), pp. 224. Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest.

WEBSTER F. (1997). Threat to full and open access to data. *Science International*, 65, 11-12.

WOCAT (1998). World Overview of Conservation Approaches and Technologies: programmes, profiles, soil and water conservation approaches database (ver. 1), *Land and Water Digital Media Series 3.* FAO, Rome.

SPATIAL ENVIRONMENTAL INFORMATION SYSTEM FOR MODELLING THE IMPACT OF CHEMICALS

John M. Hollis

Soil Survey and Land Research Centre, Cranfield University
Silsoe, BEDS, MK45 4DT. UK

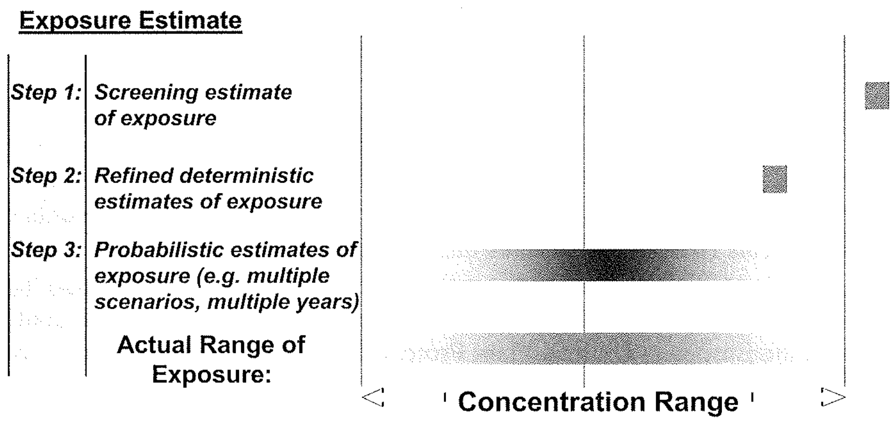
Introduction

Within Europe, there is an increasing awareness of the potential threat to the quality of national soil and water resources from the amounts of agrochemicals (pesticides, nitrates and phosphates), urban and farm wastes applied to land. This recognition is reflected in European-wide efforts to harmonise regulatory environmental risk-assessment procedures for pesticides through the European Union's Plant Protection Product Authorisation Directive (91/414/EEC), in the development of the European Water Framework Directive and in national and international initiatives to develop agreed indicators of soil quality.

Our understanding of the fate and behaviour of diffuse-source environmental contaminants is dependent on a detailed and precise knowledge of the natural environment. The complex interaction of different land use practices with various soil, hydrological, climatic and hydrogeological factors combine to determine the relative vulnerability of land and water resources in different geographical areas. When coupled with a detailed understanding of the physico-chemical behaviour of potential contaminants the likely environmental impacts of differing land management practices can be evaluated.

Increasingly, computer based modelling systems are being used at strategic and operational management levels to simulate the fate and behaviour of specific pollutants. A wide variety of models have been developed which simulate the various environmental processes affecting the fate of potential pollutants at different levels of detail (Addiscott & Wagenet, 1985; Jury & Ghodrati, 1989). Nevertheless, however detailed and mechanistic the approach used, model results and predictions can only relate to the range of chosen input parameters. The agricultural ecosystem is heterogeneous in nature and most of the factors that influence environmental fate vary spatially and/or temporally. Thus, a single set of model input parameters usually represents only one of many possible environmental scenarios. In recognition of this, stepped approaches to exposure assessments are being adopted (EC, 1995, 1996a, 1996b) with successive steps designed to produce increasingly accurate information about the likely range of environmental exposure. The procedure is illustrated in Fig. 1.

Fig. 1 - Modelling approaches to exposure estimation



Step 1 is based on an 'unrealistically worst-case' scenario designed to produce an estimated exposure concentration in excess of any that would be expected to occur in the real environment. For the other steps however, modelling results will be relevant only if there is sufficient environmental data available to identify the desired scenarios or to make realistic estimates of the required parameter ranges (Hutson, 1992). If exposure assessments need to be made at the catchment, regional or national levels, comprehensive environmental databases covering the relevant parameters are necessary. The difficulties in obtaining, managing and manipulating such databases pose a major problem for regulators, industry and researchers (IUPAC, 1987).

This paper describes the development and application of a comprehensive relational environmental information system for England and Wales (Hollis *et al.*, 1995). Particular attention is given to describing the range of soil parameters included and how the data was derived. The potential for developing a similar system for Europe is discussed.

CORE DATABASES

The environmental database management system for England and Wales, named SEISMIC (Spatial Environmental Information System for Modelling the Impact of Chemicals), is built around six core databases which can be manipulated and interrogated by means of on-screen menus which initiate software functions. There are four spatial data sets which hold cropping, crop suitability, climate and soil data for each of 6,456 5 x 5 km grids that cover all of the two countries. Two tabular data sets hold details of soil horizon properties for each of the 412 soil series that are included in the spatial soil data and of daily weather data representing the range of conditions within the two countries.

Spatial cropping data

Spatial data relating to actual and potential cropping are held within the system. There are two sets of actual crop distributions based on the 1988 and 1995 Parish Agricultural Census data gathered by the Ministry of Agriculture, Fisheries and Food. This data has been aggregated by staff of the Edinburgh University Data Library to derive a 5 x 5 km resolution digital dataset. Each geo-referenced 5 x 5 km grid in the cropping dataset comprises a list of component crops and their percentage cover. The full list of included crops is given in Table 1.

Potential cropping data is based on simple crop suitability models developed by the Soil Survey and Land Research Centre (SSLRC), incorporating land qualities based on soil, land and climate interactions. The models classify land into one of four suitability categories ranging from 'Well Suited' to 'Unsuited'. Each 5 x 5 km area of England and Wales has been categorized in this way based on its agroclimatic characteristics and the properties of its most common soil series (Jones and Thomasson, 1987).

This data has been further simplified so that for a specific crop, all 5 x 5 km blocks that are at least marginally suited are categorized as being potentially suitable. Each geo-referenced grid in the resulting database contains a list of seven crops (winter cereals, spring cereals, oilseed rape, sugar beet, maincrop potatoes, forage maize and grassland) with their potential suitability specified as 'Yes' or 'No'.

TABLE 1. Categories of crop included in the SEISMIC system

Grassland	**All vegetables grown in the open**	Plums
Grassland - short term	Peas	Cherries
Grassland - long term	Brussel Sprouts	Other Top Fruit
Rough Grazing	Cabbage (summer & autumn)	**All Small Fruit**
Cereals	Other Cabbage	Strawberries
Wheat	Cauliflower	Raspberries
Winter Barley	Calabrese	Blackcurrants
Spring Barley	Carrots	Gooseberries
Oats	Parsnips	Other Small Fruit
Mixed Corn	Beetroot	**All Hardy Nursery Stock**
Rye	Onions	Fruit trees, bushes and other fruit stock
Maize	Broad Beans	Roses
Potatoes	Runner Beans	Shrubs, Conifers etc.
Sugar Beet	French Beans	Ornamental Trees
Hops	Field Celery	Herbaceous Plants
Horticultural Crops	Lettuce	Other hardy nursery stock
Field Beans	Sweet Corn	**All Bulbs & Flowers grown in Open**
Oilseed Rape	Other Vegetables	Bulbs, Corms, Tubers & Rhizomes
Turnips & Swedes	**All Top Fruit**	
Fodder Beet & Mangolds	Apples (dessert & cooking)	Dahlias
Kale, Cabbage etc.	Cider Apples &Perry Pears	Chrysanthemums
Peas (for harvesting dry)	Pears	

Spatial climatic data

Spatial climatic datasets incorporated into the system are derived directly from the SSLRC's Agroclimatic database (Jones and Thomasson, 1985). This comprises long term mean values of agriculturally important climatic parameters calculated for each 5 x 5 km block in England and Wales using empirical regression algorithms which relate each climatic parameter to altitude, latitude and longitude. Each algorithm is derived from statistical analysis of measured data from a number of sites throughout the two countries. Data for average annual rainfall, maximum accumulated potential soil moisture deficit, duration of the field capacity period and excess winter rain are held for each geo-referenced 5 x 5 km grid.

Weather data

Weather patterns show considerable temporal and spatial variation and so, if such data is to be used in a realistic way, it is necessary to ensure that it encompasses the likely variation within the area of interest. Thus, for national modelling purposes, it is necessary to have a number of datasets that cover long periods of time and also represent the different climatic regimes present. The SEISMIC system holds daily weather datasets covering a period of 30 years, for eight representative sites across the two countries. Because of the difficulties in obtaining such comprehensive measured data, each dataset has been simulated using a weather generator model. The model used is that of Richardson and Wright (1984). It generates daily weather data from a set of probability distribution parameters derived from statistical analysis of measured weather data. Comparisons of long term monthly averages have shown that weather datasets generated in such a way are closely representative of measured weather patterns, especially if they are calibrated using monthly averages based on measured rainfall and temperature. Their limitation is that they may not include extreme weather events and this should be borne in mind when selecting appropriate modelling scenarios. The eight weather datasets in SEISMIC were generated using the appropriate probability distribution parameters derived from statistical analysis of measured weather data for each site. Each data set comprises daily values of rainfall, maximum temperature, minimum temperature and solar radiation.

Spatial soil data

The spatial soil data within SEISMIC relates to the 1:250,000 scale regional soil maps of England and Wales (Soil Survey Staff, 1983). These show the spatial distribution of 296 soil associations each of which comprises between one and eight main soil series which are found associated together within the landscape. Soil series are characterized by a precisely defined set of soil and substrate properties. They form the basic unit of soil characterization and mapping in England and Wales (Hollis and Avery, 1997). Based on the field data collected and recorded during the making of the 1:250,000 scale soil maps, an estimate of the average proportion of each soil series within each soil association has been made, with a total of 412 main soil series being recognized on the complete national map. All six regional soil vector maps of England and Wales have been digitized and resampled to create a raster database of 100 x 100 m grid resolution. Using this dataset a national soil series dataset at 5 km resolution has been created by integrating the proportion of every soil association in each 5 x 5 km grid with the proportion of each soil series within each soil association. Each geo-referenced 5 x 5 km grid in the dataset thus comprises a list of component series along with their percentage cover.

Soil parameter data

Soil parameter data are held in SEISMIC for each of the 412 soil series included on the 5km resolution soil series spatial database. For each series, parameter data is available for each characteristic soil layer present under each of four different land uses; Arable, short term rotational (Ley) grassland, long term (Permanent) managed grassland and 'Other' land under semi-natural vegetation or recreational use. Some soil series, such as those characteristic of wet upland areas, do not support all four types of land use. Combinations of land use and soil series that do not normally occur are identified in the database by the phrase 'series and land use combination does not normally occur in England & Wales'. An example of the data available for a single soil series / land use combination is given in Table 2.

TABLE 2. Example of soil parameter data for the Cuckney soil series (cambic arenosol) under arable (Figures in parentheses indicate standard deviations).

Parameter		**Soil layer**			
	A	Bw 1	Bw2	BC	C
Upper depth (cm)	0	35	50	75	100
Lower depth (cm)	35	50	75	100	125
Total sand %	81 (6.2)	84 (5.3)	879 (3.6)	90 (3.7)	95 (-1)
Total silt %	12 (5.2)	10 (4.1)	8 (3.3)	6 (3.1)	3 (-1)
Total clay %	7 (3.1)	6 (1.7)	5 (2.0)	4 (1.0)	2 (-1)
Fine sand %	26 (9.6)	30 (9.8)	30 (10.5)	28 (-1.)	30 (-1)
Organic carbon %	1.2 (0.7)	0.4 (0.1)	0.3 (0.1)	0.1 (-1)	0.1 (-1)
pH (1 :2.5 H_2O)	6.8 (0.8)	6.9 (0.7)	7.0 (0.6)	7.2 (0.6)	7.1 (-1)
Bulk density (g/cm^3)	1.49	1.45	1.47	1.47	1.47
Van Genuchten's 'alpha'	0.1068	0.1143	0.1239	0.1364	0.1583
Van Genuchten's 'n'	1.3982	1.4018	1.433	1.465	1.5573
%vol. water at SkPa	22.9	20.8	18.8	17.1	13.1
%vol. waterat 10kPa	18.8	16.8	14.8	13.2	9.4
%vol.waterat40kPa	13.1	11.1	9.5	8.1	5.2
%vol. water at 200kPa	9.3	7.4	6.2	5.1	3.0
%vol. water at 1500kPa	7	5.1	4.3	3.5	2.0
%vol. Total porosity	43.4	45.1	44.4	44.5	44.5
Saturated conductivity (cm/day)	335	497	558	448	616
Conductivity at SkPa (cm/day)	2.04	2.60	2.20	1.24	0.79

DERIVATION OF SOIL PARAMETER DATA

The range of models that are used to predict the environmental fate of chemicals is wide and many models have very specific data requirements. Any national database designed to support environmental modelling must therefore include relevant information for a large range of soil physical and chemical properties. In addition, many of the required parameters are not independently variable, some are land use dependent and some may also vary on a seasonal basis.

In order to take these factors into account, a structured approach to the derivation of soil parameters was devised. Firstly, a set of *soil primary properties* was identified. These are easily measured soil properties that can be used to derive virtually all other necessary physical and chemical characteristics. The soil primary properties comprise **particle-size distribution**, **organic carbon %** and **pH**.

Secondly, for each soil series, a set of significantly different and characteristic soil horizons were identified under each of the four basic land use types described in the section above. For each soil series / land use / soil horizon combination, an average upper and lower depth was derived using soil profile data held in SSLRC's Land Information System, LandIS (Hallett *et al.*, 1996). Spatial variation of the soil primary properties within each soil series / land use / soil horizon combination was then described in terms of a mean value and a standard deviation.

Finally, the variation of other physical and chemical properties was described using pedotransfer functions incorporating the soil primary property data and derived from analysis of large datasets of measured values.

Soil Primary Properties

Spatial variation in the soil primary properties was characterized by using SSLRC's analytical databases to derive a mean value and a standard deviation for each soil series / land use / soil horizon combination. LandIS contains measurements of particle-size fractions, organic carbon contents and pH for some 5,000 soil horizons taken from over 1,500 profiles sampled to characterise soil series during detailed field survey. An additional 'National Soil Inventory analytical database' comprises analysed values of a wide range of topsoil characteristics measured from samples taken at 5 km grid intersect points across England and Wales (McGrath and Loveland, 1992). A further 5,692 sets of measurements of topsoil particle-size fractions, organic carbon and pH are available from this source.

Mineral particle-size data were calculated directly from measurements held in LandIS. The data is not dependent on land use so the dataset was not stratified according to this category. For the majority of soil series, multiple datasets were available to adequately characterize the particle size fractions in terms of mean values and standard deviations. Nevertheless, for a few soil series there was insufficient data to undertake an adequately statistical analysis and for these series no standard deviations are given. Such cases are identified by the number '*-1*' in the standard deviation column. For most *organic* soil horizons with organic carbon contents greater than about 10%, mineral particle size fractions were not measured. In the SEISMIC datasets therefore the mineral sand silt and clay contents for such horizons are simply designated '*-7*' indicating Peat textures.

Topsoil organic carbon content and pH are very dependent on land use, even within soil series. Stratification of this data into each of the four land use categories defined above resulted in more soil series / land use combinations with insufficient data to derive meaningful statistical summaries. This was particularly the case for subsoil horizons where, for some series / land use combinations, no organic carbon content and pH data were available. In such cases expert judgement was used to estimate values based on similar soil series / land use combinations for which data was available. Estimated mean values for soil primary properties are indicated in the datasets by the number '*-9*' in the standard deviation column.

Soil Bulk Density

Bulk density is also a property that depends, at least partly, on land use. Although it is relatively easily measured and data was available for approximately 1,600 soil horizons, the dataset was still insufficient to fully characterize all combination of soil series / land use / soil horizon. A set of empirical regression equations relating bulk density to organic carbon, clay and sand content was therefore derived using the available data. Because soil parent material and pedogenesis also influence bulk density, separate regression equations were derived for different groupings of soil parent materials and for different types of diagnostic horizon. The final stratified dataset comprised:

4 groupings separated solely by the type of organic horizon.

4 mineral topsoil groupings separated solely by land use.

1 mineral subsoil groupings separated solely by parent material type (lake marl & tufa).

45 mineral subsoil groupings separated on the basis of parent material permeability and horizon type.

Each grouping was analysed statistically to derive the best possible regression equation relating bulk density to a combination of organic carbon, clay and sand content. The resulting equations explain between 6% and 74 % of the variation in measured bulk density of individual groupings. When applied to the complete bulk density dataset of 1606 measured values, they explain 77% of the total variation with an overall standard deviation of 0.1125.

The bulk density pedo transfer functions were then applied to the mean values of the primary properties dataset to derive mean bulk density values for each combination of soil series / land use / soil horizon.

Soil Hydraulic Properties

As with bulk density, insufficient measurements of soil hydraulic properties were available in the soil profile analytical database to characterize all combinations of soil series and land use from measured data. Soil hydraulic properties in SEISMIC were therefore predicted using pedotransfer functions derived from a theoretically based mathematical description of the soil water potential / moisture content / conductivity relationship using the closed form equation of van Genuchten (1980).

These pedotransfer functions were derived from measurements of bulk density an d volumetric water contents at 5 kPa, 10 kPa, 40 kPa, 200 kPa and 1500 kPa pressure from almost 1,600 soil horizons, supplemented by measurements of volumetric water content at 0 kPa pressure and mean saturated hydraulic conductivity from about 150 and 80 horizons respectively (Hall *et al.*, 1977; Thomasson and Carter, 1992).

Initial estimation of the soil water potential / moisture content curve for each horizon dataset was made using an adaptation of the Arya-Paris model (Arya and Paris, 1981). The closed form van Genuchten equation was then used to fit each curve and the parameters 'alpha' and 'n' derived. Finally, a non-linear least-squares fitting technique was used to derive regression equations relating alpha and n to measured bulk density, organic carbon, clay, silt and sand content.

Volumetric water contents at 5 kPa, 10 kPa, 40 kPa, 200 kPa and 1500 kPa pressure for each horizon were estimated using the van Genuchten parameters alpha and n predicted from the pedotransfer function described above, and the calculated 'saturated' and 'residual' water contents. These latter two water contents were calculated using multiple regression equations, again derived from statistical analysis of measured data. For this purpose, residual water content was assumed to be half that measured at 1500 kPa pressure. Using established methodology described by Hall *et al.* (1977) and Thomasson and Carter (1992), measurements of the water content at 0 kPa and at 1500 kPa pressure were related to some combination of the measured bulk density, organic carbon, clay, silt or sand content, depending on the type of horizon present. The resulting equations explain between 71 and 84% of the variation in measured water contents at 1500 kPa pressure and between 71 % and 73 % of the variation in measured water contents at 0 kPa pressure.

When percentage volumetric water contents predicted using the pedotransfer functions described above are compared with the corresponding measured data in the soil profile analytical database, the estimates have a root mean square error of 5.0 and an overall standard deviation of 3.9.

Percentage volume total porosity values for each horizon were calculated from the predicted bulk density and the particle density estimated from an assumed mineral particle density of 2.65, adjusted to take into account the fraction of organic matter present (assumed to have a density of 1.00).

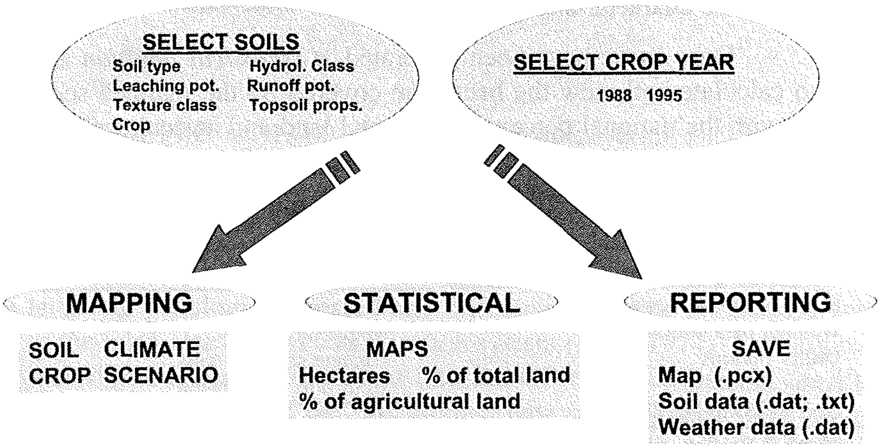
Saturated hydraulic conductivity values were predicted from empirical regression equations relating conductivity to air filled porosity at 5 kPa soil water pressure. These relationships were derived from the limited dataset of saturated conductivity measurements in the soil profile analytical database and explained between 56% and 84% of the measured variation in saturated conductivity depending on the soil texture (Hollis and Woods, 1989). When used to predict saturated hydraulic conductivity for all the measured values in the conductivity dataset, the equations explain 65% of the variation in measured values.

Finally, hydraulic conductivity at 5 kPa was estimated from the relationship between subvertical saturated conductivity, unsaturated conductivity and the saturated, residual and 5 kPa soil water contents, using the closed form equations of van Genuchten (1980).

BASIC STRUCTURE AND FUNCTIONS OF THE SYSTEM

A basic overview of the SEISMIC system is illustrated in Fig. 2 and its functions shown in Table 3. The system has been developed using the 'Clipper' database language (CA Associates, 1992) and is designed to run on a stand-alone desktop or portable notebook IBM/PC compatible micro-computer , ensuring the widest usage for the system. SEISMIC requires a powerful i80386/i80486 with approximately 80Mb of free hard disk space and 4Mb of 'EMS' RAM. Maps and reports generated by SEISMIC may be directed to screen, disk file or printer.

Fig. 2 - Overview of the SEISMIC system.



Upon initiating a SEISMIC session, the user is transferred to the 'Session options' function. This basic option enables users to select different menus that will enable them to select the year of cropping data, select soil types of interest, move to an analysis and presentation option, etc. When selecting soil types, a variety of options are possible. Selections made according to predetermined scenarios enable users to group soil types according to relatively homogeneous hydrological classes (Boorman and Hollis, 1995), organic chemical leaching potential classes, organic chemical run-off potential classes, general soil leaching potential classes (EA, 1992) or pedological subgroups (Avery, 1980). Another option allows the selection of all soil types on which a specified crop is grown. Alternatively, users can select their own soil scenarios according to topsoil and/or subsoil textures or specified ranges of topsoil pH and organic carbon, clay and silt content. All the soil series that conform to the selected scenario are added to a buffer and further menu options allow users to add, delete or modify the contents of this buffer.

The 'Analysis and Presentation' function allows the user either to generate a textual report giving the soil parameter data for each soil series within the buffer or to transfer to the 'Map Presentation' function. Map presentation allows the user either to map the distribution of the selected soil scenario or to select and map individual crop, climate or crop suitability scenarios. It also enables the user to combine the selected soil scenario with a crop scenario and map the resulting distribution, or to refine the selected scenarios by adding filters for crop suitability and/or climate characteristics. Crop suitability filters are activated by specifying one or more crops of interest, whereas climate filters require selection using defined % cover thresholds and parameter ranges respectively. Any combination of crop suitability and climate characteristics can be selected.

Once maps have been generated, a *statistical function* enables users to calculate and view the hectarage covered by the mapped scenario, together with the national percentages of total land and agricultural land represented by the scenario.

TABLE 3. Menus and functions of the SEISMIC System.

Main Menu

Run a SEISMIC session
Weather data options
Utility options
About SEISMIC
Quit SEISMIC to DOS

Menu 2 Session options

Select year of cropping data
Select soil series by category
Remove all selected soil series
Display all selected soil series
Analysis and Presentation
Return to Main menu

Menu 3 Select year of cropping data

1988
1995
Return to Select soil series menu

Menu 4 Select soil series by category

Named soil series
Hydrological class
Organic chemical leaching potential
Organic chemical run-off potential
General soil leaching potential
Soil subgroup
Soil by texture
Soil by topsoil characteristics
Soil by crop type
All soil series
Return to select soil series menu

Menu 5: Analysis and Presentation

Text report
Mapped display
Change selected soils
Return to Main menu

Menu 6: Select map type

Soil map alone
Crop suitability map alone
Crop map alone
Climate map alone
Filter map alone
Filtered soil map
Soil-crop scenario map
Filtered soil-crop map

Menu 7: Weather options

View station descriptions
View station data summaries
View station daily data
Return to Main menu

Menu 6: Utility Options

Image manager
Configure environment
Return to Main menu

Both the textual reports and the maps generated by SEISMIC may be saved to disk file in ASCII and PCX formats respectively. Such files can then be directly accessed for use in mathematical modelling.

THE POTENTIAL FOR A SIMILAR DATABASE SYSTEM FOR EUROPE

Soil

In 1985 a 1:1,000,000 scale soil map covering all 12 EC countries was published (CEC, 1985). This map represents the only harmonised source of data on the spatial distribution of soils at the EU level. The map shows the distribution of 312 Soil Map Units (SMUs), each of which comprises a number of different soil types called Soil Typological Units (STUs). The latter are pedologically-based and differentiated using an adapted version of the FAO-Unesco soil classification system (FAO, 1974). The original map was digitised and incorporated into the CORINE database of the EU (Briggs and Martin, 1988), but this original data set contained some errors and also provides little information on map unit properties other than their pedologically-based constituents. Consequently, the original digitised version of the map is difficult to interpret by non-specialist pedologists and its use is open to error. Since the original digitisation, more information has become available making it possible for many countries to improve the database.

In the early 1990s, a systematic programme for correcting and updating the map (King *et al.*, 1995) was initiated by the JRC. This involved correction of errors, delineation of new map units and improvements in defining map unit contents. The work has been co-ordinated by INRA, Orleans, France and a comprehensively upgraded version of the digital database is now available. This version (3.2.8.0) includes new data from many eastern European countries as well as for Switzerland, Norway and all fifteen countries in the European Community. The data are held in Arc/Info (version 7) and Unix format and consist of Shape (.shp) files defining the spatial polygons of the map, together with associated Table files detailing the percentage of Soil Typological Units (STU) within each Soil Map Unit and a set of basic attributes for all STU's.

In addition to the spatial data, a prototype Soil Profile Analytical Data Base for the EU has been compiled with funding from the European Commission. It contains representative soil horizon parameter data for many of the dominant soil types of each map unit at country level (Breuning

Madsen and Jones, 1995). This Soil Profile Analytical Data Base contains parameter data for all the soil primary properties identified in the section above, as well as estimated or computed data for bulk density and hydraulic characteristics. However, a number of problems exist in using it to provide soil parameter data representative of agricultural scenarios in the EU:

- None of the soil profile analytical data are directly linked to the Soil Geographic Data Base and so cannot be assigned to specific STU's.
- A significant proportion of the data are not representative of agricultural land.
- Even if the all the profile analytical data were to be linked to specific STU's in the Geographic Data Base, over four fifths of its constituent STU's would remain uncharacterised.

Because of these problems, a major effort is required to derive standardised primary property data for particle-size distribution, organic carbon content, pH and bulk density, representative of the designated dominant and secondary land uses of each STU in the Soil Geographic Data Base. The information should be based on the comprehensive soil data held by various national or regional soil organisations (Magaldi, 1995; Le Bas and Jamagne, 1996; Heineke *et al.*, 1998) and their derivation would have to involve specialist participants from all EU countries.

Once the soil primary property data for each STU is derived, soil hydraulic characteristics for modelling purposes can be derived through the use of appropriate pedo-transfer functions. A European Commission-funded project to compile measured data on soil hydraulic characteristics for Europe was completed in 1998 (Wösten *et al.*, 1998). The resulting data base, called HYPRES, contains measured hydraulic property data for 4,486 soil horizons representing 1,777 soil profiles contributed from 11 EU member states. The basic measured data has no links with either the Soil Geographic or the Soil Profile Analytical Data Bases for Europe, but it has been used to derive both broad class pedo-transfer functions and continuous pedo-transfer functions for preliminary estimation of soil hydraulic characteristics from primary soil properties. These HYPRES-derived pedo-transfer functions have been included with the European Soil Geographic and Profile Analytical Data Bases and together they constitute the European Soil Data Base, version 1.0. If a comprehensive soil primary property database for STU's were added to the European Soil Data Base, this would constitute an ideal basis for the soil component of a European level environmental information system, similar to SEISMIC

Climate and weather

The Space Applications Institute of the Joint Research Centre (JRC) at Ispra, Italy, hold data on long-term average monthly precipitation and temperature at a resolution based on a 50 km by 50 km grid. The data were compiled as part of the Monitoring Agriculture from Remote Sensing (MARS) project (Vossen and Meyer-Roux, 1995). They were derived using a method developed by the DLO-Staring Centre for Agricultural Research in the Netherlands (van der Voet *et al.*, 1993) and are based on daily data for the period 1949 through 1991 from 380 stations across Europe (Burrill *et al.*, 1995).

A second source of long-term average climatic data for Europe has been collated by the Climatic Research Unit (CRU) at the University of East Anglia, in the UK as part of the Climatic Impacts LINK Project funded by the UK Department of the Environment. The data are held at a resolution of 0.5° longitude by 0.5° latitude and include long-term monthly averages of precipitation, temperature, wind speed, sunshine hours, cloud cover, vapour pressure, relative humidity and frost days based mainly on the period from 1961 to 1990 (Hulme et al., 1995). The database was derived from various sources and is based on daily data from between 3078 and 957 weather stations across Europe, depending on the specific variable.

Neither of the data sets described above contains information on recharge volumes, which are an important requirement for an environmental information system as they indicate average volumes of leachate moving to groundwater resources. Monthly values of recharge can be calculated from precipitation and potential evapotranspiration for different crops adjusted to take into account the soil moisture deficit. Crop-specific potential evapotranspiration can be calculated with varying accuracy depending on the method used. One of the most accurate methods is based on mechanistic principles outlined by Penman and Monteith (Thompson *et al.*, 1981). However, it requires daily data on humidity, wind speed and sunshine hours which are often available from a relatively small number of meteorological stations. A far simpler, but potentially less accurate, approach is that of Thornthwaite and Mather (1952) which is empirically-based and uses only temperature, rainfall and latitude.

Having derived a set of climatic data, it will be necessary to associate it with a set of long-term daily weather databases which represent the range of climatic conditions within the agricultural regions of the European Union. As described above long-term daily weather data covering the period 1949 through 1991 for 380 stations across Europe is available through the Space

Applications Institute of the Joint Research Centre (JRC) at Ispra, Italy. Each station has daily values for 29 meteorological variables including precipitation, temperature, various indicators of cloud cover, vapour pressure or humidity, wind speed, global radiation and sunshine hours. As part of the MARS project, these data have been converted into consistent units, bound-checked and scanned for inconsistencies such as runs of days with the same value for a variable, minimum temperatures higher than maximum ones, *etc.* (Burrill *et al.*, 1995).

Cropping and land use

The only EU-wide data on the types and quantities of agricultural crops that are grown each year is held in the REGIO databases collated and administered through the Statistical Office of the European Communities; EUROSTAT. Relevant data are held in two main data sets *AGRI2LANDUSE* and *AGRI2CROPS* and hold information on: Total land area, forest, private gardens, total utilised agriculture, permanent grassland, permanent crops, vineyards, arable cultivation, green fodder (within arable land), Cereals (including rice), wheat (soft wheat, durum wheat and spelt), barley, grain maize, fodder maize, rice, potatoes, total oilseed, oilseed rape, sugar beet, sunflowers, tobacco.

The information is available on the basis of the Nomenclature of Territorial Units for Statistics (NUTS) established by EUROSTAT to provide a single uniform breakdown of territorial units for the production of regional statistics for the EU. NUTS have a hierarchical structure with four levels (0 through 4) of increasingly finer resolution, with level 0 representing a single country. Consistent REGIO data on cropping and land use for all EU countries are available at NUTS level 1 (level 2 for Sweden and Finland). These data represent a consistent and easily obtainable EU-wide set of cropping and agricultural land use data that can be used to identify the main usage areas for pesticides within Europe. However, it is statistically based and does not define actual crop distribution on the ground.

Data relating to actual land use within Europe at a resolution of 1 km by 1 km is available from the United States Geological Service (USGS) EROS Data Centre as part of its Eurasia land cover characteristics database. It has been derived from the Normalised Difference Vegetation Index (NDVI) data from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery spanning a twelve-month period from April 1992 through March 1993. Although this data set represents a very high resolution of information for Europe, there are problems in using it directly for defining potential areas of cropping:

- The range of land uses defined in the data does not include any detailed differentiation of crop types.
- The uncertainty of thematic mapping interpreted from satellite images means that even some of the broad land use categories identified in each 1 km by 1 km grid cell may be incorrectly classified. It is noted in the description of the databases that they have not yet been validated and are subject to review.

However, the USGS data set could be used to define polygons comprising non-agricultural areas; urban, forest, shrub land/grassland, *etc.* These categories are relatively easy to identify and differentiate from agricultural land on satellite images. The non-agricultural polygons could then be overlain on the NUTS level 1 polygons to mask out the non-agricultural areas. Cropping statistics for each NUTS level 1 unit can then be attached to the agricultural polygon representing that unit. In this way, accurate cropping statistics can be applied to the specific agricultural areas within each NUTS polygon.

CONCLUSIONS

It is in the interests of governments, industry and consumers alike that we can effectively utilise our land resource whilst maintaining or improving environmental quality. If this goal is to be realised, it is imperative that accurate methods are developed for assessing the environmental impact resulting from different land management practices. An easily used system for examining and accessing the critical environmental characteristics that determine chemical fate is a vital component of the environmental risk-assessment 'toolbox'.

Within Europe, whilst databases relating to soil, climate, weather and land use are either available or in preparation, none are held in a consistent and easily accessible format and there is no management system for their manipulation, correlation and interrogation. However, the techniques and principles used in the development of the SEISMIC system for England and Wales could be applied at a European level to provide an easily accessible data management system for supporting model predictions of the environmental fate of chemicals.

References

ADDISCOTT T.M., WAGENET R.J. (1985). Concepts of solute leaching in soils: a review of modelling approaches. *J. Soil Sci.* 36, 411-424.

ARYA L.M., PARIS J.F. (1981). A physico-empirical model to predict the soil moisture characteristic from particle-size distribution and bulk density data. *Soil Science Society of America Journal* 45, pp 1023-1030.

AVERY B.W. (1980). Soil Classification in England and Wales: Higher Categories. Soil Survey Technical Monograph No. 14, Harpenden. 67 pp.

BOORMAN D.B., HOLLIS J.M., LILLY A. (1995): *Hydrology of soil types: A hydrologically based classification of the soils of the United Kingdom.* Institute of Hydrology Report No. 126, Wallingford. 137 pp.

BREUNING MADSEN H., JONES R.J.A. (1995). The Establishment of a Soil Profile Analytical Database for the European Union. In: *European Land Information Systems for Agro-Environmental Monitoring.* (eds.) D. King, R.J.A. Jones, A.J. Thomasson. EUR 16232 EN, 61 - 70. Office for the Official Publications of the European Communities, Luxembourg.

BRIGGS D.J., MARTIN D.M. (1988). CORINE: an environmental information system for the European Community. *Environment Review* 2: 29-34.

BURRILL A., VOSSEN P., VAN DIEPEN C.A. (1995). A GIS Database for Crop Modelling. In: *European Land Information Systems for Agro-Environmental Monitoring.* (eds.) D. King, R.J.A. Jones, A.J. Thomasson. EUR 16232 EN, 143 - 154. Office for the Official Publications of the European Communities, Luxembourg.

CEC. (1985). *Soil Map of the European Communities 1:1,000,000.* CEC-DGVI, Luxembourg, 124 pp, 7 maps.

CA (1992). *CAClipper: Version 5.2.* Computer Associates. International Press.

EA (1998). *Policy and practice for the protection of groundwater.* Environment Agency, Almondsbury, Bristol, UK. 57pp.

EC. (1995). *Leaching Models and EU Registration: Final Report.* European Commission Directorate General for Agriculture. VI-B-II.1. DOC. 4952/VI/95. 123 pp.

EC. (1996a). *Surface Water Models and EU Registration of Plant Protection Products: Final Report.* European Commission Directorate General for Agriculture. VI-B-II.1. DOC. 6476/VI/96. 218 pp.

EC. (1996b). *Soil Persistence Models and EU Registration: Final Report.* European Commission Directorate General for Agriculture. VI-B-II.1. DOC. 7617/VI/96. 74 pp.

FAO. (1974). *FAO-Unesco Soil Map of the World. 1:5,000,000. Volume I Legend.* Unesco – Paris. 59 pp.

HALL D.G.M., REEVE M.J., THOMASSON A.J., WRIGHT V. (1977). *Water Retention, Porosity and Density of Field Soils.* Soil Survey Technical Monograph No. 9, Harpenden, UK. 75 pp.

HALLETT S.H., JONES R.J.A., KEAY C.A. (1996). Environmental Information Systems Developments for planning sustainable land use. *Int. J. Geographical Information Systems,* 10, 1, 47-64.

HEINEKE H.J., ECKLEMANN W., THOMASSON A.J., JONES R.J.A., MONTARELLA L., BUCKLEY B. (eds.) (1998). *Land Information Systems: Developments for Planning the Sustainable Use of Land Resources.* European Soil Bureau Research Report No. 4, EUR 17729 EN. 546 pp. Office for the Official Publications of the European Communities, Luxembourg.

HOLLIS J.M., WOODS S.M. (1989). *The measurement and estimation of saturated hydraulic conductivity.* SSLRC Research Report for MAFF Project c(i). SSLRC, Silsoe (UK), 25 pp.

HOLLIS J.M., THANIGASALAM P., HALLETT S.H., MAYR T.R., JARVIS N. (1995). *SEISMIC: User manual.* Soil Survey and Land Research Centre, Cranfield University, Silsoe, UK. 108 pp.

HOLLIS J.M., AVERY B.W. (1997). History of soil survey and development of the soil series concept in the U.K. In: *History of Soil Science - International Perspectives.* (Eds. Dan H. Yaalon, S. Berkowicz). *Advances in Geoecology* 29, 109-144.

HULME M., CONWAY D., JONES P.D., JIANG T., ZHOU X., BARROW E.M., TURNEY C. (1995). *A 1961-90 Gridded Surface Climatology for Europe, Version 1.0, June 1995. A report Accompanying the*

Datasets Available through the Climate Impacts LINK project. Climate Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, UK. 50 pp.

HUTSON J.L., (1992. The use of models in the regulatory decision making process. In: *Proceedings of the Brighton Crop Protection Conference - Pests and Diseases 1992*, 3, 1253-1260. British Crop Protection Council, Farnham, Surrey, 1992.

IUPAC (1987). IUPAC report on pesticides (23). Potential contamination of ground water by pesticides. *Pure and Applied Chemistry*, 10: 1419-1446.

JONES R.J.A., THOMASSON A.J. (1985). *An Agroclimatic Database for England and Wales.* Soil Survey Technical Monograph No. 16, Harpenden, UK. 45 pp.

JONES R.J.A., THOMASSON A.J. (1987). Land suitability classification for temperate arable crops. In *Quantified Land Evaluation Procedures.* eds. K.J. Beek, P.A. Burrough, D.E. McCormack, ITC Publication No. 6, pp. 2935.

JURY W.A., GHODRATI M. (1989). Overview of organic chemical environmental fate and modelling approaches. In: *Reactions and movement of organic chemicals in soils* (eds. B.L. Sawhney & K. Brown), pp 271-304. Soil Science Society of America Special Publication No. 22, Madison, Wisconsin.

KING D. BURRILL A., DAROUSSIN J., LE BAS C., TAVERNIER R., VAN RANST E. (1995). The EU Soil Geographic Database. In: *European Land Information Systems for Agro-Environmental Monitoring.* (eds.) D. King, R.J.A. Jones, A.J. Thomasson. EUR 16232 EN, 43 - 60. Office for the Official Publications of the European Communities, Luxembourg.

LE BAS C., JAMAGNE M. (eds.) (1996). *Soil Databases to Support Sustainable Development.* EUR 16371 EN. JRC-INRA, Orleans. 149 pp.

MAGALDI D. (1995). Soil mapping in EU Countries: A Short Review. In: *European Land Information Systems for Agro-Environmental Monitoring.* (eds.) D. King, R.J.A. Jones, A.J. Thomasson. EUR 16232 EN, 197 - 206. Office for the Official Publications of the European Communities, Luxembourg.

McGRATH S.P., LOVELAND P.J. (1992). *The Soil Geochemical Atlas of England and Wales.* Blackie Academic and Professional, Chapman and Hall, Glasgow. 101 pp.

RICHARDSON S.J., WRIGHT D.A. (1984). *WGEN: A model for generating daily weather variables.* ARS-8. US Department of Agriculture, Agricultural Research Service.

Soil Survey Staff (1983). The National Soil Map Of England And Wales, 1:250,000 Scale (In Six Sheets) Ordnance Survey (Crown Copyright), Southampton.

THOMASSON A.J., CARTER A.D. (1992). Current and future uses of the UK soil water retention dataset. In: *Indirect Methods for Estimating the Hydraulic Properties of Unsaturated Soils.* eds. M. Th. van Genuchten, F.J. Leij, L.J. Lund, University of California, Riverside, California. pp. 355-358.

THOMPSON N., BARRIE I.A., AYLES M. (1981). *The Meteorological Office Rainfall and Evapotranspiration Calculation System: MORECS (July, 1981).* Meteorological Hydrological Memorandum N. 45, Bracknell, UK.

THORNTHWAITE C.W., MATHER J.R. (1957). *Instructions and tables for computing potential evapotranspiration and the water balance.* Drexel Institute of Technology, Laboratory of Climatology, Volume X, Number 3, Centerton, New Jersey.

VAN DER VOET P., VAN DIEPEN C.A., OUDE VOSHAAR J. (1993). *Spatial Interpolation of Daily Meteorological Data: A knowledge-based procedure for the regions of the European Community.* SC Report 53/3. Approx. 70 pp.

VAN GENUCHTEN M.Th (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal*, 44, pp. 892-898.

VOSSEN P., MEYER-ROUX J. (1995). Crop Monitoring and Yield Forecasting Activities of the MARS Project. In: *European Land Information Systems for Agro-Environmental Monitoring.* (eds.) D. King, R.J.A. Jones, A.J. Thomasson. EUR 16232 EN, 11 - 30. Office for the Official Publications of the European Communities, Luxembourg.

WÖSTEN J.H.M., LILLY A., NEMES A., LE BAS C. (1998). *Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning. Final report on the European Union Funded Project 1998.* DLO Winand Staring Centre. Report 156. Wageningen, Netherlands. 106 pp.

SOIL VULNERABILITY AND LAND USE PLANNING IN SLOVENIA

T. Prus., B. Vršèaj, F. Lobnik

University of Ljubljana, Biotechnical Faculty
Centre for Soil and Environmental Science (CSES)

Summary

Population pressure and increasing human activities form a heavy burden on vulnerable natural terrestrial ecosystems. Factors affecting this system refer in particular to: soil type, climatic conditions and nature and intensity of human interventions.

Slovenia is characterised by a wide diversity of soils and landscapes due to the variety of geological, climatological and other conditions.

The nature of socio-economic activities is multi-faceted and its intensity increases with the shift from a rural to an urban/industrial society. Due to the Slovenian legislation an integrated environmental impact assessment has to be done in the process of planning before the human activity starts. This assessment deals with all elements of human environment including the soil.

As an example some projects are presented where the assessment of soil vulnerability was included: the national irrigation project, several projects of environmental impact assessment for highway construction and soil pollution studies.

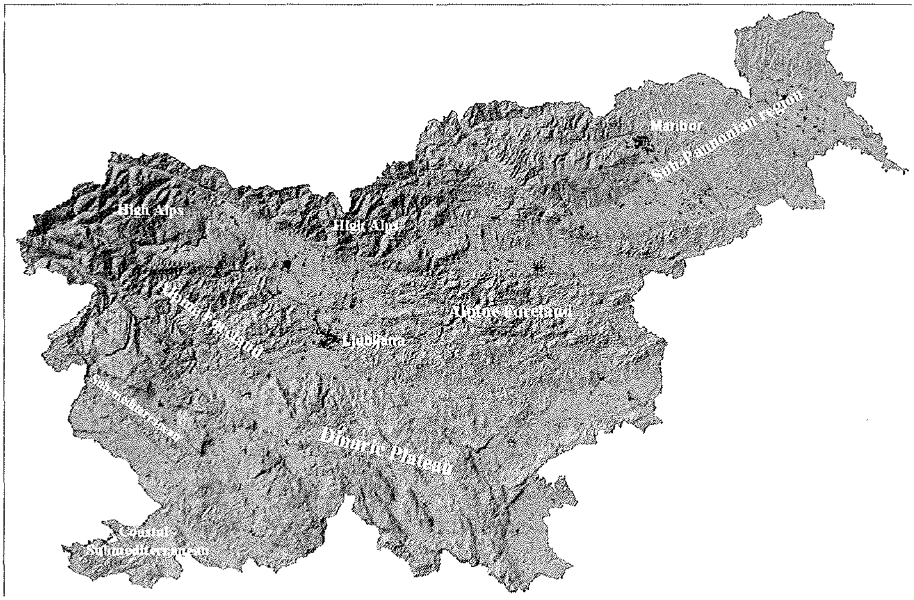
1. Introduction

The pressure of increasing human population and its activities on terrestrial ecosystems is growing. The factors that affect these systems are natural, such as soil type and climatic conditions, as well as anthropogenic, such as the nature and intensity of human interventions. For example, the areas for sludge application should be selected based on soil vulnerability and possible groundwater contamination. Even the locations for recreational objects such as ski trails and golf playgrounds, should be planned due to soil vulnerability and natural regeneration capability. Food and animal production should be planned to avoid polluted soils along the highways in around industrial areas which are sources of contaminating substances.

In Slovenia, we find a wide variety of soils and landscapes caused by high variation in geological, climatological, and other natural factors. Verheye, Prus and Lobnik (1991) classify Slovenian landscapes into six classes based on the lengths of plant growing period. They follow from the shortest to the longest: Alpine, Alpine-Dinaric, Subalpine, Subpanonian, Submediterranean – inland and Submediterranean – coastal.

Figure 1:

Slovenian Landscapes



Soils in the **Alpine region** are predominantly shallow and can contain large amounts of skelet and weakly decomposed organic matter. Soil types can be classified as Lithic, Umbric and Rendzic Leptosols (FAO-UNESCO, 1988).

At a lower altitudes, in the foothills of **Alpine and Dinaric** mountain belts, we find Leptosols, Cambisols, Luvisols and Podzoluvisols. Gleysols and Histosols can be found in depressions of higher plateaus and valleys.

Inland, in the area with the Subalpine type of growing period, the soils are medium deep, have a good structure, and can be somewhat leached. Soil types found on predominantly carbonate parent materials (mostly limestone and dolomite) are Leptosols, Cambisols and Luvisols. Soils that form on predominantly siliceous parent materials are Dystric Cambisols and Luvisols. In the large valleys and intermontane basins filled with well draind glacio-fluvial sandy gravel, we find Eutric Cambisols. Hydromorphic soils such as Fluvisols, Gleysols, Planosols and Histosols apper on loamy–clays that cover the edges of large valleys and the bottoms of small ones.

In the **Submediterranean - inland** part of Slovenia we find three main groups of soils. The first group contains Chromic Cambisols and Leptosols covering the Karstic plateaus. The second are the alluvial soils in the Vipava Valley such as Eutric Fluvisols and Eutric Cambisols which can have moderately hydromorphic properties. Non- calcareous flysch of the Brkini area is covered by Dystric Cambisols and Leptosols.

In the **Submediterranean – coastal** part Slovenia, the predominant parent material is the erodible calcareous flysch. Here, we find Eutric Regosols, Leptosols and Cambisols.

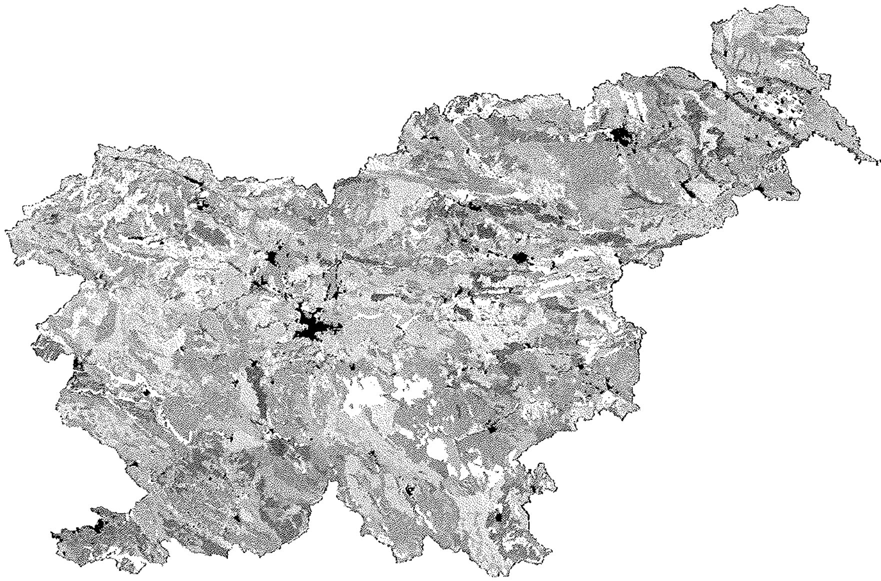
In the flatland of the **Subpanonnian area** in eastern Slovenia, we find Cambisols, Planosols, Luvisols and Acrisols.

The best agricultural land can be found at the edge of Pannonian Basin in the Northeastern Slovenia, and on the bottoms of large intramontane basins such as the Ljubljana Basin, the Savinja basin and the Drava Basin. Traditionally, the agricultural production has been an important part of local economy in these areas, and can be crop specific. The Savinja Valley, for example, is known for hop production, whereas the gently sloping edges of the Vipava Valley are home to many vineyards. Agriculture in these areas is becoming more and more intensive. It uses growing amounts of agrochemicals which endanger soils and groundwater. Mechanised agriculture is compacting soils which can reduce drainage. Sustainable agriculture is often more a wish than reality. The reduction of soils filter capacity caused by perturbed physical or chemical processes can seriously affect the quality of the groundwater.

The valleys, however, are also the preferred sites for settlement and industry. In the past 25 years, the expansion of urban and industrial areas caused a loss of more than 60.000 ha, or about 10 % of the arable land. The intensity of pressure increases with the shift from a rural to an urban/industrial society. New infrastructure and settlements are constructed; industrial areas are developed and/or enlarged. Increasing traffic causes soil contamination along roads. Industrial activity is a source of various polluting organic and metal substances.

Figure 2:

Soil map of Slovenia



A large part of the country is covered by mountains with little or no other agricultural potential than forestry and extensive grazing. The narrow alpine valleys are important traffic corridors and preferred settlement areas. Even though relatively sparsely populated, these areas are also endangered because human activities often cause soil erosion of these erosion susceptible areas.

Mountainous regions have high touristic potential. Tourist activities exert strong pressure on these vulnerable ecosystems. Skiing activities in the Alpine and Dinaric Karst regions require the development of infrastructures. These can cause soil erosion, hamper the natural flow of water, and increase sewage problems. Mountaineering can also trigger soil erosion and can be a source of specific pollution.

Because Slovenia as a small country, a careful and rational land use planning as well as the use of natural resources are of utmost importance. Therefore, the soil and landscape vulnerability should be an important factor in land use planning decision process.

First, however, we need to solve the following question:

How do we quantify soil and landscape vulnerability and introduce it into the land use planning process?

On a new constitutional basis, Parliament passed the **Act on the Protection of the Environment** in June 1993 (*Official Journal of the Republic of Slovenia*, No. 32/93). The Act contains general provisions and basic methods of protecting the environment and exploiting natural resources. On the basis of the Environmental Protection Act, new legislation regarding soil protection, has been adopted in Slovenia recently.

Slovenian legislature requires environmental impact assessment as a integral part of any land use project. As stated in the law, this assessment should be based mostly on the vulnerability of the area in question. In 1993, when this law about the environment protection was passed, there were plans to prepare a general study of environmental vulnerability for the whole state, regions and communities. The basic principle of the vulnerability study was supposed to be the study of ecosystem components. Every study should include the regenerational and neutralizational capability of environment in relation to the level of environmental impact. The study has to prepare an estimate of acceptable environmental burden and the proposal of the necessary protection measures. Several pilot studies were prepared but the results were limited because the parameters that define the vulnerability were not well defined. Moreover, the vulnerability is strongly correlated to the type of impact.

Nevertheless the integrated environmental impact assessments are requested for very different impacts. A detailed list of these interventions into the environment was published in a government decree. Some of the interventions are defined based on the affected surface area. For example, a ski trail longer than 500 m, irrigation system over 10 ha, biological compost production in the amount of more than 5000 t per year etc.

Most of these assessments deal with all of the elements of human environment including soils. However, the assessments are too often prepared by civil engineers, chemists, biologist, or geographers, who are not trained or experienced in soil science. That is why of the Center for Soil Science and Environment plan to establish a soil database that could be used by other experts. The soil vulnerability estimates should be among the attribute data in the Digital Soil Map or better in the Slovenian Soil Information System (Vršèaj B., Prus T., Lobnik F., 1998).

The Digital Soil Map of Slovenia is a part of Slovenian Soil

Information System (SIS) which has several layers: the Digital Soil Map in the scale 1:400.000, the Digital Soil Map in the scale 1:25.000, the Digital Soil Map in the scale 1:5.000 , the soil profile data, and the data on points of soil pollution monitoring (reference). The Digital Soil Map itself, however, is not sufficient for soil environmental impact assessment.

SIS was established only as an academic project. The mapping and digitalisation were funded by the Slovenian Ministry of Agriculture. The bottleneck for the environmental studies are the lack of appropriate attribute data. Though SIS contains a large amount of soil profile data, the soil are not presented in a form useful for environmental assessment by non-soil scientists. Therefore, additional funding is needed in order to prepare the attribute database that can be used also by non-soil scientists.

The Centre for Soil Science and Environment has used the existing SIS data to prepare several soil vulnerability studies described below. For these studies, we prepared the new attribute data for the areas and soil properties in question.

2 The national irrigation project

For example, we used the digital soil data to identify areas which are not suitable for irrigation because of high soil and groundwater vulnerability. The objective of the project was to identify the areas suitable for irrigation in areas where the irrigation is needed.

The project has been prepared following the FAO guidelines (FAO, 1976, 1985). The environmental impact of irrigation was an important step of the study. The following factors have been used for determination of irrigation suitability classes and in the environmental impact assessment: parent material, hydrological properties of soils, drainage, landform (slope), agro-climatic zone, the present land use, and the potential land use.

Soil parameters, that were considered, were soil texture, soil depth (effective depth), soil reaction (pH), available nutrients, and the content of organic matter. These were combined into new attribute data for each of the soil systematic units defined in the soil information system. Then, the soil systematic units have been classified into one of four suitability classes in Table 1.

Figure 3:

Vulnerable and shallow soils in lowlands (marked as 4p), which fell into the suitability subclass 4p (not suitable for irrigation) in Drava - field.

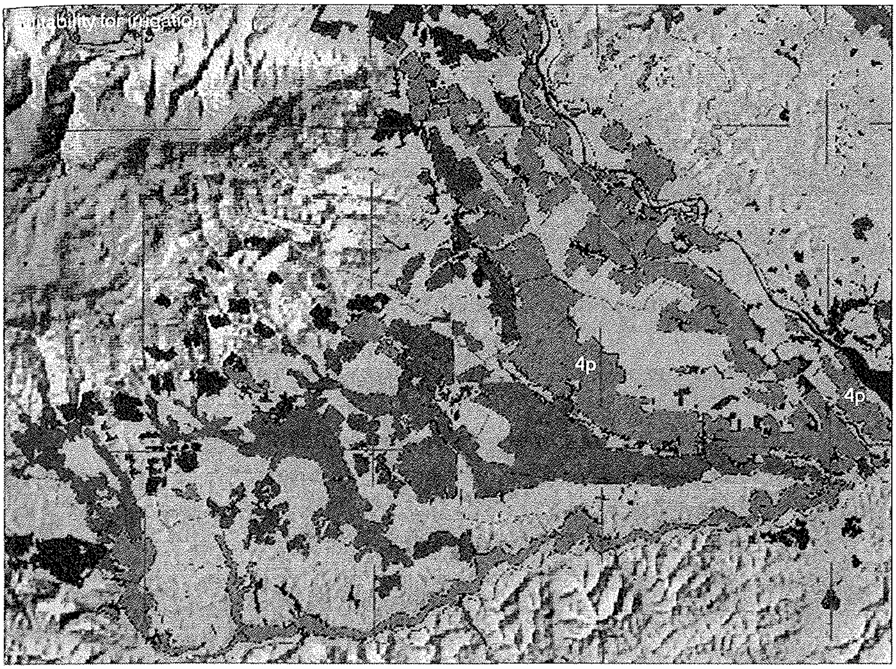


Table 1: Suitability classes for irrigated agriculture.

	suitability class 1	suitability class 2	suitability class 3	suitability class 4s	suitability class 4p
	low and flat land, the soils with very low water-holding capacity	soils with higher water holding capacity	soils with uncontrolled water regime; special irrigation techniques could be applied	slope & shallow soils & stoniness (& rockiness), special irrigation techniques could be applied	permeable and shallow soils in lowland
potential land use	**no limitations** (*no environmental constrains*)	**limitations in oxygen availability and in soil workability**	**severe limitations in oxygen availability and soil workability**	**limitations in workability and in environmental impacts**	**limitations in environmental impacts**
present land use	intensive agriculture, mostly large land facets	less agriculture, more grassland	intensive agriculture only on ameliorated areas	less agriculture, many orchards and vineyards	agriculture, field crops

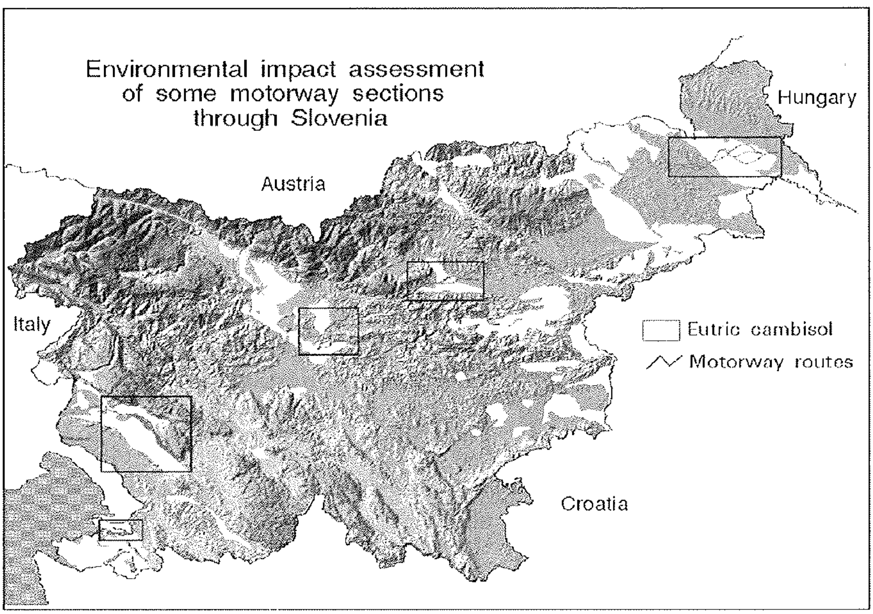
This system has resulted in identification of vulnerability of shallow soils in lowlands, which fell into the suitability subclass 4p (not suitable for irrigation) (Figure 3). Later, this vulnerability was confirmed when the groundwater pollution was found in several areas of that subclass, even without the additional burden of irrigation.

3. Environmental impact assessments for highway construction

We also used our existing data to identify areas that are especially vulnerable to highway construction The main criteria was the production potential of soils. Soil deterioration and destruction assessment has been done in the following order: soil survey, soil validation, and the calculation of the production potential index. The calculation of the lost areas for each soil unit has been performed at the first step. Afterwards, the various routes have been evaluated, and, finally, changes to the routes were proposed.

Figure 4:

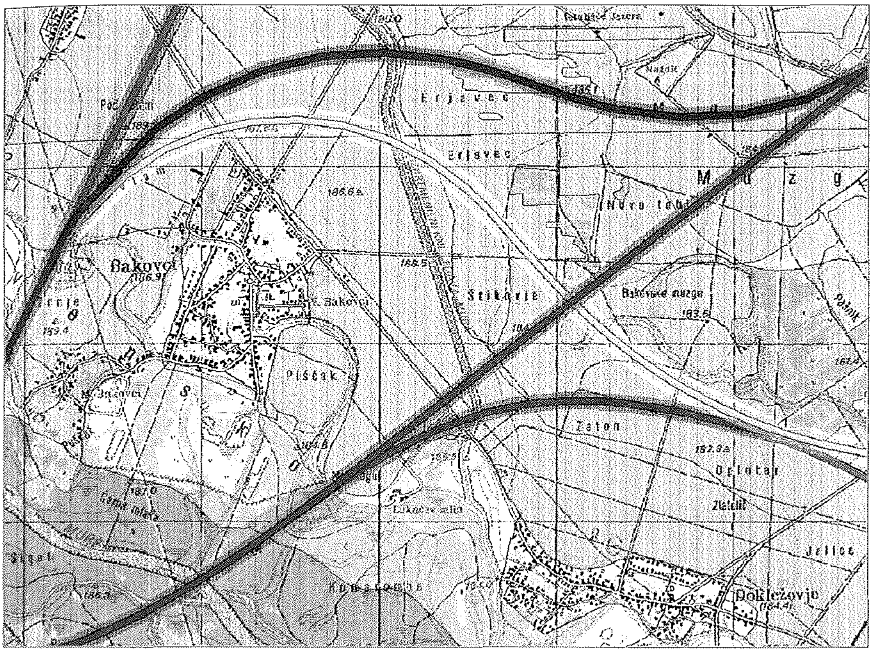
Relief of Slovenia showing the areas of prime agricultural soils superimposed by proposed highway routes.



The road designers usually provided several variations of routes for a given section of highway.

Figure 5:

Different routes proposed through an agriculturally important area, the Mura river region.



The first assessment used the existing 1:25 000 soil data. The soil map was overlain with a layer containing digitised highway routes. This resulted in a list of affected soil units and soil types and their areal extent. The width of an area affected by the highway depends on accompanying objects (onramps, bridges, crossings, rest areas, etc.). An additional zone of 30-40 m from the pavement at the each side of the highway was considered to be significantly affected and unsuitable for agriculture. This zone is usually affected during highway construction, can contain noise or wind barriers or vegetation, and will be polluted to a certain extent by traffic emissions. This land is, therefore, lost to agriculture.

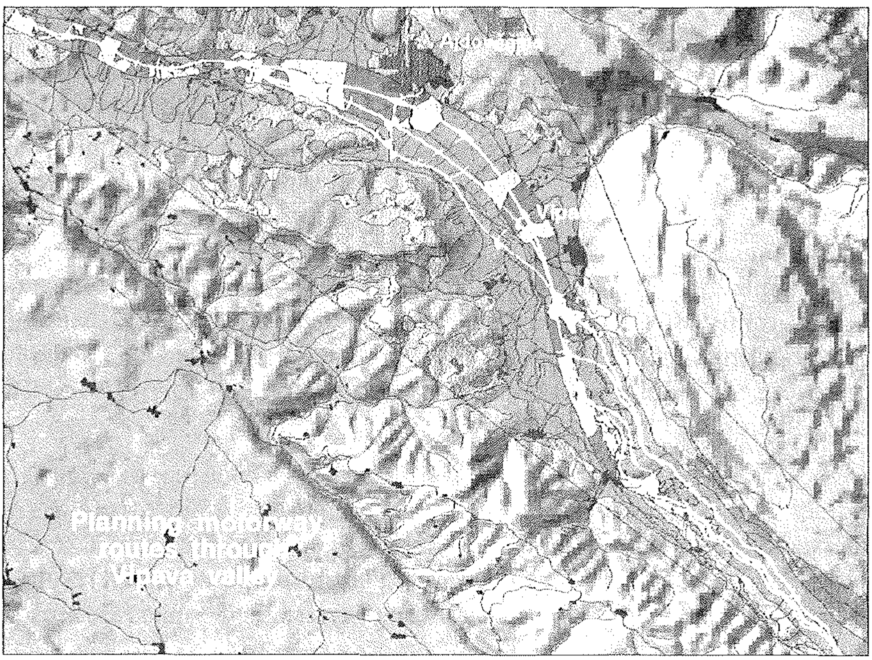
The names of the soil types usually do not mean anything to road designers. The results of a study must be presented in a form they can understand, preferably as a single number. Therefore, we adapted a parametric evaluation system developed for cadastral purposes which results in production potential index. The origin of the system is German "Bodenshätzung" (Herzog, 1941), adapted for use in Slovenia by Stepanèiè (1984).

Each soil type (SSU) of the Digital Map in the scale 1:25.000 had to be classified according to its stage of soil profile development (7 classes), parent material composition (5 classes), and textural composition (13 classes). The production potential index can then be from the table. Sometimes points have to be subtracted for less suitable topography configuration, the content of skeleton, etc. The final result is the production potential index which can range between 7 and 100 points. 100 points represent prime agricultural land (Herzog, 1941). The index is then divided into five classes and named according to common methodology which is also used for other environmental impact assessment (noise, air, forests, wild animals, etc.) (Rupreht, 1994):

- no impact, less than 30 points
- negligible impact, 30 to 43
- moderate impact, 43 to 56
- high impact, 56 to 70
- inadmissible high impact over 70 points.

Figure 6:

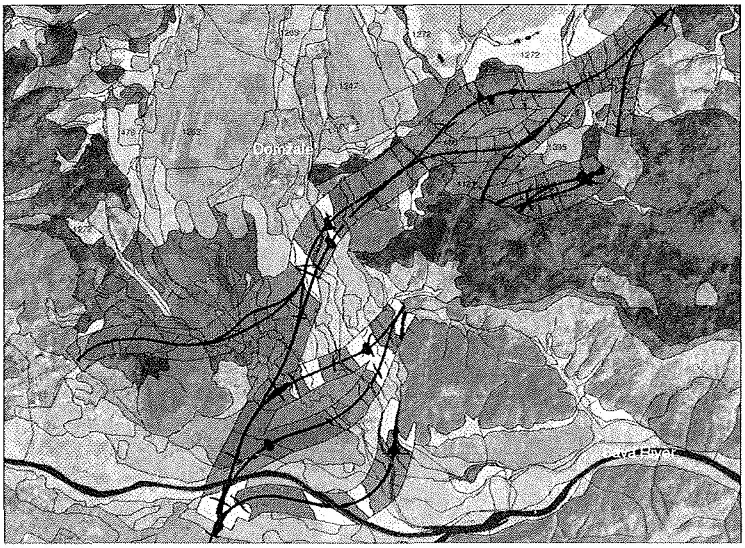
A high vulnerability of soils on gravel and sand in the surrounding of Vipava valley.



A high vulnerability of soils on gravel and sand deposits was reported especially in the surrounding of Vipava valley and Dom ale (Figures 6 and 7). This methodology was also accepted for all soil assessments done by other institutions for other sections of highway routes.

Figure 7:

A high vulnerability of soils on gravel and sand in the surrounding of Dom ale.



4 The soil vulnerability for soil pollution

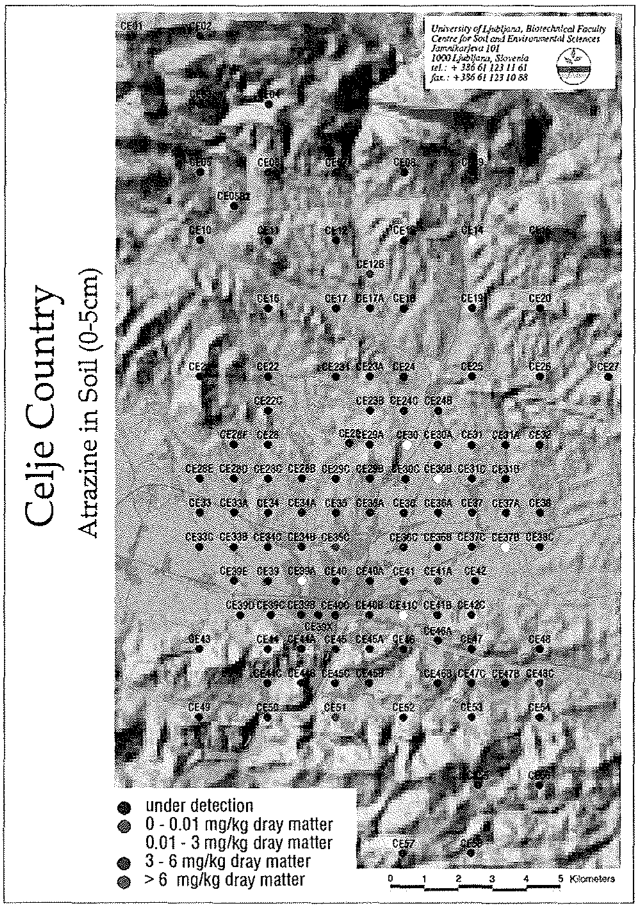
The soil vulnerability databases can also be used for soil pollution studies. **Decree on Input of Dangerous Substances and Plant Nutrients into the Soil** (*Official Journal of the Republic of Slovenia*, No. 68/96) was also adopted in November 1996 in order to regulate the input of fertilisers (both mineral and organic: manure or slurry) and heavy metals in soil. In purpose to set up maximum allowed values of dangerous substances in soil the **Decree on the Limit, Warning and Critical Concentration Values of Dangerous Substances in Soil** was adopted in 1996 (*Official Journal of the Republic of Slovenia*, No. 68/96).

Soils are the part of ecosystem which can retain polluting substances longer than air, water or living organisms. Pollution is detected when these substances which are not typical of the soils, neither in quantity nor in form, appear in the soil. Moreover, these substances can not be "neutralised" by the soils and their buffer capability. Therefore, hazardous substances can be taken up by plants or leached to the groundwater, therefore, entering into the food chain. Several case studies were prepared for different parts of Slovenia: Celje county, Me ica valley, Anhovo in Soèa valley, Jesenice, etc.

Different case studies produced similar results. Soil vulnerability to pollution depends on the nature of polluting substances on the properties of soil types (Figures 8, 9).

Figure 8:

Soil pollution assessment in Celje county.



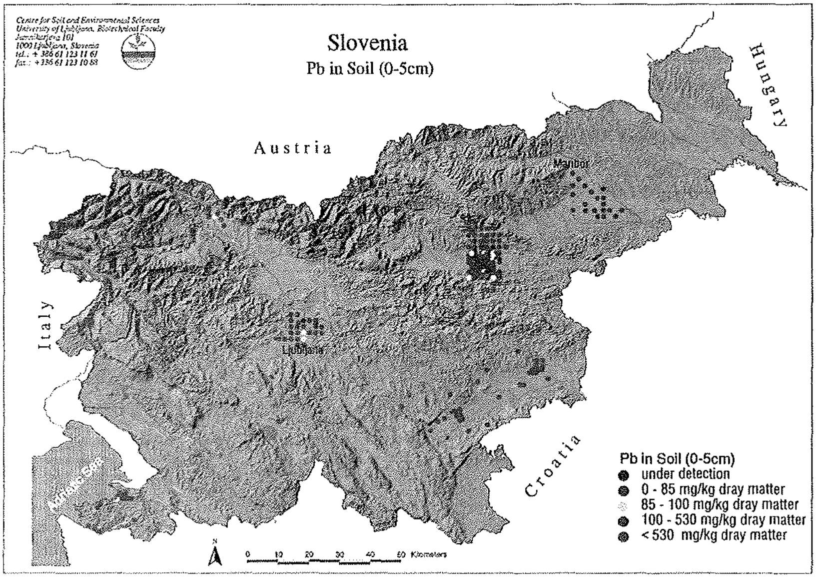
We have prepared a table that can be used for planing activities in the areas where an increase of certain substances has been detected (Table 2).

Table 2: Action plan for contaminated soils (Zupan M., 1999)

DEGREE OF POLLUTION	ENVIRON MENTAL IMPACT	ACTION	LAND USE	FOOD AND FODDER PRODUCTION AND DRINKING WATER
under detection limit	no impact	prevention	without limitations	without limitations
under limit value	no impact	prevention	without limitations	without limitations
under alarm value	hazards not to be expected	strict prevention and soil pollution control	conditionally all type of land use, not recommen ded for gardens	not recommended for production of leafy and root vegetables, periodical control of plants and water
under critical value	hazards possible	further soil pollu tion research and simple remedia tion (land use limitations)	conditionally all type of land use, but not allowed for direct food production	not recommended for vegetable production and limitations for other agricultural plants, regular and frequent control of plants and drinking water
above critical value	hazards certain	remediation and/or recultivation process	non agricultural land use	not allowed for food and fodder production, soil surface must be overgrown, regular control of drinking water

Figure 9:

A part of available soil pollution data on WWW



5. Conclusions

Soils in Slovenia, as in many parts of the Europe, are degraded by human activities, such as agriculture, industry, urban development, tourism. Although soil is a renewable resource, natural soil-forming processes are very slow. That is why the immediate action is needed to prevent future contamination.

Land use planning activities in the broadest sense should be oriented toward environmental protection. The analyses of ecosystem components should represent and important part of these activities. Moreover, the soils as a very important part of all terrestrial ecosystems should be taken in consideration. The total loss of the soil due to sealing is just one part of that consideration. The environmental impact assessment is increasingly important when we try to diminish or avoid the human impact on the environment.

The **National Environmental Action Plan** (NEAP) in Slovenia, the was adopted in September 1999 at the Parlimental level. NEAP set out the goals, guidelines and strategy for environmental protection and the use of natural resources for the next 10 years, subdivided into two five-year periods.

Our expectations and suggestions are:

- Soil should be treated individually as a medium, receiving the same attention as air and water.

- Harmonised soil monitoring system need to be established in order to record the state of soil pollution.

- Co-ordination and co-operation at EU and international level are required.

6. References:

VERHEYE W., T. PRUS, F. LOBNIK (1991). Growing Period Characteristics and their Impact on Soils Cropping Pattern and Natural Vegetation in Slovenia. *PEDOLOGIE*, XLI-2, p. 163-185, 3 tab., 3 fig., Ghent.

LOBNIK F., M. ZUPAN, V. HUDNIK, N. VIDIC JAECKS (1994). A Soil and Plant Pollution Case Study in an Industrial Area in Slovenia. 1994. *Environmental Geochemistry and Health*, Volume 16, p. 287-299, Bradford.

LOBNIK F. (co-ordinator) (1999). Digital Soil Map of Slovenia 1:25 000. Ministry of Agriculture, Forestry and Food and Ministry for Science and Technology.

VRŠÈAJ B., T. PRUS. F. LOBNIK (1998). The Soil Information System in Slovenia (SIS/TIS). 1998, International Conference on GIS for Earth Science Application, Ljubljana.

HERZOG F. (1941). Die Bedeutung der Bodenschatzung fur die Landwirtschaft. Reichsnahrftand Verlag, Berlin.

RUPREHT J. *et al.* (1994). Presoja vplivov na tla kot del okolja z valorizacijo pridelovalnega potenciala kmetijskih zemljišè za avtocesto Celje- Ljubljana odsek Arja vas - Vransko varianti "Ob daljnovodu" in "J4 z V1". Biotehniaka fakulteta, Ljubljana.

PRUS T., VRŠÈAJ B. (1994). Application of Soil Information System in the National Project of Irrigation in Slovenia. Fifth European Conference and Exhibition on Geographical Information Systems EGIS / MARI '94, Paris. p. 1457-1463.

STEPANÈIÈ D. (1984). Pravilnik za ocenjevanje tal pri ugotavljanju proizvodne sposobnosti vzorènih parcel. Republiaka geodetska uprava, Ljubljana.

VRŠÈAJ B., PRUS T. (1994). Soil Information System (SIS/TIS) in Slovenia. Fifth European Conference and Exhibition on Geographical Information Systems EGIS / MARI '94, Paris. p.382 – 390.

ZUPAN M. (1999). Contaminated soils in Slovenia. Oral presentation on 4th Meeting of the Ad Hoc International Working Group on Contaminated Land, Copenhagen, 14 - 15 June 1999.

FAO (1976). A framework for land evaluation. *FAO Soils Bull.* 32, Rome, 72 p.

FAO (1985). Guidelines: land evaluation for irrigated agriculture. *FAO Soils Bull.* 55, Rome, 231 p.

FAO (1988). Soil map of the world, Revised legend. *FAO World Soil Res. Rep.* 60, Rome, 119 p.

VULNERABILITY OF EUROPEAN FOREST SOILS TO AIR POLLUTION

Eric Van Ranst

Forest Soil Coordinating Center (FSCC), Laboratory of Soil Science,
University of Gent, Krijgslaan 281/S8, B-9000 Gent, Belgium

Abstract

The public concern for the health condition of European forest ecosystems has resulted in an extensive forest soil condition monitoring programme set up by the European Commission (EC) and the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The inventory provides information on the chemical status of the humus layer and the mineral (0-20 cm) soil, and on other soil properties of 5289 forest plots of a transnational 16 x 16 km grid, covering 28 countries. In this paper the soil condition data were used (1) to identify chemical changes in European forest soils induced by air pollution, and (2) to assess their vulnerability and sensitivity to acidification. Considering the spatial distribution of measured acid deposition load in Europe, significant differences were detected between chemical soil conditions in different deposition regions: (1) a higher nitrogen content in the organic layer of forest soils is observed in the area receiving a high atmospheric deposition load, as compared to remote areas in Europe; (2) extremely acid topsoil conditions are reported almost exclusively in the region receiving a very high acid deposition load; and (3) concentrations of lead and zinc in humus and mineral surface layers show regional gradients reflecting atmospheric deposition patterns. Available information on 1646 forest plots in 14 European countries has been used to calculate indicator values for the soil's sensitivity to acidification. Nonparametric factor analysis of variance of the indicator values shows that the vulnerability to acidification is largely determined by soil parent material and texture. Mapping the classified indicator values reveals a higher concentration of acid sensitive soils in north-west Europe, whereas soils in eastern Europe and the Mediterranean zone are usually more resistant to acidification. The results clearly show that the data collected

by this large-scale forest monitoring programme permit an evaluation of the current condition of European forest soils, but the singularity of the observations limits the interpretation to a certain extent.

Introduction

A possible reason for the loss of vitality of the European forests is the persistent input of atmospheric pollutants, which might affect forests indirectly through changes of the soil (Matzner and Murach, 1996). Soil damage forms associated to atmospheric deposition, of particular concern in European forests, are soil acidification, nutrient imbalances, and heavy metal contamination (UN/ECE and EC, 1997).

Natural soil forming processes in humid regions lead to acidification, but atmospheric deposition of sulphur compounds and nitrogen (both reduced and oxidised) compounds may accelerate this process (Erisman *et al.*, 1995). Because soils contain various compounds that may buffer acidification processes, it usually takes some time before negative effects of acid deposition, i.e. nutrient depletion, become apparent. However, with continued deposition of acids soil pH may ultimately decrease, which may mobilise potentially toxic elements, such as aluminium and manganese.

Increased levels of nitrogen in forest soils due to atmospheric deposition may lead to a more vigorous vegetation growth. This should be particularly true for trees in the Boreal zone where N is often limiting. A continuous high input of N may adversely affect ecosystem stability due to increased demands of nutrient cations and water, and an increased sensitivity to natural stress factors, such as frost, fungi attack and wind throw (Ulrich, 1995; Matzner and Murach, 1996).

Anthropogenic emissions have enhanced the soil concentrations of heavy metals even in remote areas in Europe (Andreae, 1996). Chemical immobilisation mechanisms in.the topsoil may protect plants against direct toxic effects, but are responsible for a long-term accumulation of heavy metals within the rooting zone, resulting in enhanced heavy metal exposure of plant roots and decomposer communities (Tyler *et al.*, 1989). Because soil pH plays a major role in the adsorption processes of metal cations, input of acidifying compounds can have a triggering effect on heavy metal availability.

Leaching of basic cations from exchange sites is a natural process in most European topsoils, but soil buffering processes following acid deposition accelerate this natural acidification process. Aluminium ions released into the soil solution during H^+ buffering processes compete with other cations for the occupation of exchange sites (Ulrich, 1981; de Vries and Leeters, 1995; Matzner and Murach, 1996). With its small diameter and high charge, Al^{+3} gradually supersedes the basic cations, causing a decrease of base saturation (De Coninck *et al.*, 1998). This not only reduces availability of nutrients, but it also enriches soil solutions with aluminium which may stunt roots or impair their physiological functioning. Especially Al and to a lesser extent Fe and Mn ions in soil solution are the major cause of biological harm due to acidity (e.g. Sverdrup and Warfvinge, 1993). Over time, the vitality and productivity of forests may be decreased due to fewer nutrients and higher levels of toxic metals (Sparks, 1995).

The aim of this paper is (1) to evaluate the results of the recently completed large-scale forest soil condition survey (EC *et al.*, 1997) for indications of chemical changes in forest soils of Europe induced by atmospheric pollution, and (2) to assess the soil's vulnerability and sensitivity to acidification in forest plots covering 14 European countries.

Materials and methods

European Large-scale Monitoring Programme

In response to growing concerns about forest damage caused by air pollution, the United Nations Economic Commission for Europe (UN/ECE) under its *Convention on Long-range Transboundary Air Pollution* (CLRTAP) established in 1985 the *International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests* (ICP Forests). In 1986 the Member States of the European Union (EU) agreed upon the *European Union Scheme on the Protection of Forests against Atmospheric Pollution.* Since then ICP Forests and the European Union have been annually monitoring crown condition at observation plots situated at the intersection points of a transnational 16x16 km grid. In 1997 the results of a soil survey at mostly the same observation plots became available (EC *et al.*, 1997).

Forest Soil Condition Database

Presently, the transnational Forest Soil Condition Database contains information on 5289 forest plots covering 28 countries. The database consists of five main data sets, (1) general plot information including FAO soil unit (FAO, 1988), (2) mandatory chemical parameters, (3) optional chemical parameters, (4) physical soil parameters, and (5) soil parent material.

The organic layer and the mineral soil at two or three fixed intervals between 0 and 20 cm depth were sampled at each observation plot. Soil condition parameters, their reference analysis method, data availability and coefficient of variation are given in Table 1. Although a common methodology for sampling and analysis was adopted before the start of the monitoring activities in most countries, differences in national methods exist (EC *et al.*, 1997). In order to verify the data quality of the reported analysis results, two standard samples were provided to all laboratories, participating in the survey. The results of the standard samples showed a moderate to high variability even among laboratories using the same methods (Table 1). Fortunately, a relatively low interlaboratory variability was observed for the most relevant parameters in this study (17% for pH, 11% for total N and 9% for base saturation).

Clustering Soil Observation Plots

In order to investigate the relationships between soil properties and atmospheric deposition, groups of individual soils, having similar pollution load, were compared. Based on the loads of acidity of atmospheric origin, computed for the EMEP grid cells (150x150 km) using the 1988/1989 deposition data (Hettelingh *et al.*, 1991), four "*atmospheric deposition regions*" (Fig. 1) were defined:

Region 1 (high) has a high load of acidity (> 2000 $mol_c\ ha^{-1}\ yr^{-1}$) and corresponds roughly to West and Central Europe;

Region 2 (intermediate) forms a ring around the first region and has a computed load of acidity between 1000 and 2000 $mol_c\ ha^{-1}\ yr^{-1}$;

Region 3 (low - north) largely corresponds with northern Europe, which has a load of acidity that gradually decreases from about 1000 $mol_c\ ha^{-1}\ yr^{-1}$ in southern Scandinavia and the north-eastern part of the British Isles to less than 200 $mol_c\ ha^{-1}\ yr^{-1}$ in the most northern part of Europe;

Region 4 (low - south), with a low load of acidity (< 1000 $mol_c\ ha^{-1}\ yr^{-1}$), covers most of the western Mediterranean area.

Heavy metal and nitrogen deposition may be expected to be correlated with acidic deposition in the sense that all these compounds usually emanate from industrial areas (de Vries and Bakker, 1996; van Pul *et al.*, 1994).

The nonparametric *Kruskal-Wallis one-way analysis of variance Test* and the *Sample Median Test* were used to check the statistical significance of differences between deposition regions.

Table 1

Methods of analysis, interlaboratory variability and data availability of the parameters in the European Forest Soil Condition Database.

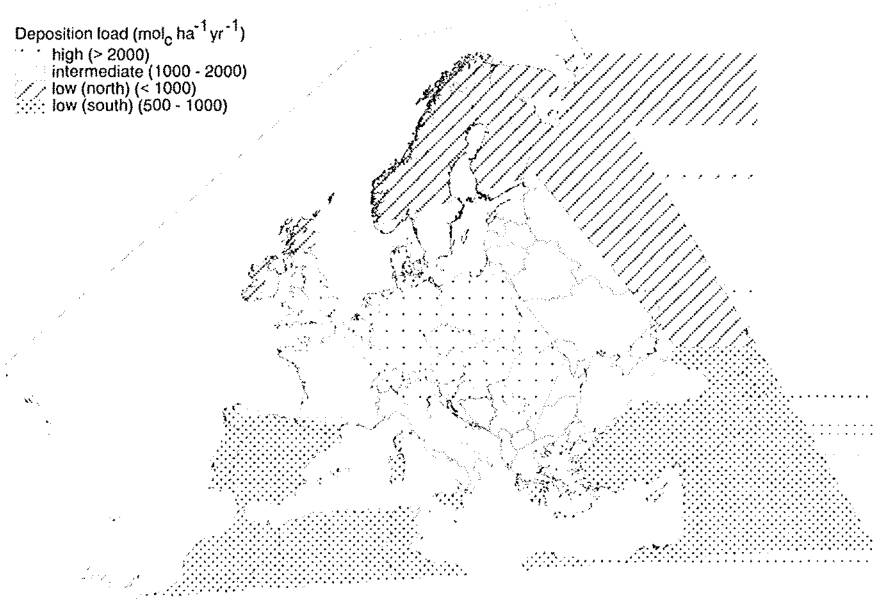
Parameter	unit	reference method	C.V. (1)	data availability O (2)	data availability M (2)
soil unit		FAO (1988)	n.d.		4284
pH		0.01M $CaCl_2$	17%	3649	4218
Org. C	g kg^{-1}	dry combustion	11%	4023	4201
$CaCO_3$	g kg^{-1}	calcimeter	n.d.	-	3807
N	g kg^{-1}	dry combustion	11%	4024	4201
P	mg kg^{-1}	aqua regia digestion	19%	2539	589
K	mg kg^{-1}	aqua regia digestion	48%	2539	501
Ca	mg kg^{-1}	aqua regia digestion	32%	2528	498
Mg	mg kg^{-1}	aqua regia digestion	12%	2532	501
Na	mg kg^{-1}	aqua regia digestion	44%	929	352
Al	mg kg^{-1}	aqua regia digestion	19%	1327	434
Fe	mg kg^{-1}	aqua regia digestion	16%	1354	458
Cr	mg kg^{-1}	aqua regia digestion	61%	1010	444
Ni	mg kg^{-1}	aqua regia digestion	33%	1010	444
Mn	mg kg^{-1}	aqua regia digestion	15%	1397	555
Zn	mg kg^{-1}	aqua regia digestion	14%	1423	555
Cu	mg kg^{-1}	aqua regia digestion	26%	1363	555
Pb	mg kg^{-1}	aqua regia digestion	31%	1241	433
Cd	mg kg^{-1}	aqua regia digestion	28%	1235	433
AcExc	cmol(+) kg^{-1}	0.1M $BaCl_2$ extraction + titration	27%	985	2171
ACE	cmol(+) kg^{-1}	0.1M $BaCl_2$ extraction, $Al^{3+}+Fe^{2+}+Mn^{2+}+H^+$	33%	452	1736
BCE	cmol(+) kg^{-1}	0.1M $BaCl_2$ extraction, $Ca^{2+}+Mg^{2+}+K^++Na^+$	13%	893	2817
CEC	cmol(+) kg^{-1}	BCE+ACE, or BCE + AcExc	17%	893	2817
BaseSat	%	100 x BCE/CEC	9%	893	2817
texture	class	no reference method	n.d.	-	3493
coarse fragments	vol%	no reference method	n.d.	-	2375
bulk density	Mg m^{-3}	no reference method	n.d.	-	2192
parent material	class	no reference method	n.d.	-	2044

(1) coefficient of variation expressing the average relative deviation from the reference value of the standard samples

(2) number of plots for which data is available for organic (O) and mineral (M) layers

Fig. 1

Atmospheric deposition regions based on the spatial distribution of the measured acid deposition load in Europe in 1988/1989.



Acid Sensitivity Assessment

Because the sensitivity to soil acidification cannot be directly measured, an indicator value was derived from a combination of individual parameter values by means of a rating system, based on a concept used by Block *et al.* (1996). Measured parameter results are attributed a class value (1 = very low; 2 = low; 3 = medium; 4 = high; 5 = very high), using mostly ecologically relevant limit values. Class values of BCE and base saturation are weighted according to depth and thickness in such a way that the sum of the weighting factors of the individual mineral layers until 20 cm equals 2. These weights are multiplied with the class values of individual mineral layers, resulting in weighted class values ranging from 0 to 10. Surface layers receive a higher weight than subsurface layers, because it is assumed that root density decreases with depth. Buffering processes against acid deposition also take place mostly in the upper part of the soil.

The class values of the parameters that determine a particular soil quality are summed, resulting in an ecologically interpretable indicator value (Fig. 2). The indicator values have only a relative meaning, but allow direct comparison between plots. The sensitivity to soil acidification is assessed by summation of the indicator values for acidification status (I_{AS}), basic cation availability (I_{BC}) and hydraulic conductivity (I_{HC}):

$$I_{SA} = I_{AS} + I_{BC} + I_{HC}$$

$$I_{AS} = pH_c + BS_c + (CaCO_3)_c$$

$$I_{BC} = BCE_c + BS_c + \frac{1}{3} \cdot (Ca_c + Mg_c + K_c)$$

where:

pH_c = cumulative class value of the pH in the organic and mineral surface layer (range 1 to 10);

BS_c = weighted class value of the base saturation in the mineral layers (range 0 to 10);

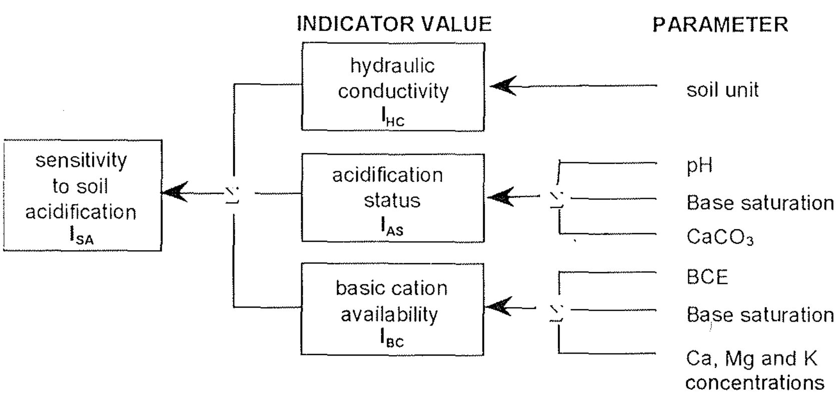
$(CaCO_3)_c$ = class value of the $CaCO_3$ concentration in the mineral surface layer (range 0 to 5).

BCE_c = weighted class value of the sum of exchangeable basic cations in the mineral layers (range 0 to 10);

Ca_c, Mg_c, K_c = class value of the concentration of Ca, Mg and K in the organic layer (range 1 to 5).

Fig. 2

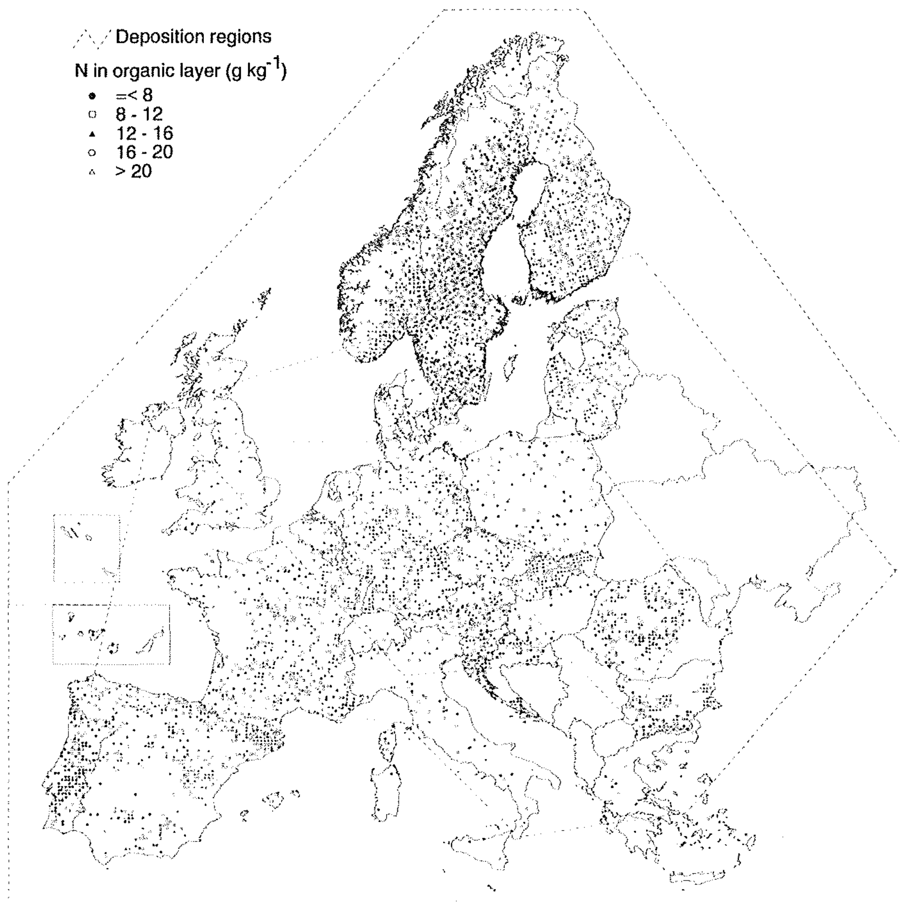
Schematic presentation of the data evaluation concept, using measured parameters to obtain indicator values ('Σ' indicates summation).



The indicator value for hydraulic conductivity (I_{HC}), which largely determines the removal of released nutrients from the rooting zone, is derived from the FAO soil classification name. It is introduced in the overall assessment as a surcharge of 5 for slowly draining soils (Vertisols, Gleysols, Planosols, Histosols and all Vertic and Stagnic subgroups) and a reduction with the same value for soils with a high hydraulic conductivity (Arenosols, Leptosols, Podzols).

Fig. 3

Nitrogen content (g kg^{-1}) in the organic layer of European forest soils.



The resulting indicator value is a measure for the susceptibility of the soil for acidification by acid input, although it disregards most biotic, climatic and forest management factors that may influence the nutrient concentration of the soil. It evaluates the soil's capability to neutralise added acids through (1) replacement of basic cations from exchange sites, (2) dissolution of carbonates, if present, and (3) release of basic cations from organic matter and during mineral weathering.

Results and discussion

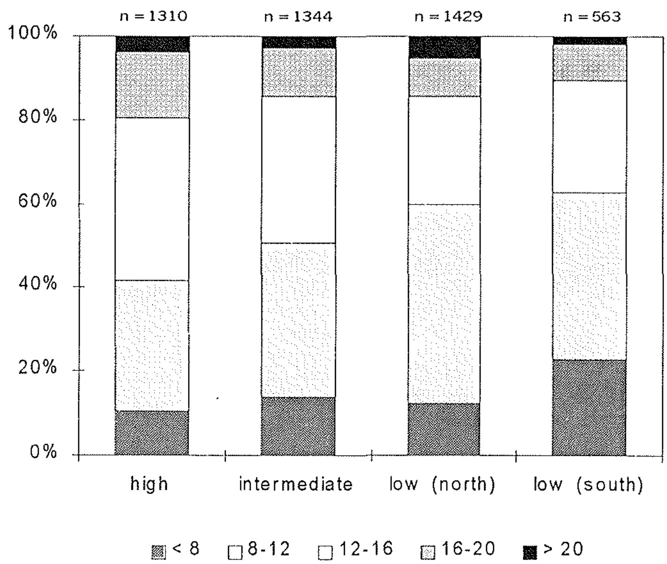
Nitrogen

A higher nitrogen content in the organic layer of forest soils is observed in the area receiving a high atmospheric deposition load, as compared to remote areas in Europe (Fig. 3).

Figure 4 shows that 59% of the organic layers in the region with the highest load of atmospheric deposition has a N concentration of more than 12 g kg^{-1}. This value is exceeded in only 39% of the plots located in the area with a low deposition load.

Fig. 4

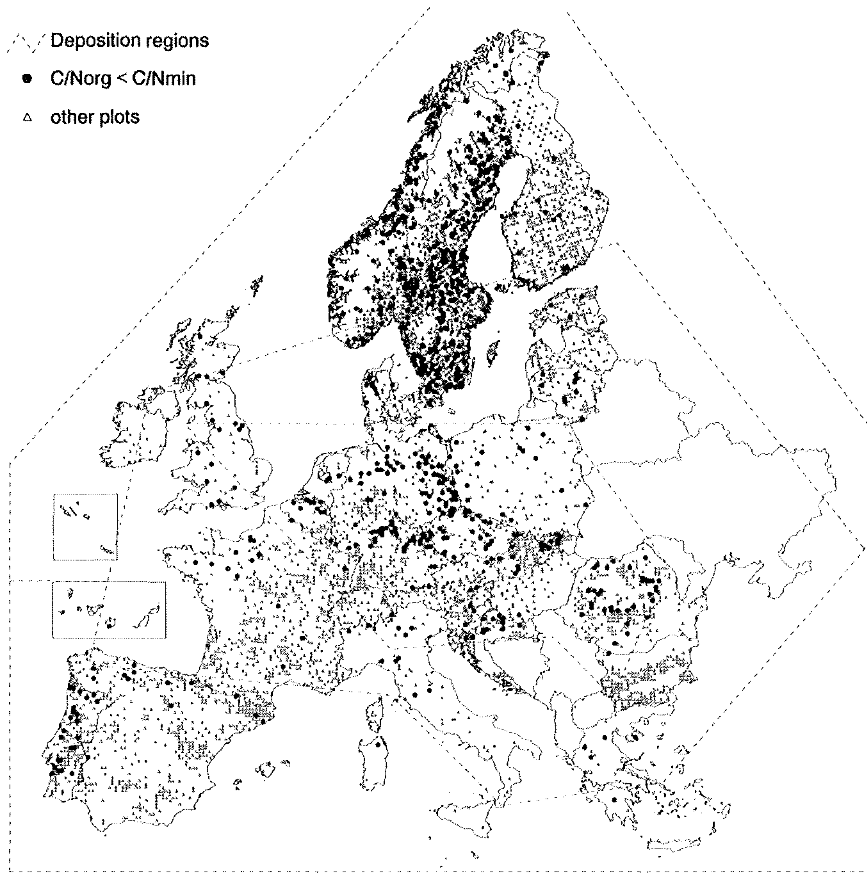
Nitrogen concentration of the organic layer in different atmospheric deposition regions (n = number of observations).



Nitrogen deposition decreases the C/N ratio in the organic layer. Unusually high N contents in the organic layer, indicated by a lower C/N ratio in this layer compared to the mineral layer, were observed in 17 % of the plots (Fig. 5). A relatively high number of plots where this unnatural situation occurs is found in north-western and northern Europe. Although the nitrogen input is low in the latter region, these results indicate that the response of nitrogen deposition on the C/N ratio may be more pronounced in areas with a climate favouring slow organic matter decomposition.

Fig. 5.

C/N ratio in European forest soils.

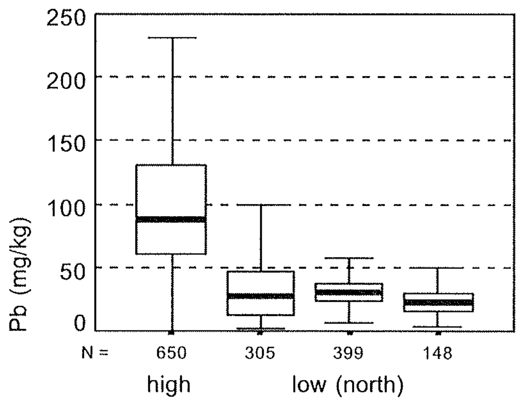


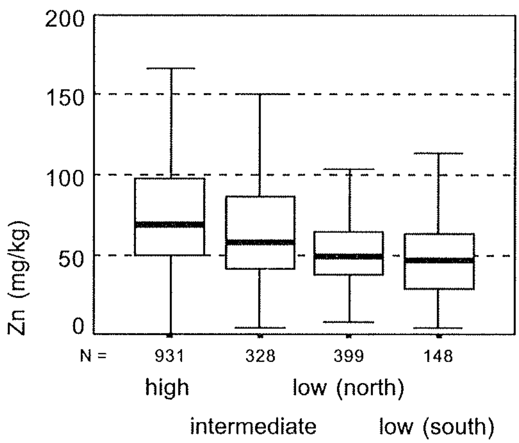
Heavy Metals

Atmospheric deposition has resulted in high levels of heavy metals in strongly industrialised areas. Concentrations of certain heavy metals, particularly lead and zinc, in humus layers and topsoils show regional gradients reflecting atmospheric deposition patterns (Fig. 6). The majority of lead (94%) and zinc (70%) concentrations of 80 mg kg^{-1} and more in the organic layer are found in the region with the highest deposition load, while this region covers less than half of the observation plots where these elements are measured.

Fig. 6.

Distribution of Pb (a) and Zn (b) concentrations in the organic layer among atmospheric deposition regions (N = number of observations).





Forests represent a potentially larger sink than grassland, snow and water surfaces due to their larger surface area and the roughness aspect (Andreae, 1996). Processes such as wet and dry deposition, canopy leaching, throughfall, stem flow and litter fall all ultimately result in the addition of heavy metals to the soil surface (Martin and Bullock, 1994). The litter layer is the repository for metals accumulated in leaves prior to shedding (Ross, 1994). The soil compartment, particularly litter and surface organic horizons, shows the highest concentrations of metals in forest ecosystems. The concentrations of metals in fallen leafs usually increase over time on the forest floor as metal ions exchange onto the cation exchange sites of the decaying litter (Ross, 1994).

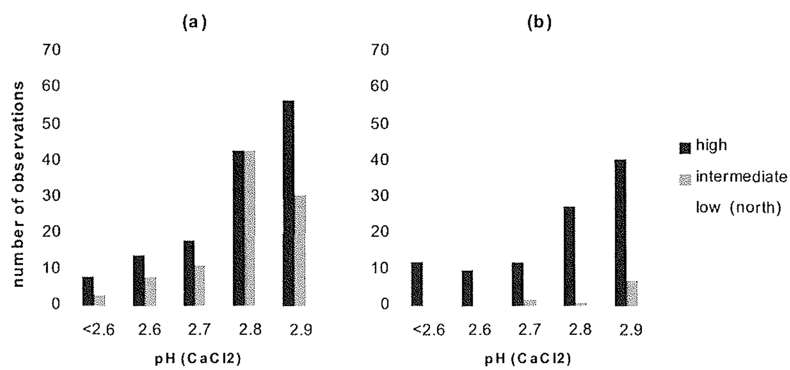
However, critical concentrations of Pb (500 mg kg^{-1}), Zn (300 mg kg^{-1}) and also Cd (3.5 mg kg^{-1}), given by Tyler (1992) for humus layers of Swedish forest soils, are exceeded in less than 1% of the plots for which values have been reported. Exceedences of critical organic layer concentrations of Cr (30 mg kg^{-1}) and especially Cu (20 mg kg^{-1}) have been reported more frequently, in 9% and 19% of the plots respectively.

Acidity

Acid conditions are very common in European forest soils. Up to 33% of the plots have topsoils with either a base saturation of 20% or less, or pH ($CaCl_2$) values below 3.5. Under strongly leaching conditions extremely low pH values, as low as pH 2.9 or 2.8, in organic layers are sometimes observed in forests producing acid litter.

Fig. 7.

Distribution of pH values below pH ($CaCl_2$) 3.0 in (a) organic and (b) mineral surface layers over regions in Europe receiving different loads of atmospheric deposition.



However, such low values are never reached in regions with both a moderate rainfall and a low acid deposition load (Fig. 7a). Mineral surface layers having pH values below 3.0, are reported for 114 plots, located almost exclusively in the region receiving a very high atmospheric deposition load (Fig. 7b). A common characteristic of these soils is a low reserve of basic exchangeable cations (BCE of 2.0 cmol(+) kg^{-1} or less), indicating a low buffering capacity against acidification.

A similar direct relationship between acid deposition and base saturation could not be substantiated. This may be due to the fact that other factors, such as parent material, climate and vegetation, strongly influence base saturation.

Sensitivity to Soil Acidification

Acid conditions are common in European forest soils, especially in surface layers. Values below pH ($CaCl_2$) 3.8 (Al/Fe buffer range) in surface mineral layers are reported in 40% of the plots. Very low values (pH < 3.2 - Fe buffer range) occur in 7% of the plots, mostly located in central Europe (EC *et al.*, 1997). A low pH generally indicates the lack of soil constituents that may act as buffers against acid input and usually coincide with a low base cation reserve. The efficiency of nutrient uptake will decrease in strongly acid soils (Barber, 1995). Soil carbonates in the topsoil constitute an important buffering power against acidification, but are reported in only 11% of the plots and are mostly associated with calcareous parent materials (EC *et al.*, 1997). Moreover, many of these calcareous soils have been leached free of carbonates in the surface layer (0-10 cm), having carbonates only in deeper layers.

The sum of total contents of Ca, Mg and K in the organic layer, is a measure for the total reserve of basic cations in this layer. Parent material influences the nutrient content of the forest floor material. Organic layers accumulate up to 3 times more Ca and Mg on soils derived from easily weatherable parent materials as compared to organic layers overlying parent materials with a slow weathering rate (EC *et al.*, 1997).

The sum of exchangeable basic cations (BCE) is a measure for the buffering capacity of carbonate-free soils, where cation exchange is the main buffering process. Less than 50% of the forest soils have a BCE of more than 1 cmol(+) kg^{-1} soil in the subsurface layer, showing that cation exchange is a buffering process that is quickly exhausted in most European forest soils (EC *et al.*, 1997).

Base saturation is an indication for the kind of buffer reaction taking place in the soil. At base saturation < 15%, the soil passes from the cation buffer range to the Al buffer range, which may cause acid stress to roots (Ulrich, 1995). About 25% of the forest soils in Europe has a mineral topsoil in which basic cations occupy only 15% or less of the cation exchange sites (EC *et al.*, 1997).

Indicator values for sensitivity to soil acidification (I_{SA}) have been calculated for all plots for which I_{BC}, I_{AS} and I_{HC} values are available, i.e. 1646 plots in 14 different countries. Classes were determined using the 10-, 30-, 70- and 90-percentile indicator values as class limits (Fig. 8).

Table 2 shows that a high proportion of acid sensitive plots are found in northern Europe (the Netherlands and Belgium) and in mountainous regions; whereas in Luxembourg, the Slovak Republic, Hungary, Slovenia and Portugal the majority of the studied forest soils is resistant to acidification.

Table 2.

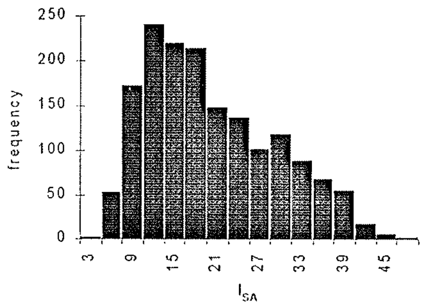
Classification of national plots according to their sensitivity to soil acidification (n = number of observations).

Country	**Class Distribution (in %)**					***n***
	Very low	**Low**	**Medium**	**High**	**Very high**	
Austria	29	25	30	11	5	*130*
Belgium	10	0	50	0	**40**	*10*
Czech Republic	0	10	51	24	**15**	*100*
Finland	1	8	42	33	**16**	*442*
France	12	21	55	7	4	*94*
Germany	7	16	57	15	5	*369*
Hungary	27	43	30	0	0	*44*
Luxembourg	50	25	25	0	0	*4*
Netherlands	0	0	9	27	**64**	*11*
Poland	1	3	31	35	**31**	*121*
Portugal	16	50	34	1	0	*146*
Slovak Republic	35	45	19	1	0	*110*
Slovenia	18	45	33	3	0	*33*
Switzerland	6	53	19	9	**13**	*32*

Shallow and leached acid soil types, such as Podzols (PZh), Cambic Arenosols (ARc) and Lithic Leptosols (LPl), are usually associated with a low acid neutralising capacity. Calcareous and nutrient-rich soil types, eg. Calcaric (calc) and Eutric (eut) subgroups, are found at the opposite end of the classification (Fig. 9). More than 80% of the Calcaric, Eutric and Chromic Cambisols, Eutric and Rendzic Leptosols, Lixisols, Gleysols (except Dystric and Umbric subgroups) and Fluvisols are attributed a 'low' or 'very low' sensitivity. In general, clayey calcareous soils score the highest ISA values, acid sandy soils the lowest.

Fig. 8.

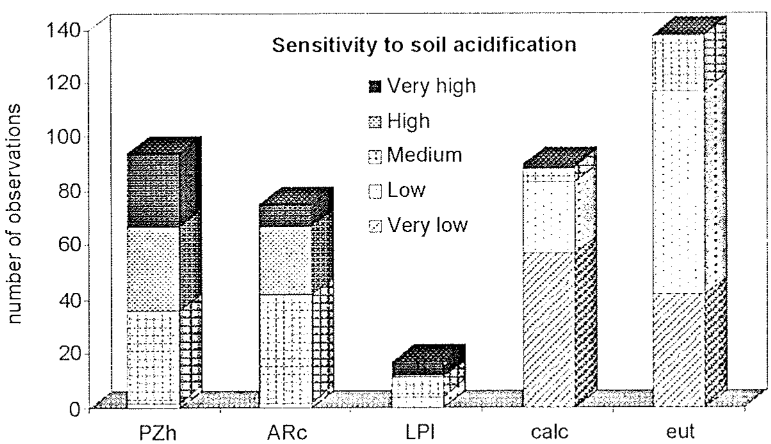
Histogram used to set the class limits of indictor values for sensitivity to soil acidification.



Sensitivity to Soil Acidification Class	I_{SA}
very low	> 32.4
low	23.3-32.4
medium	12.3-23.3
high	8.0-12.3
very high	< 8.0

Fig. 9.

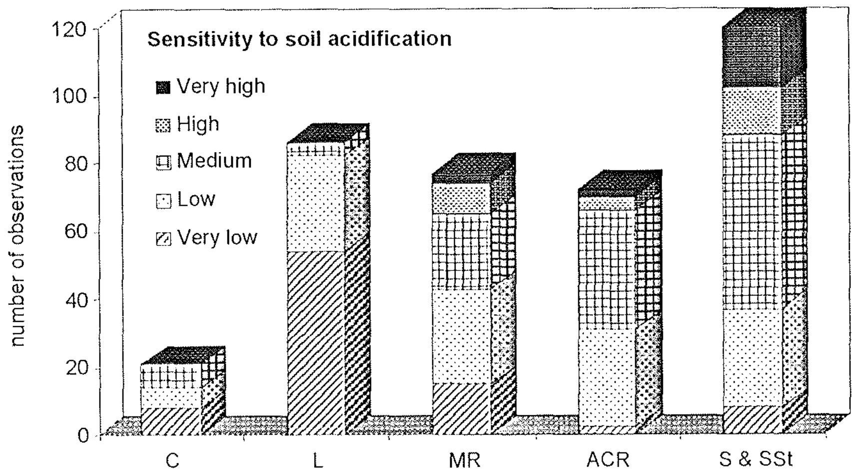
Relationship between soil type and sensitivity to soil acidification.



Nonparametric factor analysis of variance of the indicator values shows that the vulnerability to acidification is largely determined by soil parent material and texture. Soils that are classified as highly sensitive are usually derived from coarse textured or nutrient-poor parent materials, such as sands (S), sandstones (SSt) and acid crystalline rocks (ACR) (Fig. 10). Most soils derived from clays (C), limestones (L), volcanic or basic metamorphic rocks (MR), on the other hand, are able to buffer a high input of acids.

Fig. 10.

Relationship between nature of parent material and sensitivity to soil acidification.



Conclusions

The variability of forest ecosystems in Europe has resulted in a wide range of chemical soil conditions. The Forest Soil Condition Database is a valuable source of information for the investigation of cause-effect relationships associated with the observed loss of vitality of European forests.

Chemical soil conditions vary widely in European forests, but the clustering of observations according to pollution level indicated possible relationships between soil characteristics and pollution load. Atmospheric deposition of nitrogen compounds, decreasing the C/N ratio of organic layers, may disturb the mineralisation process of organic matter. Acid topsoil conditions, i.e. low pH and/or base saturation, are very common in northern, western and central Europe. Forest soils in the Mediterranean region generally have an adequate nutrient content to buffer against acidification processes. Concentrations of certain heavy metals, particularly lead and zinc, in the organic layer show regional gradients reflecting atmospheric deposition patterns.

The data of the large-scale forest monitoring programme permit an evaluation of the current condition of European forest soils, but the singularity of the observations limits the interpretation to a certain extent. A repetition of the survey within a reasonable time schedule (e.g. 10 years) would give more insight into the temporal dynamics of forest soil chemistry.

The evaluation of the observation plots in terms of their sensitivity to soil acidification, based on pH, cation exchange properties, nutrient cations and carbonate content, and estimated hydraulic conductivity, indicates acid coarse textured and shallow soils as the most responsive soil types to added acids. Many acid sensitive soils are associated with acid parent materials, such as sands, sandstones and acid crystalline rocks. Because these soil types are very common in northern Europe and in mountainous regions having soils formed on acid bedrock, these regions are highly vulnerable to acid deposition.

The assessment of the soil's sensitivity to acidification is but one step in the investigation of cause-effect relationships. Acid deposition may act as a predisposing, accompanying or even triggering factor. The impact of acid deposition on soil chemistry is often masked by many influencing factors and site conditions, such as forest stand, climate and parent material. Combinations of natural factors and interactions between natural and anthropogenic factors may be involved, but are difficult to identify with the current state of knowledge.

Acknowledgements

The author wish to express his appreciation to all persons involved in the soil monitoring activities at national level. Financial support was granted by the European Commission, the Institute for Forestry and Game Management (Ministry of the Flemish Community) and ICP Forests.

References

ANDREAE H. (1996). Ecological impacts of some heavy metals related to long-range atmospheric transport. Background Report for ICP Forests, 15 p.

BARBER S.A. (1995). *Soil Nutrient Bioavailability. A mechanistic approach*, 2nd ed. Wiley, New York, 414 p.

BLOCK J., O. BOPP, R. BUTZ-BRAUN, U. WUNN (1996). *Sensitivität rheinland-pfälzischer Waldböden gegenüber*

Bodendegradation durch Luftschadstoffbelastung. Mitteilungen aus der Forstlichen Versuchsanstalt Rheinland-Pfalz no. 35/96, Trippstadt, Germany, 298 p.

de CONINCK F., E. VAN RANST, L. VANMECHELEN (1998). Acid atmospheric pollution, buffer capacity and Al saturation of forest soils in Flanders (Belgium). Proceedings of the 16th ISSS world congress, Montpellier, France.

de VRIES W., D.J. BAKKER (1996). Manual for calculating critical loads of heavy metals for soils and surface waters. Preliminary guideline for environmental quality criterial calculation methods and data input. DLO-SC, Wageningen, the Netherlands, Report 114, 173 p.

de VRIES W., E.E.J.M. LEETERS (1995). Effects of acid deposition on 150 forest stands in the Netherlands. Chemical composition of the humus layer, mineral soil and soil solution. Report 69.1. Winand Staring Centre, Wageningen.

EC, UN/ECE and Ministry of the Flemish Community (1997). Eds. Vanmechelen, L., R. Groenemans and E. Van Ranst. *Forest Soil Condition in Europe. Results of a Large-Scale Soil Survey*. 1997 Technical Report. EC, UN/ECE, Ministry of the Flemish Community; Brussels, Geneva. 260 pp.

ERISMAN J.W., C. POTMA, W.A.J. van PUL, E.P. van LEEUWEN, G.P.J. DRAAIJERS (1995). A generalized description of the deposition of acidifying pollutants and base cations on a small scale in Europe. In: *Calculation and mapping of critical thresholds in Europe. Status Report 1995* (Eds. M. Posch, P.A.M. de Smet, J.-P. Hettelingh, R.J. Downing), Coordination Center for Effects, RIVM, the Netherlands: 61-72.

FAO (1988). *FAO-Unesco Soil Map of the World. Revised Legend*. FAO, Rome, 79 p.

HETTELINGH J.P., R.J. DOWNING, P.A.M. SMEDT (1991). *Mapping critical loads for Europe. Bilthoven, The Netherlands*, National Institute of Public Health and Environmental Protection, Coordination Centre for Effects, Technical report no. 1, 183 p.

MARTIN M.H., R.J. BULLOCK (1994). The impact and fate of heavy metals in an oak woodland ecosystem. In: *Toxic metals in soil-plant systems* (Ed. S.M. Ross), Wiley, 469 p.

MATZNER E., D. MURACH (1996). Soil changes induced by air pollutant deposition and their implication for forests in Central Europe. *Water, Air and Soil Pollution*, 85: 63-76.

ROSS S.M. (1994). Toxic metals: fate and distribution in contaminated ecosystems. In: *Toxic metals in soil-plant systems* (Ed.: S.M. Ross), Wiley, 469 p.

SPARKS D.L., (1995). *Environmental soil chemistry*. Academic Press, San Diego, California, 267 pp.

SVERDRUP H., P. WARFVINGE (1993). *The effect of soil acidification on the growth of trees, grass and herbs as expressed by the (Ca+Mg+K)/Al ratio*. Lund University, Dept. Chemical Engineering II, Report 2.

TYLER G. (1992). *Critical Concentrations of Heavy Metals in the Mor Horizon of Swedish Soils*. Swedish Environmental Protection Agency, Report 4078, 38 p.

TYLER G., A.-M. BALSBERG PAHLSSON, G. BENGTSSON, E. BAATH, L. TRANVIK (1989). Heavy metal Ecology of terrestial plants, microorganisms and invertebrates - a review. *Water, Air, Soil Pollut.*, 47: 189-215.

ULRICH B. (1981). Ökologische Gruppierung von Böden nach ihrem chemischen Bodenzustand. *Z. Pflanzenernähr. Bodenk.*, 144: 289-305.

ULRICH B. (1995). The history and possible causes of forest decline in Central Europe, with particular attention to the German situation. Environmental Reviews, Canada, Invited Paper.

UN/ECE and EC (1997). *Forest Condition in Europe*. 1997 Executive Report. Ed. Federal Research Centre for Forestry and Forest Products (BFH), Hamburg, Geneva, Brussels. UN/ECE, CEC, 41 p.

van PUL W.A.J., C. POTMA, E.P. van LEEUWEN, G.P.J. DRAAIJERS, J.W. ERISMAN (1994). *EDACS: European Deposition maps of Acidifying Compounds on a Small scale. Model description and results*. RIVM Rep. 722401005, Bilthoven, the Netherlands.

LA LEGGE NAZIONALE PER LA DIFESA DEL SUOLO ED IL RUOLO DEI CONSORZI DI BONIFICA PER LA CONSERVAZIONE E TUTELA DEL SUOLO E DELL'AMBIENTE

Annamaria Martuccelli

Direttore Generale Associazione Nazionale Bonifiche Irrigazioni

Premessa

L'odierno Convegno ricade nell'anno di compimento del decennio della fondamentale legge-quadro per la difesa del suolo del 18 maggio 1989 n.183, costituente per l'Italia un traguardo che ha concluso un lungo e complesso lavoro che ha impegnato il mondo della scienza e della tecnica, le istituzioni, le forze economiche e sociali, politiche e parlamentari per circa un ventennio atteso che i primi schemi di provvedimento risalgono agli inizi degli anni '70, sotto la spinta della storica alluvione di Firenze del 1966.

D'altra parte in Italia i problemi di difesa dalle acque, di equilibrio idraulico e di disponibilità delle risorse idriche hanno origine dalle stesse caratteristiche naturali del suolo e del clima e hanno costituito nei secoli costante preoccupazione delle popolazioni.

La letteratura in materia ricorda eventi catastrofici verificatisi nei tempi antichi, quali l'imponente rotta del Po a Ficarolo a metà del XII secolo; la grande piena dell'Adige nel 1757, che invase Verona. Già all'epoca i danni materiali non si esaurivano nelle campagne ma minacciavano anche i piccoli e grandi aggregati urbani. Il Brenta minacciava e talora investiva con le sue piene la città di Padova.

Il Governo della Repubblica Veneta aveva avvertito la determinante rilevanza dei problemi e istituito nel 1501 il Magistrato alle Acque con il compito di sovraintendere ai complessi problemi idraulici del territorio.

Sin da allora i problemi territoriali in Italia assumono un peso dominante e hanno, all'epoca, natura prevalentemente idraulica. Nella società contemporanea alle permanenti necessità di difesa idraulica si uniscono quelle di conservazione del suolo e di regolazione e tutela delle acque.

Una organica politica di difesa del suolo non si esaurisce quindi nell'azione di difesa dalle acque, ma **richiede una contemporanea azione di protezione attiva e di salvaguardia del suolo attraverso un ordinato e corretto uso del territorio, una costante opera di sistemazione e regolazione dei corsi d'acqua, una razionale utilizzazione delle risorse idriche, una diffusa azione di risanamento delle acque superficiali e sotterranee, una controllata azione di rimboschimento e di miglioramento dei boschi degradati**.

Solo in tal guisa si realizza anche quella salvaguardia ambientale costituente, nella moderna società, uno degli obiettivi prioritari della politica territoriale.

Nel nostro Paese, sin dagli anni '70 è stata fortemente avvertita la necessità di una regolamentazione della materia che tenga conto delle nuove esigenze che una moderna politica del territorio deve soddisfare.

Ne costituiscono ampia testimonianza i numerosi convegni, i molteplici studi, le diverse iniziative governative e parlamentari che periodicamente hanno coinvolto uomini politici, amministratori pubblici, illustri studiosi, tecnici altamente qualificati e giuristi della specifica materia.

Meritano particolare menzione: la istituzione, da parte del Governo, della nota Commissione De Marchi, la promozione della Conferenza nazionale delle acque, l'indagine conoscitiva condotta dalle Commissioni riunite Lavori Pubblici e Agricoltura del Senato, conclusasi con la nota relazione parlamentare Noè - Rossi Doria. I fondamentali documenti elaborati rappresentano ancora oggi un sicuro strumento di conoscenza e hanno costituito nell'ultimo ventennio punto di riferimento costante per la definizione delle linee fondamentali di una moderna politica di difesa del suolo, cui si sono ispirati i numerosi disegni di legge presentati per la disciplina della materia.

Nonostante l'impegno profuso da illustri parlamentari nelle diverse legislature succedutesi dalla metà degli anni '70, la legge organica per la difesa del suolo è stata approvata solo alla fine degli anni '80.

1. La legge 18 maggio 1989, n. 183

La legge 183/1989, che introduce una fondamentale riforma per il governo del territorio, segna l'inizio di un impegnativo cammino volto ad attuare nel Paese una nuova e moderna politica per l'assetto del territorio, che deve tener conto dei fondamentali bisogni indicati in premessa, emersi a seguito delle profonde trasformazioni di uso del territorio, del diffuso e crescente inquinamento, dei fenomeni di erosione del suolo, del dissesto idraulico, della particolare vulnerabilità del territorio del nostro Paese, della estrema variabilità, fortemente accentuatasi, del clima.

La Legge 183/1989 ha saputo cogliere tali esigenze introducendo nell'ordinamento una nuova nozione di difesa del suolo che costituisce un principio cardine della riforma.

a) Azione di difesa del suolo e bacino idrografico

Si tratta di un elemento di estrema modernità della legge secondo la quale la difesa del suolo **è attività intersettoriale ed interdisciplinare che si realizza attraverso una serie coordinata di azioni e di interventi mirati verso quattro obiettivi**:

1. sistemazione, regolazione idraulica e prevenzione;

2. razionale utilizzazione delle risorse idriche, superficiali e sotterranee, con una efficiente rete idraulica, irrigua ed idrica che ne assicuri gli usi plurimi;

3. risanamento delle acque superficiali e sotterranee;

4. manutenzione ordinaria e straordinaria delle opere e degli impianti.

Altro elemento, che caratterizza la riforma, attiene agli **ambiti territoriali** di riferimento per la realizzazione della difesa del suolo. **Essi vengono identificati nei bacini idrografici.**

Il principio fondamentale è che la programmazione, la pianificazione e l'attuazione della difesa del suolo come sopra intesa deve realizzarsi su base unitaria con riferimento al bacino idrografico di cui la legge offre, all'art. 1, lett. d), una specifica definizione.

Il bacino idrografico quale riferimento territoriale costituisce un principio fortemente innovatore. Trattasi di un ambito territoriale altamente significativo che ha grande e determinante rilevanza per l'efficacia delle azioni.

A seguito dell'intervenuto decentramento regionale ad opera del DPR n.11/1972 e 616/1977, le competenze per il settore della difesa del suolo sono state ripartite tra Stato e Regione, con la conseguente fondamentale esigenza di imprimere alla legge organica per la difesa del suolo la caratteristica di legge "cornice", costituente un quadro unitario di riferimento positivo, quale momento di oggettiva certezza per il corretto esercizio dei poteri dello Stato e delle Regioni.

Peraltro, proprio la duplice e concorrente competenza istituzionale Stato-Regioni, ha indotto a classificare i bacini in bacini nazionali (in numero di 11, raggruppati operativamente in 6), interregionali (in numero di 18), e regionali (artt. 14, 15 e 16).

Per i bacini nazionali rimane fermo il riparto di competenza Stato-Regioni, quale fissato dal D.P.R. 616/1977 successivamente modificato dal D.L. 112 del 21/3/1998; per i bacini interregionali e regionali la competenza è affidata alle Regioni che, in ordine ai primi, devono operare attraverso "intese".

a) *Piani di bacino*

Il principio fondamentale è che la difesa del suolo si realizza attraverso **piani di bacino** che sono attuati mediante programmi triennali.

L'ampia definizione di piano di bacino che la legge detta rende conto che trattasi di un piano complesso ed articolato avente carattere **conoscitivo** del sistema fisico e delle utilizzazioni e vincoli esistenti sul territorio; **normativo** in quanto disciplinante le direttive, le prescrizioni e i vincoli da rispettare per la difesa e salvaguardia del suolo, la sistemazione idrogeologica ed idraulica, l'utilizzazione delle acque e dei suoli; **tecnico-operativo** in quanto individua opere ed interventi ed il loro organico sviluppo nel tempo e provvede alla valutazione preventiva del rapporto costi-beneficio, dell'impatto ambientale e delle risorse finanziarie dei principali interventi previsti.

Il piano di bacino è quindi lo strumento fondamentale su cui si basa il nuovo ordinamento della difesa del suolo.

I suoi contenuti a carattere interdisciplinare richiedono approfondita preparazione tecnica, strumenti conoscitivi adeguati, un indispensabile coordinamento fra tutti i soggetti competenti nel settore, un incisivo adeguamento delle strutture della Pubblica Amministrazione, una idonea azione di formazione dei suoi rappresentanti ai diversi livelli. Si tratta di un nuovo modo di operare sul territorio per il quale occorre una consistente ed articolata azione riorganizzativa della Pubblica Amministrazione se non si vuol vanificare o svilire il sistema concepito dal legislatore.

La legge attribuisce al piano di bacino carattere vincolante per tutti gli enti pubblici e privati e le amministrazioni pubbliche, e prescrive che gli altri strumenti di pianificazione già in vigore (piani territoriali, piani di risanamento delle acque, piano di smaltimento dei rifiuti, piani generali di bonifica, piani di disinquinamento, piani urbanistici) devono adeguarsi al piano di bacino.

Certamente il principio si è dimostrato di difficile realizzazione sì da indurre il legislatore a prevedere i "piani di stralcio", che finora sono stati gli unici strumenti di pianificazione elaborati da alcune Autorità di bacino.

Le procedure per l'approvazione dei piani sono complesse ed articolate e richiedono una penetrante rete di interscambi tra centro e periferia e comunque tra i vari soggetti competenti, che rappresenta, nel contempo, l'unica reale garanzia per l'attuazione del nuovo sistema, ma anche un forte ostacolo per la realizzazione dello stesso.

b) *Autorità di bacino*

Per i bacini nazionali la legge prevede la istituzione della c.d. "Autorità di bacino", cui é preposto un Segretario generale.

Gli organi hanno struttura collegiale; sono costituiti da specifici comitati, la cui composizione è variamente articolata a seconda che si tratti di bacini nazionali ovvero di bacini interregionali e regionali.

Per i bacini nazionali, l'Autorità di bacino opera attraverso due Comitati (Comitato istituzionale e Comitato tecnico, dove è garantita la presenza dello Stato e delle Regioni interessate) ed un Segretario generale e relativa segreteria tecnico organizzativa.

Per i bacini interregionali gli organi di pianificazione vengono identificati nei Comitati istituzionali e nei Comitati tecnici, costituiti sulla base di intese fra le Regioni interessate.

Per i bacini regionali l'esclusiva competenza delle Regioni affida alle medesime l'individuazione degli organi.

c) *Soggetti e relative competenze*

I soggetti deputati alle diverse azioni di difesa del suolo sono individuati con norma espressa.

L'art.1, comma 4°, enuncia il seguente principio fondamentale: alla realizzazione delle attività di difesa del suolo sono chiamati **lo Stato, le Regioni a statuto speciale ed ordinario, le Province autonome di Trento e Bolzano, le Province, i Comuni, le Comunità Montane, i Consorzi di bonifica e di irrigazione e i Consorzi di bacino imbrifero montano**, secondo le rispettive competenze.

Il successivo art. 11 prevede "i comuni, le province, i loro Consorzi o asssociazioni, le comunità montane, i Consorzi di bonifica, i Consorzi di bacino imbrifero montano e gli altri enti pubblici e di diritto pubblico con sede nel bacino idrografico partecipano allo esercizio di funzioni regionali in materia di difesa del suoo nei modi e nelle forme stabilite dalle regioni singolarmente o d'intesa tra loro, nell'ambito delle competenze del sistema delle autonomie locali".

Come emerge dalle norme sopratrascritte, i Consorzi di bonifica figurano tra i soggetti istituzionali chiamati ad operare la realizzazione della difesa del suolo. I Consorzi di bonifica e di irrigazione sono gli unici enti pubblici di autogoverno che vengono deputati alla difesa del suolo unitamente agli enti territoriali e locali.

Il mondo produttivo è quindi chiamato a partecipare attivamente attraverso i Consorzi che sono enti rappresentativi delle categorie produttive maggiormente interessate alla difesa e conservazione del suolo, al più razionale uso delle risorse idriche e alla salvaguardia della qualità delle acque.

d) *Consorzi di bonifica*

Una organica regolamentazione del settore della difesa del suolo non poteva prescindere dalla posizione istituzionale e dal ruolo fondamentale svolto dai **Consorzi di bonifica e di irrigazione su oltre il 50% della superficie nazionale. I territori su cui operano i Consorzi si estendono infatti per oltre 14 milioni di ettari di cui il 60% è territorio collinare e montano**. Pertanto, **con riferimento alla sola pianura** (6 milioni di ettari circa), la superficie **su cui operano i Consorzi rappresenta oltre l'80%**; essa si estende infatti su circa 4 milioni e mezzo di ettari.

Infine, non può non sottolinearsi, per la estrema rilevanza che tale dato assume per la difesa del suolo, che i Consorzi di bonifica sono gli unici enti pubblici i cui ambiti territoriali (comprensori) sono delimitati non già in funzione di confini amministrativi bensì in ragione delle esigenze idrauliche ed irrigue con riferimento specifico ai bacini idrografici.

Va ricordato in proposito che tutte le Regioni, che hanno provveduto a disciplinare organicamente il settore della bonifica, hanno attribuito rilevanza specifica agli ambiti territoriali ed hanno provveduto ad una ridelimitazione dei comprensori dei Consorzi facendoli coincidere con interi bacini idrografici o comunque con consistenti unità idrografiche funzionali.

D'altra parte nella nuova nozione di difesa del suolo la bonifica occupa un posto fondamentale, giacché una parte considerevole e rilevante delle azioni rientranti nella nuova nozione di difesa del suolo sono costituite da attività rientranti nel sistema operativo della bonifica.

Come sovente ha ricordato Giuseppe Medici, la stabilità del suolo del nostro Paese è fortemente subordinata alla efficienza e alla piena funzionalità del sistema bonifica le cui infrastrutture ed impianti contribuiscono in misura rilevante alla regolazione ed allo scolo delle acque e quindi alla difesa e conservazione del suolo ed alla tutela del territorio.

Alcuni dati costituiscono ineccepibile testimonianza della rilevanza del sistema della bonifica idraulica sul territorio nazionale:

- **circa 100.000 chilometri di canali di scolo che servono una superficie di oltre 5 milioni di ettari, di cui 1,2 milioni circa a scolo meccanico**;
- **16.930 chilometri di argini**;
- **33.760 briglie e sbarramenti per laminazioni piene**;
- **631 impianti idrovori**;
- **1.097 impianti di sollevamento delle acque**.

D'altra parte uno specifico riconoscimento del rilievo della bonifica per la difesa del suolo è costituita dalle leggi regionali finora emanate per il settore della bonifica le quali indicano univocamente la difesa del suolo tra le finalità della bonifica stessa.

In conclusione la profonda riforma introdotta nel nostro ordinamento con la legge 183/1989 prevede un sistema di governo del territorio radicalmente diverso rispetto al passato, che presuppone consapevolezza delle nuove esigenze di tutela e conservazione del suolo che esigono a loro volta nuovi comportamenti e nuove regole non disgiunte da azioni ed interventi sul sistema di difesa idraulica e di regolazione delle acque.

Come è stato rilevato da studiosi della specifica materia, il nuovo sistema è frutto di uno sforzo compiuto nella direzione di garantire un governo del territorio che, in relazione ai problemi posti dalla società industriale e postindustriale, richiede in misura sempre maggiore il coinvolgimento di più soggetti. Assumono sempre maggior rilievo le istituzioni di collaborazione e le intese interistituzionali dovendosi dedicare più attenzione ai processi decisionali, cui devono partecipare tutti i soggetti coinvolti nella decisione di governo concordando, attraverso una valutazione complessiva e coordinata dei vari interessi interagenti, la scelta finale da adottare. Occorre cooperazione e concertazione.

Va a tale proposito ricordato che **la Corte Costituzionale**, con riferimento specifico alla Legge 183/1989, **ha sottolineato che il governo del territorio può essere perseguito soltanto attraverso la via della cooperazione fra i soggetti istituzionalmente competenti**.

Ed infatti, nel nuovo ambito territoriale, individuato dalla legge nel **bacino idrografico, sono chiamati a collaborare, con lo Stato e le Regioni, gli enti locali ed i Consorzi di bonifica e di irrigazione**.

I Consorzi di bonifica e di irrigazione hanno dato prova di essere, tra i soggetti istituzionalmente competenti, gli unici enti presenti diffusamente sul territorio, che hanno approfondita conoscenza del medesimo e che svolgono una **fondamentale funzione di presidio territoriale**.

Si avverte peraltro l'esigenza di una costante collaborazione tra i Consorzi e con gli altri soggetti chiamati ad operare per la difesa del suolo onde poter realizzare quella concertazione e quella cooperazione indispensabili a perseguire l'obiettivo comune della difesa del suolo.

Gli accordi di programma, i patti territoriali, le conferenze di servizi, devono costituire la regola costante di comportamento.

Con riferimento specifico alle competenze dei Consorzi e ai loro ambiti territoriali di operatività, bisogna tener conto che i Consorzi **costituiscono sul territorio gli organismi rappresentativi**, nell'ambito di ogni bacino idrografico, **degli utenti interessati alle azioni di bonifica**.

Per tale caratteristica la loro presenza e la loro conseguente partecipazione deve essere tenuta presente da tutte quelle istituzioni che governano il territorio e le risorse naturali, preposte alla difesa del suolo e alla tutela e salvaguardia dell'ambiente.

Si tratta in particolare delle **Autorità di bacino**, delle **Regioni**, delle **Agenzie regionali per l'ambiente**, degli **Enti parco**, delle **Province**, dei **Comuni**, delle **Comunità montane** e delle **Autorità d'ambito per i servizi idrici integrati**.

Gli strumenti di concertazione, già indicati, sono già previsti dall'ordinamento ed in alcune realtà i Consorzi hanno già assunto specifiche e positive iniziative.

I Consorzi di bonifica quali enti di autogoverno, presenti sul territorio, soggetti a tutela e vigilanza della Regione, costituiscono **reale espressione di quel principio di sussidiarietà** su cui si fonda il nuovo sistema di decentramento introdotto nel nostro ordinamento dalla legge Bassanini e che costituisce il cardine delle regole del Trattato di Maastricht per la politica del territorio e dell'ambiente. Ciò con riferimento sia alla rappresentanza diretta degli interessati che beneficiano dell'attività svolta dal Consorzio che per la snellezza operativa dell'istituto consortile nonché per la sua presenza articolata sul territorio in prossimità ai luoghi e ai soggetti che per primi avvertono i bisogni. Ciò consente di dare risposte immediate alle necessità e alle esigenze dei singoli e della collettività organizzata.

Da ciò discende anche la persistente e fondamentale attualità dell'istituto consortile di bonifica per la gestione del territorio ed in particolare per le attività di manutenzione verso le quali non sempre nel recente passato in Italia vi é stata adeguata considerazione.

Di recente sembra che nel nostro Paese inizi a trovare terreno fertile la cultura della prevenzione quale indispensabile strumento per la conservazione e difesa del suolo ed appare altresì più diffusa la sensibilità per il tema della manutenzione del territorio per la quale i Consorzi di bonifica hanno lanciato negli ultimi 20 anni allarme costante, così come testimoniato dai numerosi convegni e dibattiti che i Consorzi hanno dedicato ai problemi della manutenzione.

I Consorzi hanno costantemente invocato la necessità di **ripercorrere il cammino interrotto della tradizione manutentoria con azioni imposte dal dovere di curare quelle reti idrauliche e quegli impianti che garantiscono la sicurezza idraulica del territorio**.

Con riferimento specifico al sistema di difesa idraulica della bonifica va rilevato che quasi tutti gli impianti, a prescindere dalla vetustà, hanno imprescindibile bisogno di essere adeguati alle nuove esigenze imposte da un territorio che nell'ultimo quarantennio **si è ampiamente urbanizzato e impermeabilizzato** e richiede quindi un servizio diverso ed un **sistema scolante più adeguato** sia per la quantità di acqua che deve essere convogliata che per i tempi, atteso che, con l'impermeabilizzazione, l'acqua arriva con maggiore velocità. Sono necessarie, sia a fini di salvaguardia che di difesa dalle acque, fondamentali opere di ristrutturazione e ripristino, (adeguare e sistemare canali, potenziare ed ammodernare impianti idrovori e di sollevamento, provvedere a fondamentali sistemazioni idrauliche), i cui costi non possono gravare sui privati consorziati e non sarebbe neanche giusto in ragione dell'interesse pubblico generale che tali azioni rivestono.

Attualmente i Consorzi garantiscono il funzionamento dei predetti impianti attingendo alla contribuenza imposta ai proprietari degli immobili agricoli ed extragricoli che traggono beneficio da tali attività.

La partecipazione finanziaria dei privati, è quindi, fondamentale, ma allo stato attuale non più sufficiente a far fronte a quegli interventi di **manutenzione straordinaria** indispensabili ad assicurare piena efficienza e funzionalità agli impianti.

E' necessario quindi che, **nell'ambito del sistema della difesa del suolo** di cui alla Legge 183/89, **venga data priorità** alle azioni di manutenzione straordinaria, ristrutturazione e ripristino degli impianti di difesa idraulica e di scolo gestiti dai Consorzi di bonifica, indispensabili non solo per la tutela del suolo agricolo ma in alcune realtà in misura molto maggiore per la salvaguardia delle infrastrutture civili e industriali.

Non vi è zona di pianura nella quale città, insediamenti sparsi, zone industriali, oltre che campagne, non siano interessate dal buon funzionamento degli impianti di difesa e di regolazione delle acque gestiti dai Consorzi e non vi sono, inoltre, linee di comunicazione, stradali e ferroviarie, condotte di energia elettrica e di metano che non siano protette attraverso gli stessi impianti da esondazioni e da tumescenze idriche.

Se il sistema scolante non funzionasse e se, soprattutto, si fermassero le idrovore e gli impianti di sollevamento gestiti dai Consorzi, si tornerebbe allo stato selvaggio del Paese e fasce litoranee come quelle del basso Veneto e della Romagna, della Maremma e del Lazio, e, più giù, della Campania e della Puglia, riprenderebbero il loro assetto di paludi; in queste condizioni impedendo anche la sussistenza delle vie di comunicazione, tra le quali molte strade nazionali del litorale e aeroporti come, ad esempio, quelli di Fiumicino, di Venezia, di Lamezia.

Si tratta quindi di un fondamentale servizio pubblico svolto dai Consorzi di bonifica, del quale il territorio italiano non può prescindere.

Occorre distinguere **tra il momento della pianificazione e quello delle esigenze di intervento sul territorio**.

Una pianificazione seria che sia fondata su un'approfondita e corretta conoscenza di tutti i problemi del bacino idrografico richiede inevitabilmente tempi lunghi; **nel frattempo peraltro non può bloccarsi ogni azione di difesa del suolo soprattutto quelle a scopo di prevenzione che si traducono nella maggior parte in azioni di manutenzione**.

E' sufficiente considerare i contenuti dell'atto di indirizzo e coordinamento concernenti i criteri per la realizzazione dei piani di bacino di cui al D.P.R. 18 luglio 1995 per rendersi conto dei tempi necessari per porre in essere un quadro organizzativo delle conoscenze e per individuare gli squilibri, che sono fasi propedeutiche a quella della definizione delle azioni propositive.

I piani di bacino hanno bisogno di tempi congrui per la loro elaborazione.

Peraltro, sul territorio del nostro Paese le emergenze alluvionali, a causa della grande variabilità del clima, continuano a segnare tappe sempre più ricorrenti nella storia degli eventi che interessano da vicino l'incolumità della popolazione, la salvaguardia degli insediamenti umani, civili e produttivi e più in generale la sicurezza idraulica del territorio.

Alla tragica alluvione del Piemonte del 1994 hanno fatto seguito quella della Toscana del giugno 1996 e nel secondo semestre dello stesso anno non poche alluvioni hanno interessato diverse regioni tra cui oltre la Toscana, l'Emilia, la Campania, la Calabria e la Sicilia, nonché nell'anno successivo la devastante alluvione che ha colpito Sarno.

Le condizioni dell'assetto idrografico del territorio del nostro Paese sono tali per cui bastano piogge di poco più intense rispetto alla regola che i corsi di acqua esondano, le colline e le montagne franano con conseguente allagamento di campagne, di città ed insediamenti produttivi.

Il Paese è in continua emergenza e non appare più procrastinabile **una efficace e sistematica opera di prevenzione che tenda a limitare il rischio idraulico con interventi organici e diffusi di manutenzione**.

Il lavoro compiuto nell'anno 1997 dal Comitato paritetico delle Commissioni Ambiente Senato e Camera dei deputati, presieduto dal Sen. Veltri, che ha consentito l'elaborazione di importanti documenti, offre un quadro generale molto ampio e particolarmente significativo.

E' stato sottolineato in più sedi e non può non condividersi che in un Paese che sceglie la via dello sviluppo sostenibile **una efficace e sistematica opera di prevenzione e di manutenzione costituisce una delle grandi azioni nazionali** in quanto finalizzata alla conservazione del suolo e alla regolazione delle acque.

Il sistema idraulico e scolante del nostro Paese va adeguato per rispondere alle esigenze derivanti dalla profonda trasformazione del territorio conseguente alla convulsa espansione urbana, alla diffusa cementificazione, alla nuova subsidenza derivante dai notevolissimi emungimenti dal sottosuolo, all'abbandono della montagna.

Con riferimento al sistema territoriale della bonifica, la rete idraulica e di scolo, progettata per rispondere alle esigenze di un territorio prevalentemente agricolo, non può essere idonea a rispondere alle esigenze di un territorio oggi diffusamente urbanizzato ed impermeabilizzato che determina un afflusso delle acque nelle reti di scolo in quantità di gran lunga maggiore rispetto al passato e in tempi molto più rapidi; analoghi disagi sono connessi alla situazione della montagna. Gli impianti idrovori esistenti e le reti dei canali e dei corsi d'acqua vanno adeguati ai servizi che devono oggi essere garantiti.

In mancanza di tale azione manutentoria di adeguamento degli impianti e delle reti di scolo facenti parte del sistema idraulico della bonifica **si registra una forte diminuzione di sicurezza idraulica**.

Si tratta di interventi rientranti nell'ambito dell'azione di manutenzione straordinaria, quali il dimensionamento dei cavi, i rivestimenti di fondo o di sponda, il rafforzamento di argini, la ricostruzione di alcuni manufatti, il potenziamento di alcuni impianti idrovori, l'applicazione di apparecchiature, automatizzate o meno, per il controllo dei flussi ed in sintesi tutti quegli adeguamenti che rendono la rete idonea ad assolvere pienamente la sua funzione. Si tratta in sostanza di garantire la sicurezza idraulica.

Sono azioni manutentorie di adeguamento che si aggiungono alla manutenzione ordinaria e periodica, alle cui esigenze i Consorzi provvedono con la contribuenza consortile.

Si confida, anche in relazione alle iniziative assunte dai competenti Ministeri, che un ausilio possa provenire dai fondi strutturali europei 2000-2006 o che comunque il Governo ed il Parlamento rinvengano soluzioni adeguate per poter disporre delle necessarie risorse finanziarie.

Non va dimenticato infatti che gli ultimi due Governi hanno considerato la difesa del suolo una delle grandi priorità nazionali sottolineando le necessità di passare dalla logica di emergenza ad una efficace e sistematica opera di prevenzione e manutenzione.

Si avverte ora l'esigenza **di procedere ad un rafforzamento complessivo del sistema per la difesa del suolo previsto dalla Legge 183/1989** e di destinare adeguate risorse finanziarie alle azioni di manutenzione.

I Consorzi di bonifica rappresentano le istituzioni che possono dare un validissimo contributo in tale ambito per la conoscenza del territorio e dei suoi problemi, per la loro lunga esperienza operativa e gestionale, per il ruolo che hanno sempre svolto per la difesa e la conservazione del suolo, per l'imponente patrimonio di opere da essi realizzate e gestite su tutto il territorio nazionale, per la capacità delle loro strutture tecniche.

D'altra parte anche la recentissima legge quadro per la tutela delle acque riconosce ai Consorzi di bonifica, con norma espressa, uno specifico ruolo nel settore della tutela ambientale. Tale norma recita testualmente: "**I Consorzi di bonifica e di irrigazione**, anche attraverso appositi accordi di programma con le competenti autorità, **concorrono alla realizzazione di azioni di salvaguardia ambientale e di risanamento delle acque**, anche al fine della loro utilizzazione irrigua, della rinaturalizzazione dei corsi d'acqua e della fitodepurazione".

Merita di essere sottolineato che i Consorzi di bonifica hanno già da tempo avviato alcune delle iniziative oggi riconosciute dal legislatore quali azioni rientranti nelle competenze dei Consorzi di bonifica e ciò sulla base dell'evoluzione delle azioni della bonifica sul territorio.

Non mancano, infatti, valide e significative testimonianze diffuse sul territorio nazionale di azioni di tutela ambientale realizzate dai Consorzi, dagli interventi sul bacino scolante della laguna di Venezia, alla vivificazione di lagune, alla gestione di oasi e di aree umide, alla rinaturazione di corsi d'acqua, alla fitodepurazione, al monitoraggio delle acque, alla tutela delle risorgive e dei fontanili.

Il riconoscimento del legislatore origina quindi dalle azioni che i Consorzi hanno dimostrato di essere capaci di realizzare o promuovere per la tutela delle risorse ambientali.

Nell'ambito di **Rapporti interinali** elaborati dai competenti Ministeri per la programmazione dei fondi strutturali U.E. 2000-2006 viene sottolineato che **la manutenzione del reticolo idrografico di pianura, le opere idraulico-agrarie e idraulico forestali, che rientrano nell'ambito delle azioni della bonifica, sono azioni necessarie nel quadro complessivo ed articolato di interventi specificamente mirati al soddisfacimento delle esigenze di sicurezza e di conservazione del suolo**.

Nel nostro Paese la sicurezza fisica del territorio è diventata un elemento della competitività e della sostenibilità dello sviluppo nonché oggetto di ricorrente emergenza.

L'azione dei Consorzi di bonifica per azioni di prevenzione di conseguente riduzione del rischio è riconosciuta anche in un fondamentale documento approvato il 9 gennaio 1996 dalla Commissione agricoltura della Camera dei deputati nel corso della XII^ legislatura a conclusione di una indagine conoscitiva sui Consorzi di bonifica. In tale documento è posto in chiara evidenza, con ampia e documentata motivazione, l'insostituibile ruolo svolto dai Consorzi di bonifica nel nostro Paese a reale presidio del territorio e a tutela delle risorse naturali, suolo e acqua con la conclusione, esplicitamente espressa nello stesso documento, che i Consorzi di bonifica sono una istituzione necessaria per la difesa del suolo, la razionale utilizzazione delle acque e la tutela dell'ambiente.

I Consorzi di bonifica, quali enti pubblici di autogoverno, che svolgono la loro azione sul territorio, che sono soggetti a tutela e vigilanza della Regione, costituiscono **reale espressione di quel principio di sussidiarietà** su cui si fonda il nuovo sistema di decentramento introdotto nel nostro ordinamento dalla legge Bassanini e costituente, fra l'altro, il cardine delle regole del Trattato di Maastricht per la politica del territorio e dell'ambiente. Ciò con riferimento sia alla rappresentanza diretta degli interessati che beneficiano dell'attività svolta dal Consorzio, ai quali è affidata l'amministrazione degli enti, sia alla snellezza operativa dell'istituto consortile che alla presenza articolata sul territorio in prossimità ai luoghi e ai soggetti che per primi avvertono i bisogni. Ciò consente di dare risposte immediate alle necessità e alle esigenze dei singoli e della collettività organizzata.

Da ciò discende anche il fondamentale contributo che l'istituto consortile di bonifica può offrire per lo sviluppo sostenibile.

Ed invero se un insegnamento può trarsi dalle innovazioni provenienti dal Trattato di Maastricht é quello per cui le esigenze connesse con la salvaguardia dell'ambiente non ricevono esclusiva tutela nel momento del controllo e della repressione **bensì preventivamente**. Si stabilisce, infatti, all'art. 130, che la politica della Comunità é fondata sui principi della **precauzione e dell'azione preventiva** e sul principio della correzione alla fonte dei danni causati all'ambiente.

L'introduzione del criterio informatore della "**precauzione**" rispetto alla previsione della sola "**prevenzione**" contenuta nell'Atto unico, fa riflettere sulla necessità di **un sistema di sviluppo in cui gli interessati siano direttamente coinvolti a tale azione attraverso strumenti atti a realizzare alla fonte il contemperamento tra interessi economici e sociali e a ritrovare norme di carattere tecnico e comportamentale volte a condizionare l'esercizio della stessa attività degli utenti per il fine sociale della tutela ambientale.**

In sostanza si tende al passaggio da un approccio esclusivamente sanzionatorio ad uno comportamentale.

Tali orientamenti conducono a concludere che i soggetti istituzionali che, come i Consorzi, vedono **coesi i soggetti portatori di interessi economici** che si pongono **l'obiettivo di una utilizzazione razionale delle risorse** nel rispetto delle regole vigenti, quali quelle della conservazione e della salvaguardia, rappresentano un modello che trova ampio riconoscimento nei principi informatori dell'Atto unico europeo anche con particolare riguardo al principio di sussidiarietà.

Se si tiene conto che la politica della Unione Europea in materia ambientale deve contribuire a perseguire, tra gli altri obiettivi, anche l'utilizzazione accorta e razionale delle risorse naturali, quale garanzia migliore, per una utilizzazione accorta e razionale, dello strumento consortile? Esso é fondato **sulla solidarietà**; gli utenti consorziati aventi titolo all'utilizzazione delle risorse naturali sono i più diretti interessati a conservare e salvaguardare tali risorse, ponendo quindi in essere **una politica di precauzione** attraverso un'utilizzazione parsimoniosa, razionale e coordinata per la quale sono richiesti solidali comportamenti comuni, rispettosi delle regole per la salvaguardia della risorsa, attraverso i quali si realizza anche la tutela dello sviluppo compatibile.

D'altra parte il principio di **sussidiarietà**, costituente ormai un principio fondamentale dell'ordinamento amministrativo del nostro Paese, dovrebbe determinare una forte spinta verso la cooperazione tra i soggetti istituzionali, protagonisti locali, che sono espressioni di sussidiarietà e che, attraverso gli strumenti di concertazione, realizzano quella solidarietà che vincola a comportamenti mirati a conseguire lo sviluppo del territorio nei limiti della compatibilità.

INVESTIGATIONS ABOUT SOILS AND ENVIRONMENTAL VULNERABILITY APPLIED TO THE REALIZATION OF MUNICIPAL PLAN INSTRUMENTS

Alessandro Buscaroli**, Massimo Gherardi*, Gilmo Vianello*

* CSSAS - Experimental Centre for Soils Study and Analysis - Bologna University

** Agricultural Chemistry Institute - Bologna University

Abstract

Since the end of World War II more than eighty percent (80%) of land in Italy has undergone intense transformation due to the evolution of environmental conditions and changes in socio-economic circumstances. It is necessary, therefore, to make a careful investigation of this evolutionary process concerning land-use with an emphasis on a rational and sustainable use of agricultural and forest resources. Due to its intrinsic characteristics, soil is nature's most efficient system of self-purification. Once polluted, however, it will remain in this state for a significantly longer period of time compared with water or the atmosphere. In fact soils are capable, to a degree, of reacting against certain forms of contamination (sensitivity), until a limit is reached beyond which they begin to manifest symptoms of degradation in one or more of their chemical, physical or biological functions (vulnerability). Soils that are altered in their basic characteristics are no longer able to act as biological filters for soluble substances which can more readily pass through them, therebye increasing the risk of contamination to superficial levels of the hydrological system.

The evaluation of different soil's sensitivity and vulnerability levels, with respect to agricultural and extra-agricultural activities, requires an analysis of a complex set of environmental and human factors and particularly the acquisition of enough knowledge about natural and anthropical environmental characteristics. This is particularly true in the case of municipal territories in which the inadequacy of urban infrastructure has often contributed to the degradation of soils, especially land in areas surrounding urban centres where they have traditionally been used for fruit and vegetable farming. This complex phenomenon of environmental degradation may vary or be compounded due to other specific types of agricultural and extra-agricultural activities.

The objective of this paper is to provide local governments with tools to analyse and classify areas within their municipalities to varying degrees of environmental sensitivity and vulnerability and to correlate land-use dynamics with physical and anthropic ecosystem characteristics which have formed and evolved over time. Various climatic, hydro-geological, pedological and anthropic parameters have been considered and managed by the G.I.S. (geographical information system).

The G.I.S. represents a useful modelling instrument, with which it is possible to generate predictive models. The efficiency of the system linked with its capability to elaborate, update and transfer data sets from one operative situation to another makes the G.I.S. an important tool for environmental studies, fundamental to land-use management and planning.

Introduction

Soil must be considered an integral element of environmental conditions howning to its natural dynamic body that has formed the superficial layer of the earth's crust. It is derived from rock and living organisms and formed by the integrated action of climate, morphology, and ecological forces. Soils are formations affected by a wide range of physical, chemical and biological processes. They are known to react in different ways to natural and human interventions which influence or modify their structure and potentially lead to their degradation.

Various factors contribute to "soil resource" subtraction: urban development, erosion, pollution and agricultural production. The latter, which is intrinsically connected to the use of soil as a resource, has in the last several decades contributed to its degradation and reduced its productive capacity. On the other hand, agriculture could contribute to contrast natural degradation phenomena when conducted in the veiw within the context of "sustainable development". Important research dealing with the problem of soil degradation due to human and natural causes has been available for some time now throughout Europe. For example the "European Soil Map" of 1972, has recently found new importance in Italy with the establishment of a national co-ordination committee headed by the National Pedological Observer of the Agricultural Policy Ministry. Another important document regarding soil resource management in terms of sustainability and sensitivity is the second edition of the "Report on environment condition", published in 1997 by the Italian Environmental Ministry. This document pointed out that soil, which is considered a natural resource, as are water, air, flora and fauna, can be subjected to negative impacts capable of causing relatively rapid damage (table 1).

Table 1

Soils degradation in Italy from the "Report on environmental conditions" (Italian Environmental Ministry, 1997).

CHEMICAL DEGRADATION	a) metals contamination b) soils radioactivity c) organic matter loss d) salinization e) soils acidification f) organic refluent spreading
PHYSICAL DEGRADATION	a) hardness b) hardsetting c) superficial crust formation
RESOURCE LOSS	a) urbanisation b) superficial erosion c) mass erosion

In order to serve as effective tools, methodological approachs must, first of all, have an homogeneous information database in order to define basic environmental and territorial units, capable of supporting research aimed at solving problems at the local level. Incomplete or fractional data can often render local government administration's planning decisions inadequate. Now and in the future this will become increasingly apparent as these same governments attempt to balance the often conflicting issues of quality of life with economic/productive needs and the need for bio-diversity with resource maintenance.

Soils of the Padania plain, originally of high quality and fertility, have been increasingly exploited and subjected to intense agricultural production. On the other hand, analysis of data covering the last fifty years demonstrates that fallow areas have also increased, particularly in hilly and mountanous regions, due in most part to set-aside incentives which, in Italy, have been interpreted not as beneficial soil rest periods but as an abandon. This policy has had a negative impact on hydro-geological resources.

This phenomena creates the need for a comprehensive program of land-use management and urban planning at all levels of government. Particularly the case at the municipal government level, where comprehensive land-use data and reports detailing the causes of soils vulnerability are required. In all areas under consideration, an analysis of morphological relief has been completed, incorporating land-use maps referenced to two different time periods so that changes over time could be identified and analysed. In addition, geo-pedological and physio-chemical soil properties and characteristics have been described and outlined so as to define both superficial and deep hydrological conditions. Climatic data have also been collected and analysed.

The following research represents our common understanding and experience in the study of soil degradation. It is broken down into four sub-sets.

1) Analysis of land-use changes in order to evaluate soil depletion related to urbanization and erosion.

2) Natural fertility loss due to the impact of new or adopted agricultural practices that alter physio-chemical properties.

3) Aquifer vulnerability due to the infiltration of pollutants (e.g., pest control, herbicides, livestock sewage, sewage sludge, etc.).

4) Soil contamination as a result of the progressive concentration of harmful substances, such as heavy metals and other industrial by-products.

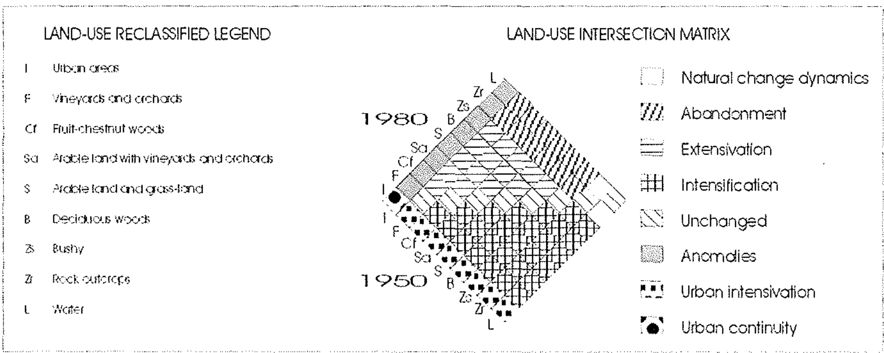
1. Land-use Changes

The adopted research methodology has permited the evaluation of changes in the use of soil resources that are primarily the result of human activities and interventions. The methodology compares land-use conditions at two distinct time periods in order to register changes that have occurred. Suitable information was obtained from the analysis of aerial photographs taken during aerial surveys made at different times which provide analogous and real images of the area at the time of the study. In addition, land-use information was obtained from consulting existing cartography, such as I.G.M. (Military Geographic Institute) maps at a scale of 1:25,000 which illustrate land-use using widely accepted symbols. Additional information was gleaned from thematic land-use maps, for example, those compiled for the Emilia Romagna region.

Information collected from different sources should lead to a fixed number of land-use classes, in order to permit a comparison between the two different situations. Once the data from each time period was made analogous, it was possible to use a cross referencing and reclassifying matrix (with two axis, each one representing a time period) to identify land-use changes or continuities during the period under consideration. Each possible cross combination was evaluated and reclassified according to the following criteria: natural change dynamics, abandonment, extensivation, intensification, unchanged, anomalies, urban intensification and urban continuity.

Figure 1

Land-use reclassified legend and example of intersecting matrix for the evaluation of land-use unchanged or changes during the period 1950 to 1980.



Case Study - Ticino Park

Ticino Park is located beside the Ticino River, in the provinces of Milan and Novara. In order to identify land-use changes that have occurred since the beginning of the century, cartography at a scale of 1:25,000 (edited by I.G.M., 1895) was used. From this analysis it is evident that land-use changes are clearly related to different geo-pedological conditions. In fact, areas close to the Po River are characterised by self-alluvial deposits with particularly deep soils. On the other hand, areas close to the Ticino River reveal, from north to south, a change from quaternary moraine cover to alluvial sediments. This zone is characterised by a band of karst springs which create interesting micro-environments. By observing the land-use changes of this region since the beginning of the century, it is evident that the Ticino River's hydrological system has kept its original form, characterised by wide river beds with steep banks.

Unfortunately, this territory has undergone progressive and often intense urban expansion, particularly within the region of Lombardy.

This urban development has been the primary and determining factor in the destruction of the region's karst springs. Furthermore, it has had a widespread and often negative impact on the region's hydrology due to the numerous wells that have been drilled for water consumption. We have overall 25% of the provinces surface area that is dedicated to urban areas. As a consequence the number of karst springs has been reduced from 280 at the beginning of the century to no more than 20 at present, with most of these occurring within illicit landfills.

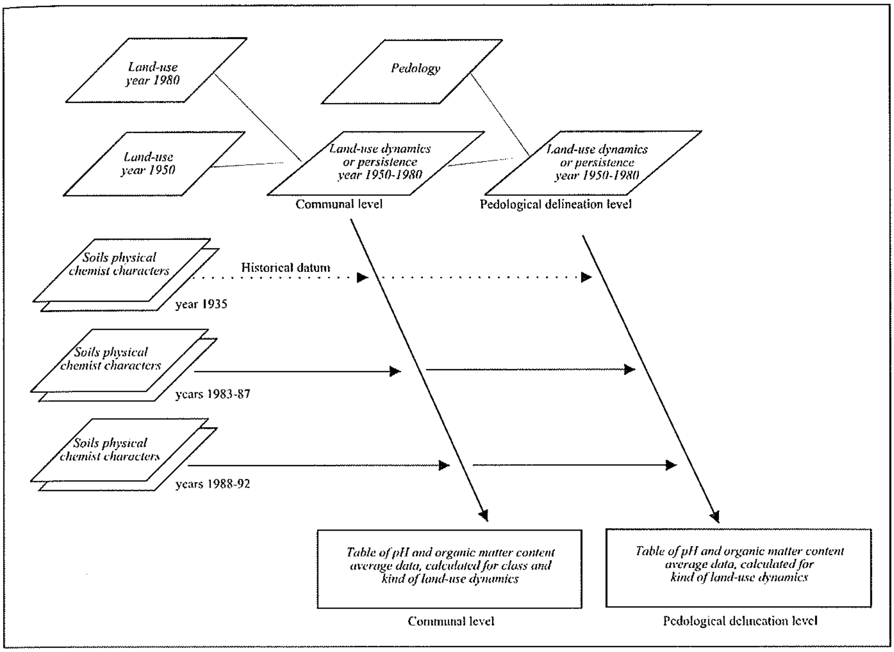
2. Evaluation of Changes to the Physio-Chemical Characteristics of Soils Using a Multi-Temporal Comparative Procedure

Substantial changes in demography and the nature of rural areas since the nineteen-fifties, due in part to advances in farming technology and agricultural management, have caused significant structural modifications to soil resources. The abandonment of marginal agricultural land on the one hand, and the concentration and intensification of agricultural activities in more restricted areas on the other hand, has been a determining factor in the alteration of soil characteristics. This phenomenon is more evident in those situations in which agricultural practice entail to soils a great contribution of fertility elements. Research into this problem, as undertaken in a preliminary study made of the Modena plain (Ballestra et al., 1996), has shown that in addition to significant modifications in land-use trends, physio-chemical changes to soil characteristics, such as increases in alkalinization, lower levels of organic matter and reduction of permeability, have also occurred. As a result of this experience, it has been decided to undertake further investigations in order to create a predictive model capable of analysing the impact of the continued agricultural practices and other current forms of human intervention on the physio-chemical nature of soils. In particular the study has consisted in the comparison and analysis of the results of various field samples made over time concerning pH levels and organic matter content.

Furthermore, within the study region comparisons were made between the different land-use dynamics in order to quantify the influence of territorial changes on variations in the averages of calculated physio-chemical data. Soil samples were further analysed in order to compare physio-chemical parameter change with their pedological characteristics.

Figure 2

Operative scheme of the adopted survey model for the evaluation of changes to the physio-chemical characteristics of soils.



Case Study

The aforementioned investigative methodology was applied to the municipalities of Nonantola and Spilamberto both located within the province of Modena in the plain regions of Emilia-Romagna. The physio-chemical data for the soils under consideration was obtained from both the 1935 geo-agronomic map of Emilia and surveys made by Emilia Romagna region cartographic service during the period from 1983 to 1992. The first document was completed by the Modena Regia Experimental Agricultural Station. The aim of this survey was to describe the pedology of the provinces within Emilia using a sampling grid ranging from 2 and 2.5 km. Each sample point, located and numbered on a map at a scale of 1:100,000, was associated with the contents of a table of physical/chemical information. This document provides an historical record of soils from the municipalities of Nonantola and Spilamberto, specifically for 13 sample locations in Nonantola and 12 in Spilamberto. For the period spanning 1983-1992, 288 samples were analysed originating from 156 geo-referenced farms located within the study area.

Colorimeter methodology was employed to analyse pH levels for samples taken in 1935. For the samples taken during the period spanning 1983-1992, a pH meter for soils using a water suspension process at a ratio of 1 to 2.5 was employed. For determining organic matter content for samples taken in 1935 the Itscherekoff method was used, whereas samples for the years 1983-1992 were analized using the Walkley-Black method. Parameters for pH levels and organic matter content were evaluated during the first phase of the study by comparing the average value of samples for the year 1935 with the average value of samples taken first during the years 1983-1987 and then during the years 1988-1992. The results were crossed referenced with land-use change catagories (e.g. unchange, intensification, extensivation, etc.) and with transformation typologies (e.g. arable land-orchards, arable land-urban area, etc.) that occurred in study areas during the period under consideration (1950-1980).

A comparison of the physio-chemical data from the two sub-periods (1983-1987 and 1988-1992) tends to generates better results because the analytical methodologies for both periods are analogous. When pH values were analysed for both municipalities, taking into account all of the dynamic categories under consideration, a marked increase was observed between 1935 and the average condition during the years spanning 1983-1987, with soils passing from neutral to weak or moderate alkalinity. Specifically, in the case of Spilamberto a comparison of the data from the period 1983-1987 and the period 1988-1992 a limited decrease of pH values was noted to a condition of weak alkalinity. For Nonantola, the comparison showed considerable stability in pH values over time with soils remaining moderately alkaline.

With regards to organic matter content, it has to be considered the different analysis methodology adopted, which makes the data of the year 1935 under appraisal of 1/4 (Saltini, 1973). For both communes and in the first considered period, a decrease of 0.6-0.7% is registered, in dynamic classes "intensification" and "extensivation".

When the data for the years 1988-1992 were studied it is noteworthy that for the catagory of "unchanged" relatively stable values were registered. This trend toward stability for "unchanged" catagories, is in contrast to the data analysed for "intensification" and "extensivation" catagories, where a moderate increase in values was registered.

3. Evaluation of Environmental Vulnerability Due to Infiltration

Last year's reports concerning environmental conditions illustrate how effective planning and management of underground hydrological resources is closely linked to soil conservation and the monitoring of human activities that impact these resources. These studies concluded that the protection of soil and water as natural resources is becoming increasingly important. On the basis of territorial intrinsic vulnerability condition to determine levels of vulnerability as a function of various sources of contanimation that are for the most part anthropical in origin.

Of particular significance are those methodologies which estimate the possible transfer of soluble pollutants from topographical surfaces to the upper most levels of the water table and, as a consequence, the possible migration of these contaminants to deeper aquifers from where drinking water is taken.

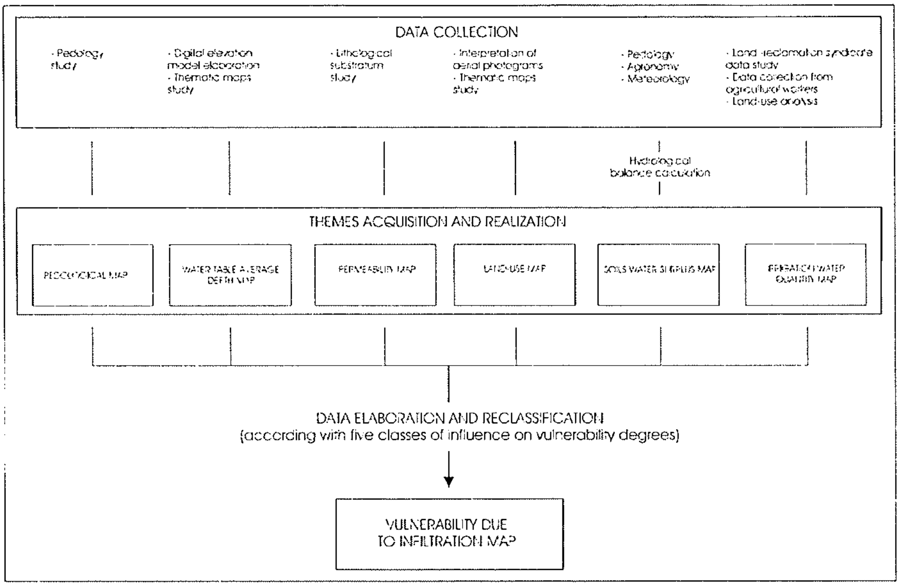
Beginning in the early 1980's the European Community Council issued regulations concerning the quality of water destined for human consumption (80/778/CEE) and supported many research projects aimed at the issue of soil vulnerability, for example the "World Soils Policy Programme" (UNEP, 1982). During the last ten years, urgent problems linked to water pollution and resources degradation have led to the creation of many survey models for studying environmental impact. These could be classified into two main typologies: numeric models and parametric models.

Certainly those most used for the realisation of thematic cartography are parametric models, in which territories are divided in classes of vulnerability. The development of computer technology and particularly that of G.I.S. has greatly simplified all phases of parametric studies while at the same time introducing the possibility to evaluate the impact of human interventions on the environment in the immediate and not too distant future (predictive modelling).

The model applied to this study (figure 3) derives from information and regulations used by European Commission workgroups inside the SOVEUR project. This research project started in 1991 by the Netherland's Ministry of Housing, Physical Planning and Environment (VROM) in collaboration with ILASA (International Soil Reference and Information Centre, Wageningen), has among its goal the creation of a "soils vulnerability map for specific categories of chemical compounds" at a scale of 1:1,500,000.

Figure 3

Simplified model for land classification into areas with different degrees of environmental vulnerability due to infiltration.



The same methodology was adopted in 1991 by Ciavatta, Sequi and Vianello within the Finalised Project PANDA (Agricultural Production in Environmental Protection) with the aim of improving the criteria for defining and representing areas of vulnerability within Italy. In particular to improve the criteria used for evaluating the Padana Plain not only in terms of the contamination of subsurface hydrological resources but also with special emphasis on soil protection.

The model is based on a simple parametric rating system in which:

- a group of environmental parameters that influence infiltration is defined;

- every category for each parameter is evaluated with an appropriately weighted vulnerability value; these values ranged from 1 to 5, corresponding, respectively, to minimum and maximum levels of infiltration; for every parameter the region is mapped and reclassified into analogous areas having equal infiltration properties and therefore equally weighted values of vulnerability;

- by cross referencing the different reclassified thematic maps, a sum of weighted values is made relative to each area;

- resulting values is reclassified to distinguish each environmental vulnerability with respect to infiltration classes.

Water is considered a potential solvent for substances present on the soil's surface or lying within its matrix and thus as a potential vehicle for contaminants. The model, therefore, evaluates the possibility of water passing through the soil to the water table below. The following are the parameters that were analysed: soils hydrological surplus, irrigation water quantity, pedological characteristics, soil permeability, water table depth and land-use.

Case Study - Use of Pesticide

The case study applies the predictive model for environmental vulnerability due to infiltration to the use of pesticides in the municipality of Fidenza (PR). The model is a tool used to evaluate the risk of pesticide pollution. The concept of vulnerability is linked primarily to site characteristics while the evaluation of a particular substance's environmental impact requires consideration of its chemical/dynamic characteristics.

In order to evaluate the environmental impact of pesticides some researchers have proposed the codification of environmental indexes (Gustafson, 1989; Jury *et al.*, 1987). These indexes permit researchers to assign to each type of molecule, for every particular environmental context, a level of toxicity or hazardous rating, which can, in turn, be used to evaluate the amount of active elements that may reach the water table. Furthermore, when these indexes are assigned to the specific dynamic chemical properties of particular pesticides and different soil data, potentially hazardous levels of contamination reaching the water table can be assertained. Among indexes surveyed in the literature of soil studies, *Attenuation Factor* (AF) (Rao *et al.*, 1985) has been adopted for the present study

$$AF = exp\ [\ -\ (\ 0.693\ (\ L\ (\ FC + (\ r\, f_{oc}\, K_{oc}\ ) + (\ AC\, K_h\ )\ )\ /\ J_w\ /\ t_{0.5}\ )\ ]$$

In this formula, L is the water table depth expressed in meters (m); FC is the field capacity (Kg/Kg); r is the bulk density (Kg/m^3); f_{oc} is the organic carbon; K_{oc} is the adsorption coefficient (m^3/Kg); AC is the porosity; K_h is the constant of Henry; J_w is the net recharge (m/year); $t_{0.5}$ is the half life in soil (days).

The data pertains to pesticide properties and also to soil, climate and water table depth characteristics. In the case of the municipality of Fidenza commune, the two most frequently used pesticide in agricultural practice have been considered: metolachlor and trifluralin.

Metolachlor is a colourless liquid with quite good water solubility (530 mg/l at 25°C), in addition to its high level of solubility in organic solvents. It is moderately persistent in soil (approximately 3 months). It is an inhibitor of Graminaceae seed germination and is selective to cotton, corn and potatoes; it is classified as non hazardous for mammals having an oral rat DL50 of 2,800 mg/Kg. The use of metolachor in the municipality of Fidenza is approximately 247.45 Kg/year.

Trifluralin is a solid substance with low water solubility (< 1 mg/l at 27°C), and persists in soils from 2 to 5 months. It is used for selective weeding of numerous crops (e.g., wheat, lucerne, etc.). It controls various types of infesting Graminaceae and is very volatile and must, therefore, be buried after use. It is considered non hazardous for mammals due to its oral rat DL50 of 16,000 ml/Kg. The use of trifluralin in the municipality of Fidenza is approximately 177.57 Kg/year.

The physio-chemical and chemo-dynamic parameters which are necessary for AF calculation have been derived from the existing literature (M. Trevisan *et al.*,1991; C. Gardi, 1993). Water table depth has been considered constant at 1 meter as well as soil depth; physio-chemical soil data (table 2) for *AF* calculation has been estimated on the basis of the "Regional Catalogue of Emilia Romagna Soil Types". Porosity, specific weight and field capacity have been calculated on the basis of empirical data which allows to associate a particular texture class with the value cited above. Organic carbon has been derived from the amount of organic matter present in the soils using a conventional conversion factor; hydrological surplus and net recharge have been calculated in advance for each type of soil and crop.

Values for the *AF* factor have been codified into several classes of danger by Khan and Liang in 1989. For each class, a weighted danger value of potential contamination to the water table has been given; a minimum value for the first class and value maximum for the fifth.

Reclassification of the pedological map has been obtained using specific software for database updating. It is observable that for metolachlor, which possesses a low K_{oc} value and long half-life time, the risk of contamination is high and uniform throughout the whole study area. On the other hand, in the case of trifluralin in spite of the relative homogeneity of pedological characteristics, there is variance in the risk of contamination in the different territorial areas, with values ranging from medium to high.

Table 2

Physical-chemist parameters used for *AF* index calculation, relative to different pedological units; *AF* index calculated for every different pedological unit relative to metolachlor distributed on maize and trifluralin applied to wheat, in Fidenza commune.

Pedological units	FC	AC	r	f_{oc}	J_w wheat	J_w maize	AF metolachlor on maize	AF trifluralin on wheat
2Aa	0,45	0,50	1,35	0,70	0,25	0,299	0,888	0,232
2Ca	0,44	0,47	1,27	1,43	0,25	0,299	0,814	0,061
2Cb	0,39	0,53	1,41	1,11	0,232	0,27	0,82	0,076
3Aa	0,39	0,53	1,41	0,81	0,25	0,299	0,87	0,172
3Ba	0,33	0,56	1,49	0,90	0,25	0,299	0,859	0,127
4Aa	0,33	0,55	1,47	0,58	0,232	0,26	0,886	0,236
4Ab	0,31	0,55	1,47	0,64	0,232	0,26	0,878	0,203
4Ba	0,39	0,55	1,47	0,35	0,232	0,27	0,922	0,417
5Ab	0,35	0,56	1,48	0,40	0,232	0,27	0,917	0,373
5De	0,35	0,56	1,48	0,40	0,232	0,26	0,914	0,373

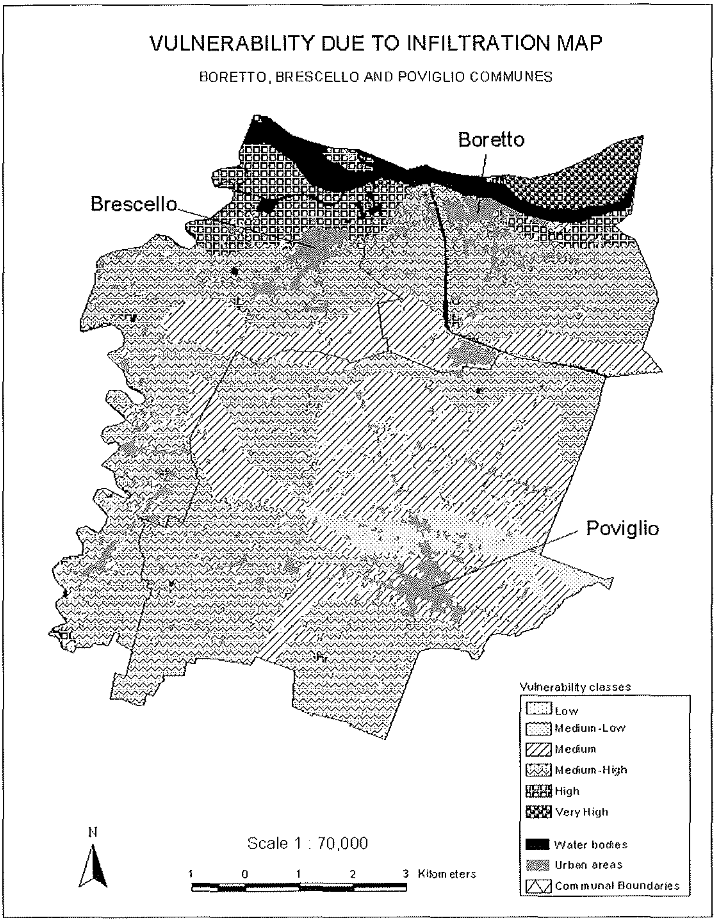
The water table contamination danger map that was obtained using the *AF* formula provides an evaluation of the problem that derives specifically from the pedological and hydrological characteristics of the study area. In order to obtain an overall analysis of the risks involved that takes into account the full complex of environmental characteristics, an overlay map has been produced that integrates the danger map and the vulnerability due to infiltration map, thus obtaining by their sum, an integrated vulnerability map for each pesticide under consideration with reference to each specific crop.

Case Study - Irrigation Water

This case study explores the application of the vulnerability due to infiltration map (figure 4) for the use of irrigation water in the municipalities of Boretto, Brescello and Poviglio (RE). The problem of the quality of irrigation water raises particular concerns in the study areas because of its use primarily in the agricultural sector. Monitoring of irrigation canal waters is one of the projects being undertaken by ARPA (Regional Environmental Protection Agency) but unfortunately, until now, it has not been applied due to a series of problems.

Figure 4

Vulnerability due to infiltration map (Boretto, Brescello and Poviglio communes).

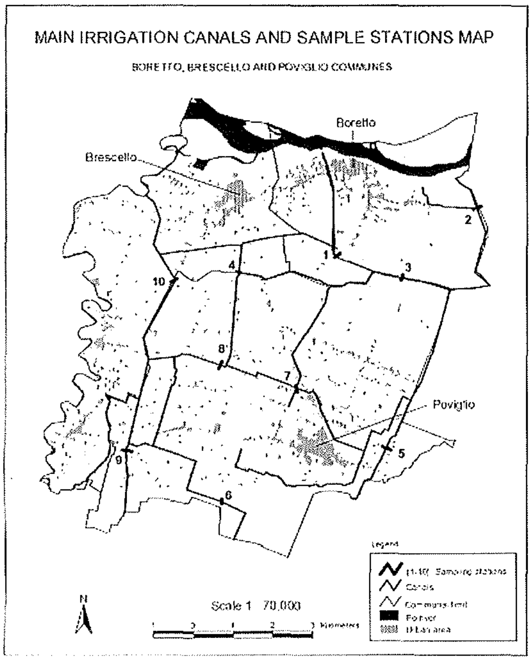


Throughout the study area several canals from which irrigation water is derived, have been sampled. Ten cases of water table contamination caused by high levels of ammonia have been registered. Concentrations of nitrate in the aquifer are greater than 15-20 mg/l, except in the areas near the dispersing course of rivers where levels decrease. Contamination often derives from the spread of sewages, use of soluble fertilizers in irrigation water and conventional irrigation practices using water containing high levels of organic matter and in quantities that exceed the real requirements of crops.

Sampling stations along the main canals, where to test water, have been established (figure 5). In addition, near the main urban and industrial areas a couple of additional stations, one before and one after these areas, have been set up in order to verify any possible increase in contamination arising from the crossing of these areas.

Figure 5

Main irrigation canals and sample stations map (Boretto, Brescello and Poviglio communes).



Sampling was undertaken on June 3rd and 5th 1997. Analysis was carried out at the Environmental Science Department of Parma University. The following parameters were chosen to analyse the samples: pH, conductivity as salinity indicator, soluble reactive phosphorus (SRP), nitric, nitrous and ammoniacal nitrogen.

Sample number 1 (table 3) exhibits analogy between stations number 4, 6, 10, stations number 1, 3, 7 and stations 5, 8. The second sample exhibits similarities between stations 1, 3, 5 and stations 6, 7, 8, 10, whereas stations 2, 4 and 9 exhibit considerably distinct levels of contamination. In particular, the groups comprising the second sample may be interpreted as follows: stations 1, 3, 5 located on the Cavo Deviatore and connected to the Cavo di Risalita where nitrate and ammoniacal nitrogen concentrations gradually decrease; stations 6, 7, 8, 10 containing almost equal concentrations of nitrate; and stations 2, 4, 9 where levels of contaminants consistently differ from one another.

Table 3

Results of the analysis of irrigation water canal samples (I = first sample; II = second sample).

N° station	Concentrations (in μg/l)								pH		Conductivity (μS/cm)	
	$P\text{-}PO_4$		$N\text{-}NO_2$		$N\text{-}NO_3$		$N\text{-}NH_4$					
	I	II	I	II	I	II	I	II	I	II	I	II
1	56	58	39	58	1260	1834	133	237	8.10	7.90	419	354
2	10	4	25	28	3164	302	116	41	7.96	7.94	365	391
3	62	62	42	58	1232	1722	88	225	8.09	8.03	392	365
4	311	133	107	120	608	134	537	309	8.02	7.82	500	627
5	187	76	42	63	969	1593	27	224	8.32	8.06	396	367
6	429	0	51	103	966	935	140	53	8.18	8.33	438	504
7	158	245	67	34	1016	526	140	41	7.88	7.98	379	451
8	62	104	60	76	644	368	25	36	8.20	8.29	435	493
9	409	369	144	132	2414	1702	564	83	7.80	8.19	441	560
10	271	261	65	74	1159	736	215	92	8.04	8.19	513	536

Water flowing from Cavo Derivatore comes directly from the Po river, and therefore, it is interesting to compare the measurements taken at stations number 1 and 3 with those reported by ARPA for Reggio Emilia's water quality near Boretto in the Po river valley. What emerges from a comparison of the data is that the water quality at Cavo Deviatore sampling stations 1 and 3 is similar to the water quality of the Po river, with the exception of nitrate concentrations which greatly decrease from the outlet work to station number 3.

The difference in values between stations 2 and 9 reflects their marginally distinct geographical positions, particularly station number 9 where a high concentration of nutrients were detected due to its location near the Brescello "canalazzo" which collects most of the waste originating on the high plain. Despite its location on the same canal, pollution levels decrease on the opposite side of Brescello municipality at sampling station 10 since there are no factories or live stock farms in the area. Near station number 9, however, there is a cattle breeding farm and a cheese factory which may be discharging organic matter directly into the canal, influencing both nitrogen and phosphorous concentrations.

Case Study - Breeding Sewage Discharge

This case study explores the application of the vulnerability due to infiltration map to breeding sewage discharge in the municipality of Visano (Bs). Animal breeding load in Visano is quite high and is linked to sewage discharge problems. With respect to Regional Law 37/93, the municiplity falls within the low soils vulnerability and high zootechnical load area. This regulation stipulates that livestock farms in this area must present an agricultural utilization plan (P.U.A.) when the amount of live animal weight exceeds 3 tons/hectare; in all other cases they must present a simplified agricultural utilization plan (P.U.A.S.). Territorial classification is based on the evaluation of soil vulnerability, which does not always correspond to phreatic aquifer vulnerability. In some cases, including that of Visano, an area with low soil vulnerability may also exhibit high phreatic aquifer vulnerability.

Reclassification of the vulnerability infiltration map legend was carried out using four classes of suitability: suitable, moderately suitable, slightly suitable, and not suitable (table 4). Observing the map one can see that most of the study area is only slightly suitable for agricultural expansion, a small part being moderately suitable and the area situated along side the Chiese River being not suitable.

The next step in the analysis consisted in attributing to each suitability class a tolerable animal breeding load. This information was collected from existing reports contained in the literature (ERSAL, 1991). At the moment the municipality of Visano can not discharge the totality of its breeding sewage within its boundaries.

Under these circumstances, a sewage disposal plant could represent a possible solution. A breeding sewage treatment plant currently under construction represents a partial solution to the problem. The treatmnet plant user basin could encompass Visano and adjacent municipalities with a total load of around 100,000 pigs which corresponds to 125,000 q. By-products such as the processed solid waste could be use as fertilizer to the agricultural sector, and biogases could be reused by the plant to generate its own electricity or sold to the national electric company (E.N.E.L.). Livestock breeders who utilize the new sewage treatment plant will not have to increase their sewage storage capacity and would not be obligated to respect the ratio between live weight and cultivated surface area. The municipality, in particular, could manage zootechnical waste entirely inside its borders and thus sewage discharge and livestock activities would become completely separate from territorial issues.

Table 4

Correlating table between vulnerability due to infiltration classes, sewage spread gift classes, territorial bearable amount of zootechnical load, territorial gift to spreading classes, areas and animal breeding load relative and total, accepted from territory.

Water table vulnerability classes	*Sevage spread gift classes*	*Bearable zootechnical load (live weight)*	*Area*	*Relative accepted load*	*Total accepted load*
very low	suitable	35-30 q\ha			
low	suitable	35-30 q\ha			
medium	moderately suitable	25-20 q\ha	59.18 ha	25-20 q\ha	1479.5-1183.6 q
high	slight suitable	15-10 q\ha	887.6 ha	15-10 q\ha	13314-8876 q
very high	not suitable	0 q\ha	99.89 ha	0 q\ha	0 q
total					14793.5-10059.6 q

4. Metal Distribution and Concentration in Soils as a Result of Natural and Human Activities

The presence of heavy metals in soils, as a consequence of human activity, occurs for the most part when air laden with ashes, powders or atmospheric dust resettles on the ground, or when they are diffused by water (the superficial flowing of polluted water). In other cases it may result from their presence in products such as fertilizers or soil conditioners (e.g., livestock sewage, depuration mud, conditioning sludge).

Soils that are contaminated by heavy metals present, depending on the level of pedogenesis, a low possibility of reducing of the concentration of contaminants primarily because of their negligible migratory quality through the strata or secondarily, due to their low absorption rate in significant quantities by cultivated crops. Because of this, a determination of the total amount of heavy metal and micronutrient content for soils has low significance. In fact, it would be better to consider the grade of bioavailability, in other words, the correlation between the soil's soluble or extractable metal fraction and the one that is effectively absorbed by the crop.

Experiments made up till now have targeted the diffusion and the concentration of some heavy metals and micronutrients (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Ti and Zn) present in soils as a function of the different kinds of added biomass (e.g., zootechnical sewage, depuration mud, conditioning sludge), in order to create a database that correlates different geo-pedological typology with micronutrients and heavy metals concentrations. Special attention has been given to those with values greater than the limits imposed by national and local regulations, (as total amounts or as exchangeable amounts) and to standardise the analytical procedures for their determination. Furthermore, other field of studies made the comparison between the application of Law 99/92, which refers to total amounts and the proposal to evaluate the metal's effective hazardousness considering their extractable amounts.

Case Study - Incinerator System

In collaboration with the Regional Agency for Environmental Protection (A.R.P.A.) for the province of Bologna, heavy metal concentrations in soil-plant systems were evaluated as a result of the resettling of atmospheric emissions from the Frullo incinerator. The study began by generating a theoretical resettling map of pollutant scatter obtained using a mathematical model I.S.C.L.T. (Industrial Source Complex Long Term) undertaken by the Physics Department of the University of Bologna.

The A.R.P.A. provided a passive monitoring, locating Lolium Multiflorum cultivated plots, regularly mowed on a monthly basis from January to May 1998. In addition, adequate soil samples at fixed depths were made next to the Lolium Multiflorum plots and at different fixed distances from the incinerator system.

Concerning the soil samples with heavy metals determinations, both total and extractable (EDTA and DTPA) calculations have been made, in addition to routine analysis for pedological soil characterisation. Analytical results have shown the existence of a good correlation with the provisional relapsing model; in fact profile number 2, which is inside the area considered at highest risk, revealed the highest concentrations for all elements and for all soil's depth conditions. The reliability of the results was confirmed by the trend correspondence of calculated averages between metal concentrations into the different test locations grouped for the different positions with respect to the incinerator.

There is in fact (mainly for Cd, Pb, Cu and Ni) a negative gradient starting from the south-east towards the north-west, passing crosswise from the south-west where average concentrations are at intermediate levels relative to the other direction's average calculated values.

Even if at present the actual metal relapsing levels are not dangerous in this area, the situation at plots 1 and 2, in particular with respect to Ni, Cd, and Cu, for which known concentrations are close to or greater than acceptable lower limits, requires a permanent phyto-pedological and meteorological monitoring.

Conclusions

Methodological procedures and examples shown before, may represent useful investigative techniques at a detailed scale in the revision of municipal and urban planning instruments, and in programming of environmental protection procedures and productive resource sustainability with particular emphasis on agricultural soils.

It is desirable that municipal administrations provide themselves with documents which permit them to plan territorial interventions, as well as evaluating the relationship between urban systems, demographic trends, quality of life issues and economic development for a clearer awareness of expected soils consumption and of all possible related resources degradation risks.

References

ABBOT M.B., BATHURST J.C., CUNGE J.A., O' CONNELL P.E., RASMUSSEN G. (1986). An introduction to the European Hydrological System - Systeme Hydrologique Europeen, SHE, Part.1: History and philosophy of a phisically-based, distributed modelling system. *J. of Hydrology*. 87: 45-59.

ANNALI REGIA STAZIONE SPERIMENTALE DI MODENA (1935). Carta geopedologica della pianura di Modena. *Boll. delle ricerche e della sperimentazione*, IV.

BALDINI U., FORTELLI M., LUPATELLI G., PIRAZZOLI M., VIANELLO G. (1987). *Un modello interpretativo dei caratteri strutturali delle relazioni tra sistemi urbani e settore agricolo nell'utilizzzione di risorse territoriali*. P.F. Ipra-CNR, pubbl. n. 1284, pp. 149-279.

BALLESTRA G., BERTOZZI R., BUSCAROLI A., GHERARDI M., VIANELLO G. (1996). *Applicazione dei sistemi informativi geografici nella valutazione delle modificazioni ambientali e territoriali*. FrancoAngeli Editore. Milano.

BERTOZZI R., BUSCAROLI A., GARDI C., SEQUI P., VIANELLO G. (1993). A GIS application to the evaluation of the grade of sensibility of soils for their utilization. *Proceedings EGIS* '93. 1:1533-1016-1025.

BERTOZZI R., BUSCAROLI A., GARDI C., SEQUI P., VIANELLO G. (1994). *A GIS application for the evaluation of the soil's vulnerability map.* (1994). ISBN/ISSN: ISBN 90-73414-13-X.

BLUM W.E.H. (1989). *Soil pollution by heavy metals. Steering Committee for the Conservation and Management of the Enviroment and Natural Habitats.* Council of Europe, Strasbourg.

BUSINELLI M., VISCHETTI C., COLETTI A. 1992. Validation of the Koc approach for modelling the fate of some herbicides in italian soils. *Fresenius Envir. Bull.* 1. 583-588.

CIAVATTA C., MARZADORI C., SIMONI A., VIANELLO G. (1992). Distribuzione di metalli pesanti (totali e assimilabili) nei suoli della fascia costiera adriatica: area meridionale della provincia di Venezia. *Atti del X Convegno Nazionale della Società Italiana di Chimica Agraria*, 129-136.

GARDI C., (1993). *Metodi di studio per la valutazione della mobilità degli erbicidi nelle acque.* Tesi di specializz. Scuola di specializz. in fitopatologia. Università Studi di Bologna.

GESSA C., SIMONI A., VIANELLO G. (1993). Metalli pesanti nei suoli italiani per cause naturali o per fattori antropici: valutazioni su scala nazionale. Atti convegno Ciclo biogeochimico dei metalli pesanti, da "*Studi Sassaresi*"; sez. III, *annali della Facoltà di Agraria dell'Università di Sassari*; Vol. 35 (2°), 229-240.

GOUPTA S.K., VOLLMER M.K., KREBS R. (1994). *The importance of mobile, mobilizable and pseudo total heavy metal fractions in soil for three level risk assessment and risk management.* The Science of Total Environment.

GUSTAFSON D.I. (1989). Groundwater Ubiquity Score: a simple method for assessing pesticide leachability. *Env. Toxicology and Chemistry.* 8: 339-357.

HOLLIS J., BROWN C. (1993). An integrated approach to acquifer vulnerability mapping. *Proceedings IX Simposium Pesticide Chemistry.* 633-644.

HUGHES J.C., NOBLE A.D. (1991). Extraction of chromium, nickel and iron and the availability of chromium and nickel to plants from some serpentinite-derived soils from the eastern transvaal as revealed by various single and sequential extraction techniques. *Commun. Soil Sci. Plant Anal.*, 22 (17&18), 1753-1766.

JURY W.A., FOCHT D.D., FARMER W.J. (1987). Evaluation of pesticide groundwater pollution potential from standard indices of soil chemical adsorption and biodegradation. *J. Environmental Qual.* 12: 558-564.

KABATA-PENDIAS A., PENDIAS H. (1992). *Trace elements in soils and plants*, CRC Press, Boca Raton, Fla.

KHAN M. A., LIANG T. (1989). Mapping pesticide contamination potential. *Environmental Management*, 13: 233-242.

MINISTERO AGRICOLTURA E FORESTE (1992). *Metodi ufficiali di analisi chimica del suolo.* Suppl. Ord G. U., n. 121 del 25.05.1992.

MINISTERO DELL'AMBIENTE (1997). *Relazione sullo stato dell'ambiente.* Istituto Poligrafico e Zecca dello Stato.

MINISTERO DELLE RISORSE AGRICOLE ALIMENTARI E FORESTALI (1994). *Metodi ufficiali di analisi chimica del suolo con commenti e analisi.* Osservatorio Nazionale Pedologico e per la Qualità del Suolo, ISMEA, Roma.

PETRUZZELLI R. (1989). Recycling wastes in agricolture: heavy metal bioavailability. *Agricolture, Ecosystems and Environment* 27, 493-503.

RAO P.S.C., HORNSBY A.G., JESSUP R.E. (1985). Indices for ranking the potential for pesticide contamination of groundwater. *Proc. Soil Crop Sci. Soc. Fla.*, 44:1-8.

RASIO R., VIANELLO G. (1990). *Cartografia pedologica nella pianificazione e gestione del territorio.* P.F. IPRA-CNR, Collana Sistema Agricolo Italiano, pp. 267, FrancoAngeli Editore, Milano.

SALTINI A., FARINI A. (1973). Bilancio di lungo periodo della sostanza organica in terreni basso-padani di bonifica. *Rivista di Agronomia*, 2-3: 53-62.

SEQUI P., VIANELLO G. (a cura di) .(1998). *Sensibilità e vulnerabilità del suolo: metodi e strumenti d'indagine.* P.F. RAISA-CNR e PANDA-MiPA, Collana Sistema Agricolo Italiano, pp. 404, FrancoAngeli Editore, Milano.

TREVISAN M., CAPRI E., GHEBBIONI C. (1991). L'uso di indici per prevedere la contaminazione delle acque. *Acqua-Aria* n.9

VIANELLO G. (1993). *Il problema della conservazione del suolo nel bacino padano. "L'impatto delle agro-tecnologie nel bacino del Po"*. P.F. RAISA-CNR, Collana Sistema Agricolo Italiano, pp.123-127, FrancoAngeli Editore, Milano.

WALKER A., ROBERTS S.J. 1993. Degradation, biodegradation and enhanced biodegradation. *Proceedings IX Simposium Pesticide Chemistry*. 357-370.

LAND PLANNING FOR SUSTAINABLE DEVELOPMENT: RURAL LANDS IN THE GENERAL LAND PLANNING OF THE ITALIAN COMMUNES. EXPERIENCE IN THE SIENESE CHIANTI

Pier Carlo Tesi

Architect, Istituto Nazionale di Urbanistica (the Italian National Institute for Town-planning, organised in regional sections), Toscana

I would like to offer my thanks for the opportunity to speak at this important congress on my work to improve land planning using Science of soils results. This is an indispensable step for a sustainable development, as I will now demonstrate. In this work, I found the valuable assistance with the Experimental Institute for Soil Study and Conservation (Italian Ministry of Agriculture and Forestry), directed by Dr. Marcello Pagliai.

What is sustainable development?

Sustainability is not a cosmetic applicable a *posteriori* to any development model. To put to one self the problem of sustainability means first of all to reflect on what development means.

Indefinite economic growth, almost exclusively measured by the GDP, is intrinsically unsustainable, because it is based on the growing and unlimited consumption of finite and unrenewable resources. Take the example of fossil fuels: until now they have been abundant, but not infinite, and above all not without negative side effects, like the increase of carbon dioxide in the atmosphere and therefore the greenhouse effect.

The GDP substantially measures the flows of money, blind to the goals, that is the *quality* of the economic processes in play. Paradoxically, the senseless rape of natural resources could increase GDP; to the profit of the employed companies and salaries paid, but the final result would be an unreversable reduction in natural capital, and therefore impoverishment.

Therefore, we must stop mechanically associating the idea of development with the idea of *gain*, and instead identify it with the idea of *improvement*. Development means living better, that is more health, more justice, more security, and this does not necessarily involve having more, it is an objective that we can reach not only consuming more. Quality of life and standard of living are not the same thing.

The price does not always express the value, because it only takes into account work and capital produced, not natural capital and services provided by nature. For example, how much does clean city air cost? In fact, for having such great value, it does not have a *price*. Like the photosynthesis, because no human activity can produce oxygen and carbohydrates using only sunlight, carbon dioxide and water. And yet without photosynthesis there would not be life on earth.

As long as economics does not take into account the true costs of the processes, including the effects on the natural capital, which is externalities, positive or negative, it will be difficult to build a sustainable development.

According to Bruntland Report (1987) "Development is sustainable if it satisfies the needs of the present generation, without compromising the possibilities for future generations to satisfy their needs". If we accept this definition, we must use renewable natural resources at a pace compatible with their renewal and non-renewable resources at a pace compatible at least with our ability to find valid substitutes.

In other words, we must use natural capital better, and understand that natural capital is worth more then the labour and the capital necessary to use it.

Land planning for sustainable development

Until a short time ago, land planning was concerned with almost only the problem of *where* to put the needs of urban growth, considering the land an isomorphic support, of which only geometric characteristics - such as distance and extension – are considered.

The land register, which represents not the shape of the territory but its properties (and is obviously deprived of any altimetric elements) is the obligatory and significant cartographic support for this planning.

Recently, with the slow progress in the preparation of the Regional Technical Maps, height, sloping, hydrographic network, in some cases the land use, have been taken into account as a corrective even though within a topological conception.

It is the antiseismic law, which obliges to evaluate a non-geometric conception of the land: its vulnerability to the seismic risk is the synthesis parameter of several physical aspects.

But if the theme is sustainable development, planning has to adopt a conception of land, which is functional to this goal; we have to consider soil no more as a support but as a complex network of resources. We have also to realise that not only we live *on* the land but also – or above all – *thanks* to the land.

Not only an increased ecological awareness but also some regional laws now expressly require land planning to guarantee the sustainable use of resources: for instance, the Regional law of Tuscany 16.01.1995, n.5, art.1, significantly entitled " Sustainable development " says:

1. "*This law, aiming at reforming the principles and modalities for the governing of the land, directs the action of public authorities and private activities in favour of a sustainable development in Tuscany, by guaranteeing the transparency of decisional processes and the participation of citizens in the choices concerning the governing of the land.*"

2. "*We can consider sustainable that kind of development which ensures equal potentialities of growth for the welfare of citizens while safeguarding the rights of present and future generations alike to take advantage of land resources.*"

The general Land Planning can no more be confined to planning urbanisation, rather, it has to re-write the rules of use of resources, that is, it has to become the "Statute" of the relationship between local community and its environment. It derives that the object of planning is no longer the town, or those sections of land destined to become urban areas but the land on the whole, including rural land.

Until now, traditional planning has paid little attention to rural land, since it has confined itself only to building aspects, or, in the best cases, to visual aspects but neglecting the analysis of the productive dynamics which model rural landscape.

Rural land was a residual category, what were left once the town had been planned, its expansion and accessories.

Now we are just beginning to realise the complexity of the open land as the place-function of reproduction of survival conditions; at last, we have the crisis of the term "extra-urban" by which old planning designated anything, which was not town, and therefore what it didn't understand. It is interesting to notice that for decades mountains and valleys alike, rivers and lakes, woods and cultivated fields have not been recognised for what they actually are, but for what they are not: non –town.

A better knowledge for a better planning.

If the land is no longer a support but the whole of available resources organised in ecosystems, the instruments of planning have first of all to get to know more deeply land resources. Among these, a particular relevance for agricultural processes is the soil resource, a kind of finite resource, not fungible, not renewable and also vulnerable.

Usually a land planning lies on huge analyses and research but not always choices are consistent with the analyses since the knowledge apparatus looks like an autonomous and self-referential effort.

Besides, too often it is the land resource which is not sufficiently investigated and almost ever only to detect seismic risks.

It is indispensable, instead, to get to know soil accurately, both for its productive potentialities (what we usually call *vocations*) and its vulnerability to phenomena of degradation, such as upheaval, erosion, tendency to alluvions.

Luckily, at last, in the technical teams called to design a plan there is always a geologist, but still in a very limited number of cases, a pedologist as well. Productive potentialities and vulnerability of the land are instead the frame within which planning has to make its choices if we want – as it has to be- define rules of rational use of resources so as to contribute to correcting the development model toward sustainability.

Instead, what happens is that too often the choices where to locate urban expansion, industrial areas, infrastructure and services neglect this analysis. Just to make an example, over the last sixty years it has been calculated that millions of hectares of fertile soil have been taken away from agriculture to be used for urban or para-urban uses.

We do not want to deny urban needs but we only want to make them compatible with the land: a factory does not need fertile soil but agriculture cannot do without it and it is totally irrational to squander the fertility resource, above all in a country like Italy, which is relatively poor as far as fertile soil is concerned.

Moreover, pushing agriculture toward marginal soils means an increase in the use of chemical products and also choosing risky agricultural areas for what concerns the stability of versants and the resistance to erosion.

As to the urban section of the land, new planning should adopt some ecological measures as, for example, the waterproofing of the soil, and rethink standards no longer only in dimensional terms but, above all, in performance ones.

Indeed, it is no longer sufficient to ensure everyone a given portion of green but we need to evaluate the quantity of atmospheric carbon that green is able to make organic in relation to the carbon released in the atmosphere. It is no more sufficient to ensure everyone a given quantity of services but we have to verify if these are accessible in relation to the system of urban mobility, which is a decisive factor for the quality of life.

If a service is offered in only one place, that can be economical for the organisation of the facility itself but at the same time anti-economical for the commuting to which we are obliged.

In that case, we need to evaluate whether it is more expensive to distribute services over more places or increase mobility.

It is not rational, indeed, to have supermarkets, shopping centres or shops- which attract traffic- in areas deprived of adequate parking lots because this is the worst and most irrational form of mobility, that is, the traffic of motorists helplessly looking for a place where to park!

The experience of the Sienese Chianti

The example of the Sienese Chianti is useful to understand the processes in progress in rural areas, the risks implied in transformations and the role of planning to prevent and reduce them.

Although the Chianti is quite well known, it may be useful to summarise some data about it.

First of all, by Chianti is meant the territory between Florence and Siena belonging to the Communes of San Casciano in Val di Pesa, Greve in Chianti, Tavarnelle V.P. and of Barberino in Val d'Elsa (in the province of Florence) and Castellina in Chianti, Radda in Chianti, Gaiole in Chianti and Castelnuovo Berardenga (in the province of Siena). The production area of the famous Chianti Classico wine is a bit restricted, excluding part of the Communes of San Casciano, Tavarnelle, Barberino and Castelnuovo: about

70,000 hectares, of which only 6,972 are the areas where the Chianti Classico is produced.

	Total surface ha	Vineyard surface Ha	Vineyard surface % on total	Vineyard surface % on vineyard
Castellina	4 567	570	12.2	14.8
Radda	1 650	431	26.1	11.2
Gaiole	12 800	1 081	8.4	28.1
Castelnuovo B.	17 700	1 768	10.0	45.9
Sienese Chianti	**36 807**	**3 850**	**10.5**	**100.0**

The Chianti area is a hilly and steep territory, mainly covered with woods. In the past agriculture – characterised by sharecropping production relationships and centuries of refinement – had found a balance of its own between economy and environment well shown by the terracing arrangement of slopes on dry-stone walls. Terracing was first of all employed for the production of cereals, which were indispensable for the sharecropping economy in spite of the low yield at this altitude. We have also consider the link between production relationships (take, for example, the structure of costs) and agrarian arrangements: terracing is the expression of production relationships in which hilly medium- high slopes are employed for promiscuous cultures and in which the necessary manpower is available plentifully and at low costs.

This balance underwent an irreversible crisis with the end of the sharecropping system, which basically means on one side the end of hilly culture of cereals and on the other exponential increase in manpower costs, to which, nevertheless, corresponds an increased availability of energy. Consequently, firms get to be organised along two lines: productive specialisation and mechanisation of operations. In agriculture fossil energy begins to be employed. Traditional arrangements are no longer useful: indeed, they are abandoned or destroyed; in their place, in the sixties, we have specialised vineyards arranged " a rittochino", that is, with the rows arranged parallel to the line of maximum sloping.

This arrangement makes mechanisation possible, but, at the same time, is a formidable accelerator of the times of accumulation of rainwater. This means increase in erosion and alluvion risks. If we think that the Chianti area is relatively young and that the thickness of fertile soils is generally weak, it is then easy to guess that an erosion ten times superior in comparison to terracing arrangements (according to CNR studies[1]), may dangerously anticipate the surfacing of the original rock, then the end of the productive life of the versant, without forgetting the increased risk of upheaval and the worsening of alluvial phenomena.

The greenhouse effect, mainly caused by the increase in CO_2 (it has been estimated that in only one generation the increase has been equal to 37%) implies above all the evaporation of large masses of water, then the increase in the frequency of rains characterised by downpours. We have then to face a worse climate with a versant system less suitable to retain and optimise the regime of watercourses in case of rain.

As a consequence, we have a new divergence between social sustainability and environmental sustainability of some farming activities. How does planning react? What can be done in situations in which terraced versants are no longer cultivated and cultivated versants are terraced? Should we restore terraced areas or their hydrogeological performances? Should we impose arrangements belonging to the past or rather convert the present arrangements keeping in mind environmental sustainability? If the problem is by now present in "new generation" plans there are still differences and uncertainties about the possible solutions.

Some experts, who are admirers of the hydrogeological performances of terracing, but not very curious about the links between productive structure and agrarian landscape, suggest the generalised restoration of the surviving terraced areas, but without clarifying what should be done in the remaining areas of the land, the ones cultivated and at erosion risk, and, above all, the relationships between restored terraced areas and production. One is also perplexed also because this suggestion omits to show who should bear the restoration costs: one could fear that *sic et simpliciter* it would be up to farmers!

A contribution to this debate comes from the "Landscape Programmes" of the PTC of Florence: well, the "guide plan" for the working out of these experimental instruments deals with the Chianti area[2], by studying – among other things – just terracing and estimates the restoration costs of the dry-stone walls ranging from a minimum of 75,000 lira per linear metre for more simple maintenance works to 380,000 lira per linear metre for more complex interventions[3]. It is not difficult then to estimate that the restoration costs of the dry-stone walls, if we exclude the interventions on the soil, would easily go beyond 60 million lira per hectare and go close to 100 million lira. With these costs, the restoration of dry-stone walls – which is praiseworthy in itself - could be proposed within a project (not necessarily public, or, at least *only* public) able to insert this action in a productive circuit – cultural aspects concerning tourism and museums - which might at least cooperate in financing this operation.

On the opposite side, the Chianti Project and the Structural Plans of Gaiole and Castellina, but also the PRG of Castelnuovo deal instead with the reconciliation of mechanisation and sustainability or, in other words, with making sustainable the necessary mechanisation. The Castelnuovo plan suggests interesting solutions, such as the "counterslope level-hole roads", while the Chianti Project and the Structural Plans of Gaiole and Castellina, which represent the accomplishment of that, suggest a more articulated strategy: as a strategic investment they suggest creating a **Map of tolerable erosion**, which, along with the **Vocation Map** of the territories which are admitted to produce the Chianti Classico and the varieties of olive trees, would constitute a strategic guide for land planning, for economic planning and farming strategies.

Until these strategic instruments are not available, the correct use of soils relies on the following instruments:

1. a body of suggestions for the correct management of soils;

2. the project of intervention of a new implant by a qualified technician;

3. the public control of the quality of the project and of its correct accomplishment.

The formulation is of a performance type: the requisites to be respected are stated but entrepreneurs are left free to choose the most suitable means for specific situations and public administration has only to control correctness and efficacy. The core of the problem is stating the culture of the project also for agrarian arrangements: in delicate situations such as the Chianti area, the installation of a new vineyard, or the replacement of a worn out one, cannot only be confined to the control of immediate farming costs. It is necessary, instead, to look forward, to plan with the necessary competence agrarian arrangements able to optimise adequately the regime of waters and to keep erosion within tolerable limits. This not only to minimise the negative externalities of the implant, but also to guarantee in time the farm investment against degradation risks concerning upheaval, washing away, impoverishment, worn out vines, which could even jeopardise the implant, or, in any case, would imply intervention with works and chemicals.

The additional costs of advanced and careful arrangements, for the part possibly not compensated by the guarantee of the investment (then by the saving of correctives) could be sustained by public contribution, since we are not dealing here with *subsidies* for agriculture but with *collective* *investment* in safeguarding environmental resources.

On the other side, we know that PAC is abandoning the idea of financing existing agriculture as it is to reward, on the contrary, environmental quality and positive externalities, in such terms s as land maintenance and regeneration processes of the conditions of human survival on earth.

The new Plans do not obviously neglect building in rural areas, both to guarantee the active preservation of historical memories, to satisfy the rationalisation needs of farms, and to encourage light forms of rural tourism. The clear choice of bioarchitecture and the employment of renewable energy explicitly aims at improving the energetic balance of rural building, by reducing the dependence on fossil fuels and the connection to technological networks and, at the same time, improving rural aesthetics.

Participation, simplification, co-ordination

The new planning, oriented toward sustainability of rural development, lies on four foundations: we have already mentioned knowledge, to be extended to the intrinsic qualities of soils and to their vulnerability; the other three are:

1. active participation of operators;
2. administrative simplification;
3. co-ordination of sectorial and expenditure policies.

On the basis of new and deepened elements of knowledge made available by the plan, operators are to be made jointly responsible in writing the rules for the sustainable use of land resources. This not only to exploit the heritage of experience, of knowledge and planning of the farming system but also to shift the relationship between public administration and operators from the ground of bureaucracy to the ground of awareness and cooperation.

In this way we can build the indispensable consensus for the analysis and the lines of governance of the land, then a more mature relationship among more aware subjects, which reduce the need – then the bureaucratic weight- of control. In Italy the bureaucratic burden has become intolerable, it is an improper and unproductive cost we can no longer afford. Planning based on shared knowledge and responsibility makes possible the writing of more simple and effective rules so as to simplify procedures. Also the governance of the land takes advantage of that along with democracy, which is a precious and vulnerable resource among natural resources.

The governance of the land is the result of many and different actions by subjects - public and private as well- who are different and rarely co-ordinated: this is the main deficiency in human intervention as concerns environment: "*Natural processes are unitarian, while human interventions tend to be fragmentary and incremental*[4]."

The exasperated sectorialisation of economy and administration hinders a holistic vision of processes and effective control of environmental effects. Autonomous and non-co-ordinated development of sectors and the consequent multiplication and juxtaposition of subjects, powers and competencies produce incoherent and contradictory actions.

On the same square metre there is a plethora of norms and measures which co-act, each one of competence of so many different subjects that it is hard to recompose in a unitarian and comprehensible framework what must be done (or must not be done) on that square metre.

This is an insurmountable obstacle to development sustainability.

What is needed is a holistic and courageous action of co-ordination, of simplification, of coherence of all sectorial and expenditure policies able to affect the territory and the use of resources.

It is clear that this action goes beyond the competence and capacities of communal plans and it is a crucial theme within the planning of wider areas, such as the Province and the Region.

In particular, the Province seems to be now at an important institutional turning point, as now it has also land competence, such as the Co-ordination Land Plan: it is a brand new instrument (although introduced by the Law 08.06.1990, n.142), which faces the planning of wide areas and co-ordination meant (and to be meant) not only as co-ordination of territorial choices, but also and perhaps above all as reference to territory of sectorial and expenditure policies to make them consistent with sustainability. In it, there is an explicit awareness- although not unanimous – of this need: it will be up to those who are responsible for sectorial policies to make their actions meet with the goals of sustainability as they are shown in the Plan. This will be the main verification concerning the usefulness and efficacy of this new instrument: if it is positive, that will be real progress.

The Siena Land Plan of Co-ordination[5] starts by defining "*land as a unitarian resource preceding and exceeding different present uses*" and aiming explicitly at drawing "*a holistic governance for the province of Siena*". This is just what is needed.

References

This new conception of land planning in favour of sustainable development is inspired by the Cork Declaration "A living rural Europe" (09.11.1996). Over the last few years, both on a national and regional level, this statement has been discussed in important cultural and administrative initiatives: we have mentioned the Chianti Project (1995), from which the structural Plans of Gaiole and Castellina borrow the general lines for the rational use of the soil resource and the "Lines for a good management of soils", reported in one of the enclosed appendixes.

In 1997 the National Association of the Wine Towns, which puts together more than three hundred Communes of wine great renown, while warning against the inadequate traditional planning in managing rationally the high vocation territories, has asked a group of experts to work out a method of specific planning: the Regulating Plan of the Wine Towns was published in the same year and approved in the assembly of the Association in Faenza in November 1997 and verified in a long series of meetings and conferences (Sirmione, Cormòns, Diano d'Alba, Riolo Terme, Rufina, Sondrio, Monte S. Pietro, Imola, Lonigo, Montescudaio). A summary can be found in the appendix.

In 1998 the International Symposium "Territory and Wine" dedicated its third session (Bolgheri, 21.05.1998) to the "Tourism and urban aspects in the Regulating Wine Plan". The chairman was Professor Vicente Sotés Ruiz, of the Universidad Politécnica of Madrid with an introductory paper by Professor Stefano Stanghellini, the INU chairman.

Again, in 1998 the INU (Town Planning National Institute) Tuscan Section organised an information and close examination workshop on the new Communal plan as worked out by the Regional Law 16.01.1995, n.5. and dedicating the fifth session to the "Sustainable planning of extra-urban areas" (Arezzo, 29.05.1999). The point of view of the Tuscan INU, widely and deeply discussed there, can be found in the appendix. The Tuscan INU has published the workshop's results.

This year, in May, the Italian Academy of Forest Sciences, financed by the G.A.L. (Group of Local Action), Eurochianti, within the European Community initiative Leader II, has organised the conference "Agriculture and sustainable development in the Chianti Classico" (Volpaia, 29.05.1999). Its results are now being published.

Appendix 1

Lines for a good management of soils[6]

1. *General lines for the safeguard of the soil*

1. The interventions capable of affecting the consistency, stability, hydrogeological balance, productive capacity of soils, such as uprooting or cutting down trees, pulling down straight walls of any kind, pulling down terracing, movement of soil, levelling, breaking down, ploughing, ripping at a depth superior to 80cms or of the half of the thickness of the soil if inferior, accomplishment or modification of irrigation or drainage works, formation of artificial basins, opening or modification of roads, in any case interventions going beyond ordinary superficial agricultural works are subjected to authorisation, according the following rules and procedures.

2. A report, written by a qualified technician, is enclosed in the requested authorisation: it has to contain the insertion in the CTR (Regional Technical Map), scale 1:5,000 and following a topographic survey, geognostic inquiry on site, on the results of the executed physical measurements asserts:

- that the requested interventions will not cause phenomena of macroscopic upheaval;

- that erosion[7] will be inferior to 2.0 tons/ha/year, in any case inferior to the tolerable erosion on the specific site.

3. the tolerable erosion is shown by maps provided by the communal administration or, if not available, is calculated by the technician.

4. In more simple cases (such as, for example, interventions on areas 1ha, not being influential on the stratum balance, on very stable versants, on soils with 12,0% sloping, outside the range B[8], farther than 50 metres from Communal roads or superior), the report concerning point 3 can be limited to asserting the foreseen interventions will not cause upheaval and will not increase soil erosion.

5. In any case, interventions on soil have to be carried out under the responsibility of a qualified technician, who, at the end of the works, will sign and deposit at the Town Hall a report asserting their correct execution.

6. Along with the above-mentioned principles, interventions have to stick to the following specific rules.

2. *Levelling*

1. Levelling is allowed only if the report concerning point 2 paragraph 1 shows the impossibility to form terracing or connected edging.

2. For levelling the report concerning point 2 paragraph 1 also contains:

a) the section representation of the juxtaposed layer, with excavations marked in yellow and the embankments marked in red;

b) the foreseen consolidation plan (grassing or geotextile);

c) an economic account showing that with levelling an increase in income will be obtained not inferior to the one deemed as minimal in case a plan for a land improvement is proposed;

d) the assertion that the deep and superficial water-bearing strata will not be reached, although temporary.

3. Levelling is forbidden :

a) in areas subjected to landslide movement either in progress or potential;

b) for thickness of arable soil inferior to 1.50 m;

c) if along the profile of the soil clayey or " muddy- clayey " horizons are present with a depth inferior to 1.50 m from surface both before and after levelling;

4. The superficial fertile soil, taken away from the excavation areas, has to be heaped separately and redistributed evenly on the whole surface after levelling.

5. Grassing of the surface with rapid growth Graminae (Festuca ovina, Festuca arundinacea, Festuca rubra, Agrostis tenuis, Poa pratensis) must immediately follow levelling. Sowing is to be completed within 7 days from the works of soil movement, helping the growth of grass with irrigation and manuring. If the irrigation of the levelled surfaces is not possible, the alternative use of geotextile is allowed.

3. *Terracing*

1. If the site chosen for the new implant is terraced, the implant

project must first of all evaluate the possibility of preserving the existing terracing, comparing implanting and management costs for the whole productive life, and keep terracing if costs are close to the ones of different arrangements.

2. I the report concerning point 2 of paragraph 1 shows that keeping the existing terracing is either technically or economically impossible, before taking into consideration levelling, the possibility of forming connected terracing, which allows mechanisation, is to be evaluated.

3. If connected terracing replaces degraded terracing, the number of plans can be reduced provided that the final stability of the versant is proved along with the containment of soil within tolerable limits.

4. *New cultivation*

1. For the implant of new vineyards the report concerning point 2 paragraph 1 also asserts:

- that rows form an angle as close as possible to 90° with the line of maximum sloping, without going beyond the allowed maximum lateral inclination for operating machinery along the inter-row;

- channelling and drainage works, works of slope breaking down (holes, levelling, etc.);

- the possible works for the depositing of sediments at the origin of water bodies[9];

- the agro-technical plan for the grassing of the inter-row and any device meant to reduce significantly erosion.

2. The cultivation of wooded areas or of forestry interest is forbidden.

3. In case of renewal of obsolete vineyards[10], the farms which prove that, when planning agro-environmental improvements[11], or with a report signed by a qualified technician, that they do not have suitable soils for a new implant, they can explant the obsolete vineyard and rest the soil for at least three years by destining it to the constitution of an environment suitable for wild fauna[12], then implant the new vineyard following the rules of the new implants.

4. For vine support cherry tree poles are to be used.

5. In the areas most closely adjacent the new implant the rapid establishment of spontaneous vegetation is to be favoured.

5. *Abandonment of cultivation*

1. Sheer abandonment is forbidden: the soil object of explantation is to be reconsolidated

- if with >25% sloping, with reforestation with typical essences, according to the criteria stated by the wood Plan;

- if with <25% sloping, with grassland; in that case, the sowing of cultivation destined to wild fauna is allowed, if suitable to the reconsolidation of the versant;

2. In the choice of vineyards to be explanted the following priority order is to be followed:

a) implants directly involved in upheaval and placed in basins with upheaval in progress;

b) implants involved in upheaval wherever they are located;

c) implants on versants with >25% sloping;

Implants aged more than 30 years.

The respect of these criteria, in equality with other requisites, is a priority title to obtain public subsidies.

3. Forms of set aside are allowed if coherent with the primary above-mentioned need of safeguarding soil. Alternative cultivation is encouraged such as: breeding, both of wild and semi-wild game, reforestation with autochthonous species, and, as regarding only valley bottoms, wooded implants of rapid growth.

6. *Cultivation in progress*

1. The firms having cultivation on areas with water widespread superficial erosion, on areas with rill erosion, on areas with severe deeply channelled erosion, as shown in the **geomorphic Map**[13] within two years since the approval of these urgent measures form and carry out a project of hydrogeological arrangements of sites meant to reduce drastically the upheaval in progress.

2. All firms reduce significantly soil erosion with grassing of the inter- row, with channelling and drainage works, with works of breaking of the slope (holes, levelling, etc.) With works for the deposit of sediments at the origin of water bodies and with any other useful device.

3. The deposited sediments are periodically redistributed on the versant of origin.

4. In the most closely adjacent cultivation areas rapid reconstitution of spontaneous vegetation is to be favoured.

7. Recovery of degraded situations

1. Considering the prevailing public interest in preserving the hydrogeological balance and the productive capacity of soils in time, wherever the communal administration ascertains degraded situations of hillside slopes, it can order holders to form and execute in an adequate period of time hydrogeological arrangement projects of the versant in order to restore the ascertained degenerative phenomena.

2. By degraded situations we mean landslides, landslips, soil flowing, mud pouring, accentuated erosion and apparent symptoms of such phenomena.

3. If holders do not comply, the administration warns them and gives them a further deadline not superior to the half of the first and if this one is not met, or if urgency forbids further delays, the administration executes the necessary works and imposes on defaulters an administrative penalty equal to the double of the sustained expenses.

Appendix 2

The land planning of wine towns

The "Land planning of Wine Towns" is the General Land planning of a Commune belonging to wine towns, modelled on the Method worked out and published by the Association of the Wine Towns in November 1997: the aim of this Method is to orientate the General Land planning toward a sustainable development, following the principles of the Cork Statement "A living rural Europe" (9 November 1996), with particular attention to the active preservation of those soils more suitable to wine production. This method is based on four main points:

1. **Knowledge**. Soil aspects are studied, especially those soils neglected by traditional planning such as attitude to produce wine grapes, and vulnerability (tendency to upheaval and erosion). Urbanisation areas (residence, production, infrastructure, and services) are to be chosen among those not suitable to produce wine grapes and with low hydrogeological danger. In any case, the Plan avoids urbanisation negative effects on vineyards and takes care of the landscape.

2. **Participation**. Farmers are requested to collaborate in the writing of the rules of use of productive soils, on the basis of data made available by research and personal experience. In this way farmers write and accept better rules since the very beginning and are made jointly responsible in sustainable development.

3. **Simplification**. Thanks to the combined responsibility of farmers, the accomplishment of the Plan is based more on consensus rather than control so as reduce substantially bureaucracy.

4. **Coherence**. The Land planning of the Wine Towns allows all public administrations to orientate their actions toward helping farmers who adopt sustainable productive techniques (such as hydraulic- agrarian arrangements meant to reduce erosion), to offer valid alternatives for the areas recognised as not suitable for viticulture, to mitigate urbanisation negative effects: the Land planning of Wine Towns provides the criteria to reward the positive externalities of quality viticulture and to reduce possible negative externalities.

Pier Carlo Tesi
architect for urban planning, co-ordinator of the Technical Group
Alessandro Bracchini, architect,
professor Mario Fregoni
professor Alberto Magnaghi, architect,
Dr. Giancarlo Montaldo;
Consultants:
Gianni Braccini
Antonio Rafanelli, geologist

APPENDIX 3

INU TUSCAN SECTION

Information and deepening workshop

With the support of Tuscany Region

5th session, Arezzo, Chamber of Commerce hall, 29 May 1998, h 9.00

Sustainable planning of extra-urban areas

Areas: Arezzo, Siena, and Grosseto

Pier Carlo Tesi: The Tuscan INU's point of view

References:

- Tuscan Regional Law 16.01. 1995, n.5

- European Conference on rural development, Cork, Ireland, 7.09.1996 (Cork Statement, "A living rural Europe", 09.11.1996)

- Conference, "Integrated development of rural Communes and towns, the South, Europe", Irsina (Mt), 11.04.1997

- INU, "The new planning law. Guides for the reform of the planning process of towns and land". Document approved by CDN on 07.11.1997 (Urbanistica Informazioni n.157).

- INU congress "What sustainable development for agricultural areas?", Grosseto, 10.01.1998

- International Symposium "Territory and wine. Zoning as knowledge instrument for quality", official paper by Stefano Stanghellini, INU chairman in the session dedicated to urban and tourist aspects and to the wine land planning, Bolgheri, 21.05.1998

The new plan for the open land: aims, contents and methods

1. At present the objective of planning is sustainable development, and no longer only the regulation of urbanisation processes (edifica-

tion, infrastructure and services). The plan is requested to guarantee the sustainable use of resources so as to become the "statute" of the relationship between society and environment.

2. All this requires a unitarian and integrated approach; the exasperated sectorial division deprived of efficacious synthesis reveals itself to be more and more inadequate to solve problems. On the method plan, it is the ultimate confirmation of pluridisciplinarity, which, indeed, has to be extended further to the necessary competencies for a complete diagnosis of land resources.

3. The importance of the open land for sustainability is more and more needed. The plan re-adjusts attention and interest, it abandons the "urbanocentric" vision; the open land is no longer secondary in development perspectives and is no more "anything which is left over once the town and its infrastructure have been planned". Crisis of the term "extraurban".

4. The open land has complex functions not immediately linked to sheer agriculture.

4.1. Functions of preservation/improvement of survival conditions: air (carbon made organic) soil/water (hydrogeological equilibrium), nutrition.

4.2. Non-nutritional productive functions (raw materials, fuels).

4.3. Vital functions: regeneration, recreation (tourism, hiking)

4.4. Cultural functions: landscape as the place of memory and identity.

Knowledge, Rules, Participation, Simplification

5. The knowledge framework is above all useful to identify resources: in the case of soils basically vocations and vulnerability. Along with traditional parameters, specific "ecological and sustainability indicators" may be worked out, which are useful to define both behavioural rules and criteria for the evaluation of results.

6. Rules are needed to guarantee the use of resources in a sustainable way.

7. Operators have to be involved in the writing of rules, on the basis of shared knowledge made available by the plan: participation as shared responsibility and reduction of bureaucracy. A pact based on responsibi-

lity and awareness then replaces the bureaucratic relationship between citizens and bureaucracy.

Reference fields, competence, subsidies, coherence.

8. The open land makes part of the structural dimension of the plan, it is a typical theme in planning wide areas.

9. Rural land systems rarely coincide with Communal boundaries (sometimes not even with the province ones)

10. Rural land mostly belongs to "small" communes, which are not endowed with adequate technical means or structures (but we are used to considering as small a commune with few inhabitants: paradoxically, a commune of 200 square kilometres and 3,000 inhabitants is defined as small!). Structured and permanent collaboration and co-ordination among communes are necessary – above all, the small ones belonging to homogeneous districts.

11. The Law 142/1990 only offers the fusion instrument, which might humiliate legitimate and well-rooted feelings of belonging and diversity, and in this there is the biggest obstacle; therefore, new forms of collaboration are to looked for: these should separate and safeguard both the heritage of local identity and gather the forces to organise services (then also planning) for optimal fields and with adequate means.

12. A contradiction: the Commune is the authority which best knows the problems of its open land, but its competency is limited to building matters, while its competencies and powers are limited (and probably not sufficient) as to the management of soil and use of resources. Important competencies, such as the hydrogeological and landscape obligations, are attributed to other subjects, let alone the basin Plan. The Province, in particular, has a lot of competencies on the open land, both as a planning agency (PTC) and as deputed authority in agriculture and forestry.

13. Often the hierarchy of acts is not clear, in any case "the proliferation of plans and institutions, along with the progressive fragmentation of competencies between ministries and councillor's offices, provokes uncontrollable procedure complications and a marked uncertainty about the outcomes", then "the co-ordination and harmonisation of competencies and related plans is a very relevant and inevitable problem" (INU Document for the new Planning Law, quotation, p. V).

14. The planning of the open land is the optimal trial for the ability of authorities to collaborate efficiently, namely, to execute and co-ordinate their own competencies to make the different planning acts coherent among them and also for what concerns the sustainability of choices.

15. About the management of the open land, the transitory system of the regional law 5/95, with the collaboration between Commune, Province and Region in the formation of the Structural Plans, because of the lack of PIT and PTC, is a positive experience, to be safeguarded, provided that the agreed engagements by different agencies in the planning agreement are punctually respected and all administrative actions converge on agreed objectives, and not only on planning actions but also on sectorial and expenditure policies.

16. A land plan built in function of the sustainable use of resources can /must be a criterion of coherence for the sectorial and expenditure policies. All the most recent theses in favour of sustainable development and the regional law 571995 itself call for coherence between land planning and economic programming.

Note

1. CHISCI, Giancarlo, "Agricultural practices and versant instability", in "*The management of landslide areas*", by Paolo Canuti and Enzo Pranzini, Rome, Edizioni delle Autonomie, n. 28, 1988, p. 84-105.

2. BALDESCHI, Paolo, "A guide plan for the safeguard of historical hillside landscape", in "*Paesaggio Urbano* (*Urban Landscape*)", supplement to n. 5/98, from p. 4.

3. "Paesaggio Urbano (Urban Landscape)", quoted from p. 14.

4. McHARG, Ian L., "*Design with Nature*", New York, 1969, Italian translation by Girolamo Mancuso, Padova, 1989. The quotation is from the Italian translation.

5. The Siena Land Plan of Co-ordination (PTCP) states that "land planning brings in an essential contribution to the governance policies of resources and sets them free both from the narrowness of traditional local urban planning and the inadequacy of incentive interventions exclusively directed to specific sectors".

6. This version, worked out for the Commune of Castellina in Chianti, substantially reproposes the lines of the Chianti Project, and specifically, of the Vector-Project "Soil" (collaboration of Dr. Paolo Bazzoffi and Dr. Sergio Pellegrini, of the Experimental Institute for Soil Study and Conservation, and Dr. geologist Antonio Rafanelli).

7. Deduced from the universal equation for soil losses by Wischmeier and Smith.

8. "Areas at altimetric heights inferior in relation to the height placed at 2 metres above the external base of the embankment or, in lack of it, the edge of the bank" (that is, the areas higher no more than 2 metres from the bank), as defined by the article n.5 of the D.C.R. 21.06.1994, n. 230 bearing " Measures for the hydraulic risk with reference to the articles 3 and 4 of the Regional Law 31.12.1984. n.74, Adoption of prescriptions and obligations: Approval of guidelines", in Ordinary Supplement to the Official Bulletin of the Region

Tuscany (B.U.R.T.) n.46 of 06.07.1994.

9. For instance, small earth dams devoted to be filled by sediments: a) to keep eroded material "in situ"; b) to prevent sediment yield and transport to off-site areas; barrages such as rush matting and similia.

10. See the Resolution of the Regional Tuscan Board 09.06.1997, n. 645 "Modalities and technical-administrative procedures for the realisation of vineyard surfaces in Tuscany: approval: Annulment resolutions, n. 4480/89, 55446/89, 4656/90, 4524/923, 4475/95" (Special Supplement to B.U.R.T., n. 31 of 06.08.1997).

11. Foreseen by art. 4 of the Regional Tuscan Law 14.04.1995, n. 64.

12. As concerns incentive for maintenance and environmental works, see now Regional Tuscan Law 12.01.1994, n.3.

13. Made for the Chianti Project, third phase (vector projects); the Map is shown in the Soil Project, chapter 1.4. Both the papers make part of the enclosed survey outline.

Zoning and land use: the case of Comune di Castel S. Pietro Terme, Bologna

Francesco Sacchetti

Dipartimento di Urbanistica e Pianificazione del Territorio
Via Micheli, 2 - 50121 Firenze

1. Introduction

The town planning is an expression of human needs. Traditionally it rules "the renovation and the growing of towns"[1]. Today it has to rule the land use and transformations for the environment protection[2].

With a recent decision, the Corte Costituzionale has defined the town planning "As an ordering function, compatible with the use and transformation of the land in the spatial dimension considered and in the ordering times forecasted"[3]. This does not mean that the town planning tools should decide for everything, but it is stated the principle that the town plan (PRG) has the rule of "composing", for reciprocal compatibility, the use and transformation of the whole town land (this is the spatial dimension). This is a very complex operation because both discordant interests (use has economical relevance: one use may be more profitable than another), and competence of several subjects because multidisciplinary knowledge is necessary for the reasoning definition of the land use.

The dimension of the town administration may not be the most suitable to cope with the problems related to the physical reality (there is no coincidence between physical interest and administration), but it is therefore true that towns are the first interlocutor for the historical relation that they have with land and with communities. In addition in the present legislation many of the transformations of the land are under control of the Major, with evident contradictions. To modify a window in a building the authorisation of the Major is necessary, but if I change a slope to have a different land division, if the area is not under special restrictions, authorisation is not necessary. Certainly the second action is more important for the hydrogeological balance (and for general interest). There has not been a correspondence between the genetic change of the town planning tools and the modifications in the actions under town authority control (the permits as a corollary of the town plan have never changed).

For the urban areas new tools to intervene in new parts and to refurbish existing ones (Council-house Building plans, industrial areas, recovering plans of existing buildings). But this has not happened for rural areas because the town plan does not have tools for action. In this contest plans rich of indications and analysis are like inactive giants.

In this consideration we can find the new town plan of Comune di Castel S. Pietro Terme. The attempt is to create a town plan tool that could be both a traditional town plan and a project for rural areas.

Only one land drawing in which the local community, the first subject of the plan, could find all the rules for the land transformations and indications to concretely promote intervention.

Two questions have been fundamental: the way to organise the zoning and tools for managing the land configuration (urban areas, rural areas).

The first point concerns the definition of the "criteria" that doesn't make the zoning a list of areas connected by sectorial analysis, but to be an interfacial instrument with the specific needs of the land and to be readable in relation to the regulated values.

The different generations of the town plans, that have faced the problem of rural areas zoning from the Seventies on, to actuate regional urban laws more restrictive for environmental problems, give a every rich and deep methodological base.

The second point concerns the search of "actions", "economical incentives" and "subjects" to realise the prefigured land arrangement, therefore to "manage" the relation of the plan. A new field, poor of experiences and of legal indications.

For this purpose, the town plan of the Comune di Castel San Pietro Terme, has been "connected" to a new management tool, the "agro-environmental plan", able to "connect" the "land zoning" and rural-environmental discussions of town plan to the economical resources of the Region and of CEE and to specific operations.

In this sense, the role of the town plan does not relate to the things "which must not be done" (in some case necessary) but, in a positive way, searching and promoting the things "which must be done".

2. Criteria for "zoning"

The town plan structure uses territorial zoning, that (with a simplification) gives different roles to the parts of the town lands in relation to their characteristics, or better in relation to the specificity of their actual or potential contribution in the physical-territorial and antrophic-cultural dynamics.

As a consequence of this roles the arrangement of possible uses and management ways is configured.

So the zoning is based on different aspect witch characterise the territory (geomorphologic, cultural, natural, historical, etc.). The restitution of the state of things (and neither a definition of any ipothetical final state), but a reference program for the management of the territorial arrangement coherent with several natural and antrophic dynamics.

In this sense three sub-systems have been found.

A natural dynamic sub-system, formed by parts of land, that for different aspects contribute to insure the conservation of vital balances of the whole land. The hydrographic network, superficial and underground, the vegetation to help hydrogeological conservation, areas with great animals an vegetation interest are all elements forming this sub-system, to be conserved (or restored) having the role of physical resources generator.

The agriculture sub-system, to which many functions are attributed: from the "productive" function (with many options), depending on the economical situation (even european), and conditioned by ground characteristics (pedology, hydrogeological vulnerability, instability), to the "cultural" function of knowledge, culture environmental and landscape transfer.

The urbanisation sub-system, formed by centripetal phenomena of the "centralising" (the urban aggregations with concentration of people, production, exchange, communication, service, transforming group of people in communities) and by centrifugal phenomena of mobility.

Only the first two sub-systems are interesting for this relation and only these will be analysed.

I) The natural dynamic sub-system

The natural dynamic sub-system formed by "pertinential areas of rivers" and by "hill areas with hydrogeological protection". All the relevant hydrogeological functions have been considered in the "pertinential areas of rivers". Part of the land, which includes the outfall drain system of superficial water, from the small canals to greater streams, including the areas and basins involved in possible floods or in gradual river-bed modifications; directly connected terrace relating superficial hydrogeology and underground aquifer. Important areas for maintenance or recovery of river environment: areas with protective vegetation, areas near river flow, with low flow capabilities or with marginal agriculture, which could be recovered. The knowledge of the Autorità di Bacino del Reno, of the geologist, and the updating of land use by the geologist are included in this sub-system, without this experiences, this operation will not be finished.

These discriminated areas are part of a more general hydraulic system, comprehensive of deep and superficial dynamics. The zoning locates necessarily only the superficial portion of this system and the plan has the objective to defend the natural cycle of water through the regulation of the use allowed (a second tool linked to the town plan has been introduced and natural cycle defence and artificial cycle control. The water cycle plan "has the role to define the actions and prescriptions to insure the feasibility of cities, in respect to captation, usage and carry-off of water).

This operation inside the town land, does not involve conservative actions, but a solid program of "transformation":

• In the main water flow the Sillaro river, recovery action of degradated situations from the hydrogeological functionality point of view has an effect of several excavations. Through project involving the Autorità di Bacino, to start natural mechanisms in order to aggregate the cave areas in the river mechanics. Regarding the Sillaro river a project was started in the area of Imola to guarantee as final destination, the hydraulic/naturalistic one (expansion areas for floods, areas for the reintroduction of vegetation, areas for repopulating of birds);

• In minor rivers: actions for opening the river-bed to increase the protective vegetation (especially in plane areas) as a tool for filtering diffused pollution also. For the environmental importance of these areas the uses allowed depend on the environmental function: impermeabilization, escavation, polluting substances discharge, buildings are not allowed. Median areas of Sillaro and Quaderna rivers are designated to be urban/territorial parks, with several specific tools (some already existing).

Other dispositions, without direct influence on these areas, have the same role of conservation of water resources: laws concerning discharges (LR 50/95 e delibera Consiglio regionale n. 3074/96). Lows concerning the creation of equivalent water basins in case of agricultural discharges been substituted by underground drains, the planning of basin for water collection and distribution in case of critical situations.

The "hill areas of hydrogeological defence" includes areas that have functions of hydrogeological defence (aree boscate) and that, for their characteristics of hydrogeological fragility and possible instability of slopes must be protected from environmental degrading actions. In that sense the geo-morphological nature of soils and the abandonment have developed environments of natural interest (shale gullies, the forest of "isolated heights", bushy slopes).

The complexity of areas forms the "shales landscape" typical of the major part of the hills; various are the characteristic elements of this landscape and contradictory: "natural "landscape with relevant elements with strong landscape impact. But also typical of the abandonment, and for this reason not only naturally evolving but also uncontrolled degradation of balances once cares by the man. Complex of information coming from geological analysis, vegetation analysis and demo-graphical analysis. The programmed action for this areas, for hydrogeological defence (care of forest and rivers) and environmental/landscape are scheduled for "action". As from the agro-environmental plan linked to the town plan, involving employment aspects (associations for environmental defence and for soils care); economical activities in the area (honey production is involved in the reutilization of abandoned or bushy areas). Economical incentives (CEE, regional founds) and agreements between associations (for monitoring critical situations and potentially dangerous aspects). The town plan individuates the "zone", environmental role, and proper managing ways. The agro-environmental plan, instead, individuates the subjects to be involved, specific initiatives and economical incentives.

The typical "town planning" prescriptions subordinate the building authorisations to conservation or to plantation of indigenous vegetable species and, where the pertinence of buildings are relevant, to convention related to management aspect of lands; they also control the actions on slopes. Several are the elements constituting the natural dynamics subsystem (rivers, forests, bushy areas and non-cultivated areas), but care has been given, where possible, to the community between the different elements and the connection between environmentally rich areas and degradated ones, in the way to create a "continuous" organism for the natural dynamics conservation, to incentivate through this continuity the vitality and bio-diversity of the single parts (ecological network).

II) The Agricultural Production sub-System

The agricultural production sub-system is formed by the agricultural areas (as shown in the plan drawings through land use of '94); such defined areas, mainly involved in agricultural activities in the past and in a complex settlement network related to agricultural production, is today a complexity of interests: the agricultural production (with cultures strongly different from those of the past years, in the plane for the modification of the production method on the hills for the abandonment; and with subject different from the traditionally land-worker); the use of the free time (especially on the hills) in relation to the industrial economy have included specific land uses and occupations. The non-rural abode; in the dual form of permanent abode and of temporaneus abode is largely prevailing on rural abode with great impact on mobility, on services and on the building aspects of areas once agricultural.

The plan defines this large part of town land as "agricultural production sub-system" because it attributes to the town land the agricultural production as the main function, both as an activity (cultural and economical) and as a function to be conserved.

For this reason four different agricultural zones have been chosen, in relation to the different geo-morphological characteristics of the land with different point of weakness, different productive potentials, and with different landscapes and settlements.

The four zones are: the "zona agricola di pianura", the "zona agricola dell'alta pianura", the "zona agricola delle sabbie gialle e dei pianalti" and the "zona agricola delll'alta collina".

The "zona agricola di pianura" as a part of the alluvial plane, formed by sedimentation processes of rivers, resulting also in higher parts (in the town land by river Quaderna and Sillaro) and in topographically depressed areas, soils have a low permeability and do not generate problems for the deep aquifer, with good agronomic qualities. Agriculture in these areas is economically very profitable and there are not fluctuations in the number of operators, with high percentage of young people involved. Settlement is the one of the past century in the land distribution, and it is characterised by a member of buildings unused (this aspect is connected to mechanisation, decreasing the needs of workers), and by new service buildings closed to unused barns. The traditional "image" of agricultural territory has been modified not only by cultural choose, but also by the disappearances of tree rows, hedges, natural vegetation along the ditches, and in some cases of typical vegetation of colonial courts.

The "zona agricola dell'alta pianura" the area at the alluvial cone of the river Sillaro, Quaderna and smaller rivers, area of transition from the hills to plane with high permeability of the soils (in the specific case fine semi-permeability sediments). The agricultural economy is similar to the plane one; the settlement asset has a high concentration of infrastructures (via Emilia, railroad, and highway) and houses non-related to agricultural.

The "zona agricola della collina delle sabbie gialle e dei pianalti", including all the agricultural areas of the lower hills, typically with Yellow Sands of Imola and with portions of ancient plane floods. Today elevated, the Yellow Sands have a high permeability and are probably a zone of aquifer charging. The whole lower hills area, for its morphological characteristic is the reference background of the via Emilia, a significant element in the territory. In addition with high landscape relevance due to the cultural richness of natural elements (hedges, forest along the rivers, isolated trees, tree rows) and typical cultures (vineyards and orchards). Population is very high and all this area (with two major towns) is characterised by spread houses and vacation residences.

The "zona agricola dell'alta collina", with agricultural areas of the shales, is characterised by hydrical problems with instability (mass movements, gullies). Agricultural activities for the production of forage for zootechnical activities. Agricultural use of the ground has been reduced and a further reduction is forecasted for the future. The highest part of the land is dedicated to non-rural activities and vacation residences.

The geomorphologic, cultural and economical differences developed in the areas have brought to the creation of "addressees" for the use of the land not only concerning buildings but finalised together with environmental production to the search for specific economies.

For this reason in the agricultural areas of the high hills zootecnics, permanent cultures and annual cultures are incentivated, together with the conservation of natural elements and, at the same time, a commercial valorisation for less environmental impacting cultures.

In the agricultural areas of the Yellow Sands biological or integrated agriculture is incentivated, for the permeability characteristic of the area, hedges maintenance, etc and these are very important for the environmental and landscape aspect). A study for "vineyards zoning" is also planned (vineyards are the most important culture in the high hills). To verify the attitude of the soils to the different vines for a quality improvement. In the agricultural areas of the high plane and of the plane, the creation of a "natural reinforcement" is incentivated trough the introduction of bushes and tree along rivers for the recovery of biodiversity-nowadays absolutely residual; and along the major routes to keep the plantations away from these and with the function of protection against austic and atmospheric pollution.

A managing indication for the whole system for water distribution in agricultural areas is also given:

Ditches are progressively substituted by underground drains, with limitation of the "open water" in the territory (as a consequence limitation of vegetation, with faunistic and climatic changes connected).

To balance this, it is mandatory to realise a water basin with the same surface of the eliminated one (as for aerophotogrammetical cartography from town plan) with the proper vegetation.

For ditches for waters from urban areas sometimes flooding into nearby agricultural areas, basin must be provided at the confluence of waters from urban areas and ditches.

The last indication is about the plantation of local vegetation. At present in many rural houses there are new exotic culture or no vegetation at all. The new plan and the agro-environmental plan incentivate local species with typical associations to maintain the identity of agricultural zones.

3. Managing tools: the "agro-environmental plan"

The agro-environmental plan is configured as a tool to realise the indications of the town plan on the use of the land not for the "building" aspect but for the more general aspect of the management of the resources. Even if the town plan started analysing the territory to define the "roles" of the different parts according to specific characteristics, potentialities and wicknesses, the managing aspect do not have the possibility of concretely act.

The agro-environmental plan[4] of the Comune di Castel San Pietro Terme has been designed as an "actuative tool" of the managing program of the territory prefigured from the town plan. In this tool the knowledge aspect previously investigated in the town plan have been deeply studied and integrated. In this plan addresses are indicated, economical incentives (CEE, Region, other) specific initiatives to be carried on, in order to move the attention for prescriptions to a more propositive role.

The "agro-environmental plan" is formed by a synthetic drawing (scale 1:25.000) in which reference territorial zoning is shown together with six synthetical drawings of the zones of the two subsystem.

Each drawing has three parts: the first one shows the "actual state" and resumes the "reference elements" (geomorphologic aspect, vegetation aspect, etc., together with territory description and main uses). The second part specifies "the indications on the uses and management".

The third part "indications actuation" has two parts: "incentives" and "proposals for specific initiatives".

The "agro-environmental plan" has been contextually approved with the town plan adoption, with independent action and will be updated again with an action of the Consiglio Comunale anytime it will be necessary (it will certainly be updated for actuation of the new disposition from CEE to be actuated by Regione Emilia Romagna).

---

[1] Art. 1, legge urbanistica 17 agosto 1942, n. 1150.

[2] Il DPR 27 luglio 1977, n. 616 con il quale sono state attuate le deleghe della legge 22 luglio 1975, n. 382, all'art. 80, stabilisce che: "le funzioni amministrative relative alla materia 'urbanistica' concernono la disciplina dell'uso del territorio comprensiva di tutti gli aspetti conoscitivi, normativi e gestionali riguardanti le operazioni di salvaguardia e di trasformazione del suolo nonchè la protezione dell'ambiente".

[3] Corte Costituzionale, sentenza 24 giugno 1986, n. 151.

[4] I tecnici incaricati sono: prof. Francesco Sacchetti, architetto (coordinatore); dott. Raffaella Bedosti, architetto (redattori del nuovo PRG); dott. Nicola Filippi, pedologo (Ufficio Pedologico, Regione ER); dott. Maurizio Pirazzoli, agronomo; dott. Giovanni Viel, geologo. Contributi specialisti: dott. Giuseppe Benciolini, pedologo (Iter, s.coop.srl); dott. Elisabetta Campiani geologo (fotointerprete); dott. Alessandra Furlani agronomo; dott. Andrea Giapponesi (Servizio Sviluppo Sistema Agroalimentare, Regione ER); dott. Silvia Pullega, naturalista.

AQUIFER VULNERABILITY AND SOIL VULNERABILITY. AN APPLICATION IN THE PROVINCES OF PADUA AND VENICE OF THE VENETO REGIONAL REGULATION CONCERNING MAPPING OF SOIL SUITABILITY APPLIED TO SPREADING OF LIVESTOCK EFFLUENTS

L. Baracco (*), V. Bassan (**), B. Basso (***), P. Rosetti (****)
A. Vitturi (*****), P. Zangheri (**)

(*) Province of Padua, (**) Free-lance geologist, (***) Free-lance agronomist,
(****) University of Bologna, (*****) Province of Venice

1. Introduction

The existing regulations at regional and provincial level concerning the use in agriculture of livestock effluents take different approaches in tackling the theme of the assessment of the suitability of soils for the spreading of livestock effluents.

In fact, while from a general point of view the various existing regulations may be traced back to two basic elements, namely:

1. regulation of the spreading of livestock effluents, configuring their use as agronomic practice and not as waste disposal;

2. safeguarding of the underground waters against pollution (cf. EEC Directive 91/676 knows as the "Nitrates Directive");

on the other hand the technical specifications (in the Italian areas alone) for mapping soil suitability for the spreading of effluents are quite different, even though all may be in some way traced back to zonations based on a variable number of hydrogeologic and geopedologic parameters.

The reasons for the existing different approaches of the regional regulations may be attributed to a series of causes, among which the following may be mentioned:

1. the extreme variety of the geologic (and, consequently, pedologic) situations of the Italian regions;

2. the ratio between quantity and quality of the data necessary for a correct definition of mapping and the cost of both hydrogeologic and pedologic data;

3. the limited amount of existing experience of crossed processing of pedologic and hydrogeologic data which make an overall assessment of the intrinsic vulnerability of the aquifer and of the soil vulnerability.

In the approach chosen by the Veneto regulations (among the most recent on the subject), also with the aim of overcoming the above-mentioned limits, a choice is made which may be summed up as follows: realisation and computerisation of geo-referenced data bases which are increased with time and which are summed up and processed in hydrogeologic, pedologic and agronomic maps, all of which contribute to the overall assessment of the soil suitability for the spreading of effluents.

So the approach, completely based on the creation of data banks, which the Provinces have ordered to be continuously updated and integrated, allows correct tackling of what is one of the principal difficulties of the problem, namely the extreme lack in the Veneto (but presumably also in other Italian regions) of both hydrogeologic and pedologic data, which would allow us to have mapping tools conceived in such a way as to be improved and updated with time.

This note will present:

1. the guide lines of the *unified method* contemplated by the Veneto regulation (D.G.R.V. 615/96);

2. an example of a first application of the *unified method* in a sample area of the provinces of Padua and Venice;

3. a critical examination of the method.

2. Guide lines of the Veneto regional regulation (D.G.R.V. 615/96)

The Regional Plan for Water (PRRA) of the Veneto Region contemplates regulation of the spreading of livestock effluents, configuring their use as agronomic practice and not as waste disposal. This enclosure assigns the Provinces the task of drawing up the necessary maps to allow identification of the different degree of soil suitability for the spreading of livestock effluents. The Veneto Region has drawn up a *unified method* (D.G.R.V.

615/96) for standardising the maps made by the individual Provinces.

In the preparation of this document, the methods adopted in current investigations or available in the literature were considered, including studies and legislative applications in other Regions and the opinions of research bodies.

The "*unified method*" recalls the contents of the EEC "*Nitrates Directive*" (91/676/EEC). The nitrates directive draws attention, at European level, to the severe problem of water pollution caused by nitrates from agricultural sources. It contemplates the identification of "polluting waters or which could be polluting" both on the surface and underground, considering both the actual concentration of nitrates in the water itself and the aquifer vulnerability. This leads to the mapping of "*vulnerable zones*" on which various programming operations must be carried out, ranging from the adoption of codes of good farming practice to the training and information of farmers and, last but not least, planning which considers the need to reduce the amount of nitrogen in the waters.

It must be pointed out that today, in the plain of the Veneto, the problem of nitrates in the ground waters is the principal cause of the impoverishment in quality of the underground water resources.

This aspect is of even greater importance in the Provinces of Padua and Venice, where a large part of the territory belongs to the basin that drains into the Lagoon of Venice - an area with considerable naturalistic and environmental value, but with a precarious ecological equilibrium.

The "*unified method*" contemplates the realisation of specific studies of a pedologic, hydrogeologic and agronomic nature, with the acquisition of experimental data and the creation of data bases.

The data collected are processed to provide zonations with reference to soil vulnerability on one hand and aquifer vulnerability on the other; by cross-referencing these data we obtain the assessment of the soil suitability for the spreading of livestock effluents.

Unlike other regional methods which consider either the pedologic or the hydrogeologic aspect, the *unified method* considers each of the two approaches, giving a crossed reading, the result of which is a map of the soil suitability for the spreading of livestock effluents.

In brief, the project is realised by developing the logic path summed up in Figure 1, by means of a synergy of three disciplines which are applied in different stages of the work, coordinated in time:

◊ **Pedology:** ***map of the soil and map of the pedologic orientation for the spreading of livestock effluents***

◊ **Hydrogeology:** ***map of the intrinsic vulnerability of the aquifers to pollution***

◊ **Territorial information science:** ***geo-referenced data banks concerning the soil and the sub-soil, connected to GIS***.

The result of the project is the "*map of the soil suitability for the spreading of livestock effluents*".

Figure 1 - Unified method (D.G.R.V. 615/96) - Logic path

Unified method (D.G.R.V. 615/96) - Logic path

1. Census and definition of the livestock load for the realisation of the map concerning the nitrogen loads per commune, with the aim of identifying the priority areas to be studied.
2. Identification of geomorphologic units.
3. Subdivision of the territory into homogeneous areas as regards type of soil.
4. Drafting of the map of the pedologic orientation for the spreading of livestock effluents.
5. Definition of the intrinsic aquifer vulnerability.
6. Cross-referencing of the two classifications (pedologic and hydrogeologic) and drafting of the map of the soil suitability for the spreading of livestock effluents.

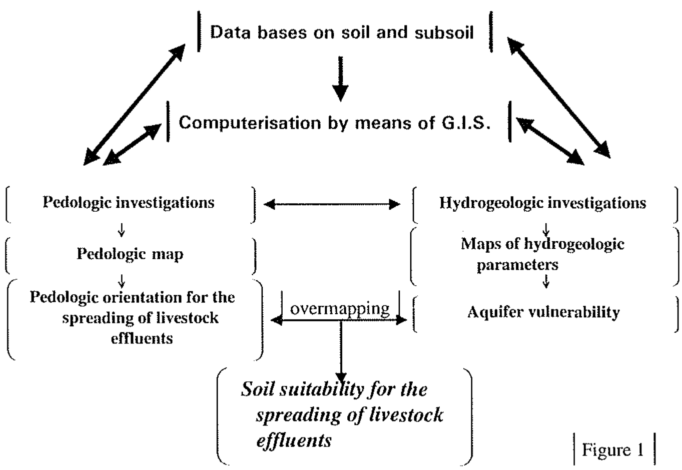


Figure 1

The method offers an opportunity for the creation, organisation and updating of various data banks on the soil and the sub-soil, generally absent in the Veneto provinces, which were also very useful for other institutional tasks assigned to the Provinces in the sector of the defence of the soil, agriculture, ten environment and territorial planing (Provincial Territorial Plan, Quarries Plan, Waste Management Plan, Civil Defence Plans, etc.). In particular it is the archive of geognostic tests (stratigraphies of boring operations, tests, drilling, trenches; graphs of penetrometric tests...), of pedologic data (drillings, profiles, analyses), of hydrogeologic data (censuses and experimental measurements on water points...) and the archive of livestock farms.

The *unified method* intends the archives to be computerised and connected to G.I.S. so that the data may be always updated and more easily consulted. In the case of the two Provinces considered, these data banks were computerised by means of G.I.S.

Pedologic aspects

The need to create a pedologic guidance map for the spreading of livestock effluents springs from the fact that the soil carries out a fundamental interface action between the effluents, the plants which should benefit from them, the surface waters and the subsoil, with the water table contained there. Each of the components involved in this agricultural practice must relate to the soil.

The pedologic study is composed of the following phases:

1 - Environmental investigation

The environmental investigation contemplates a systematic collection of information which must lead, as a final result, to the distinction of territorial environments with specific ecological characteristics. For this phase, bibliographic and climatic data were collected and CTR (Regional Technical Committee) cartographic processing was used on scale 1:10,000 and 1:20,000 and on IGM (Military Geographic Institute) base 1:25,000 relating to:

⇒ microrelief and altimetric maps;

⇒ map of the geomorphologic units obtained by means of photointerpretation;

⇒ geolithologic map;

⇒ hydrography and surface drainage;

⇒ hydraulic risk;

⇒ historic maps;

⇒ use of the soil.

Some of these maps were prepared *ad hoc*, others were already available as they had been made for other tasks assigned to the provinces.

The synthesis of the environmental investigation is the definition and identification on maps of the territory units which represent the synthetic picture of the causes and phenomena which have led to the formation and evolution of the different soils: the soils contained in the same unit, with similar climatic, geolithologic, hydrographic, and morphological characters, vegetation and crops, have strong probabilities of being relatively homogeneous, because they have followed the same genesis, a similar evolutionary history which has led them to have a similar appearance and therefore similar behaviour.

2 - Identification and characterisation of the types of soil

The knowledge of the soil is achieved by using, on the one hand, recording methods on the site and, on the other, chemical and physical analysis in the laboratory.

On the basis of the results obtained from the environmental investigation, the on-site survey is planned. This survey deals principally with the characteristics of the mapped territory units, that is their frequency, dimensions and emergence: rigid grid sampling are not carried out, but a reasoned survey is made. It is achieved by means of:

⇒ expeditious surveys or drillings able to highlight any peculiar and repeatable characteristics in areas classified with the same name of unit or sub-unit of the territory. For each drilling a standard form is filled in with the principal pedologic information (identification of the horizons, texture, colour, mottling, concretion, effervescence, humidity, etc.);

⇒ pedologic profiles, representing homogeneous areas as regards type of soil, for defining their outstanding characteristics. This involves the description by means of forms (identification and definition of the horizons, texture, colour, mottling, concretion, effervescence, etc.) of sections shown with the digging of trenches, in which samples of soil are taken and sent to the laboratory for analysis;

⇒ chemical and physical analysis of samples of soil (pH, organic substance, texture, C.S.C., etc.).

The data thus recorded are filed on special forms prepared by the Experimental Institute for the Study and Defence of the Soil in Florence on the "ISSDS" program under "Access".

3 - Drafting of the map of the soil

The classification of the soil and its cartographic representation are achieved by means of procedures that are now standard at an international and national level: in the first phase (drilling campaign), the types of soil present in the area are identified; they are then fully described, sampled and classified according to the Soil Taxonomy (USDA) and FAO-UNESCO methods with the description of the profiles (profiles campaign); the limits of the pedologic units identified are then checked.

On the basis of the results of the environmental investigation and of the survey, the pedologic map is drawn up which indicates the cartographic units with homogeneous types of soil.

The legend that accompanies the map is generally divided into two parts: the first lists the elements related to the environmental system, that is the territory units and sub-units, while the second indicates the soil characteristics, that is its description and classification.

4 - Drafting of the map of pedologic guidance for the spreading of livestock effluents

On the basis of the previously identified soil characteristics, it is possible to extrapolate the distribution of the pedologic factors according to the classes contemplated by the *unified method.*

In particular the Regional method contemplates the zonation of the territory on the basis of the factors that limit the spreading of effluents; these factors refer on one hand to environmental characteristics and, on the other, to the characteristics of the soil.

The following table, extracted from the Regional Method, lists the limiting factors that are considered and the values for which they determine whether the soil belongs to one specific area or class or to another.

Table 1

Chart for defining the classes of pedologic suitability for the spreading of livestock effluents.

Limiting factors	*Suitable*	*Moderately suitable*	*Slightly suitable*	*Not suitable*
		ENVIRONMENTAL CHARACTERISTICS		
Natural vegetation				Present
Liability to flood	Absent	Once every 5 years	More than once every 5 years	Once a year
Rockiness (%)		0-2	2-10	>10
Stoniness (%)	0-15	15-35	35-50	>50
Slope (%)	0-5	5-10	10-15	>15
Sunken morphology		Strongly sunken areas: Slip down one class		→
		SOIL CHARACTERISTICS		
Internal drainage	Good Mediocre Slow	Slow (with groundwater) Very slow	Very slow (with groundwater) Fast	Difficult Fast (with groundwater)
Skeleton (%)	<35	35-50	50-70	>70
Surface cracks	Present with fine or moderately fine substratum	Present with moderately loose substratum within 100 cm	Present with loose substratum within 100 cm	Present with loose substratum within 100 cm with water table
Permeable layer depth (cm)	80-100	50-80	30-50	30-50 with water table within 150 cm
Texture (internal profile)	F - AS - FSA - FA - FL - L - FLA - A - AL	FS	SF	S or SF with water table within 150 cm
Peat	Absent	Present between 100 and 150 cm	Present between 50 and 100 cm	Present within 50 cm

Each cartographic unit defined in the pedologic map is assessed according to the above diagram, superimposing - by GIS - the theme maps for the eight pedologic parameters which therefore represent intermediate maps.

A determined class of pedologic suitability for the spreading of livestock effluents is then assigned to each unit, always referring to the factor that is most limiting.

In the first application of the method, besides the matrix in table 1, a variation (table 2) was used, concerning only the soil characteristics, according to the FAO method, referring to the work carried out by the Lombardy Regional Body for Agricultural Development as part of the Pedologic Mapping Project ("The soils of the Ticino Park, northern sector").

Table 2

Chart for defining the classes of soil vulnerability to the spreading of livestock effluents.

Degree of vulnerability as a function of the limiting factors	*LOW*	*MODERATE*	*HIGH*	*STRONG*	*VERY STRONG*
Soil characteristics	Weighted values with respect to the limiting values				
	Weight 1	Weight 3	Weight 5	Weight 7	Weight 9
Texture (entire profile)	F-FA-FL-FLA	FSA-AS-A-AL-L	FS	SF	SF with water table <150 cm or S
Peat (presence)	Absent	200-150 cm	150-100 cm	100-50 cm	<50 cm
Surface cracks	Absent	Present with fine or moderately fine substratum	Present with moderately loose substratum within 100 cm	Present with loose substratum within 100 cm	Present with loose substratum within 100 cm with water table
Impermeable layer depth	>120 cm	120-80 cm	80-50 cm	50-30 cm	50-30 cm with water table within 150 cm
Skeleton	<10%	10-35%	35-50%	50-70%	>70%
Internal drainage	Normal	Slow	Slow (with groundwater) or very slow	Very slow (with groundwater) or fast	Fast (with groundwater) or difficult

As may be seen, a fifth column has been added so as to better differentiate the degree of suitability and the minimum degree of limitation. A weighted value, increasing from left to right, is attributed to each column; in this way it was possible to identify the maximum limiting value for each soil characteristic and to add up the various limiting factors, suitable weighted, which were present in any given pedologic unit.

Table 3

Degree of pedologic suitability for the spreading of livestock effluents as a function of the overall degree of limiting factors

Degree of soil suitability		*Interval of weighted values*
Suitable soils	Soils presenting no important limitations	6
Moderately suitable soils	Soils moderately suitable in wet periods and suitable in dry periods	7-11
Slightly suitable soils	Soils slightly suitable in wet periods and suitable in dry periods	12-17
	Soils slightly suitable in wet periods and moderately suitable in dry periods	18-22
Unsuitable soils	Soils unsuitable in wet periods and slightly suitable in dry periods	23-28
	Soils permanently unsuitable: cannot be used for spreading in any period of the year	>28

The sum of the weights makes it possible to attribute to each pedologic unit the degree of suitability for the spreading of livestock effluents as a function of the total characteristics of the soils present there and of the period of spreading.

The difference from the regional method, applied in the same way, is that the class of suitability derives from the sum of the limiting factor (each with its own weight) and not on the most limiting factor alone.

Hydrogeologic aspects

The maps of the intrinsic vulnerability to contamination are an operative tool which allows an assessment of the susceptibility of the subsoil to absorb a polluting substance carried in water.

This form of mapping has been widely used, for several decades, in many parts of the world. From the Eighties onwards, numerous examples of these maps have been developed, applying them in various sectors. With specific reference to the Italian situation, table 4 illustrates the historic evolution of vulnerability maps and the standards they refer to.

Table 4

Technical evolution and standards of the maps of aquifer vulnerability to contamination.

Sixties	First examples of the creation of aquifer vulnerability maps, especially in the field of research
Seventies	The B.R.G.M. begins systematic mapping of the French territory.
Seventies-Eighties	Aquifer vulnerability maps spread to many countries in the world; many different methods for assessing vulnerability are drawn up.
Eighties	The C.N.R. (1985) creates a line of research "Assessment of aquifer vulnerability" within the National Group for Defence against Hydrogeologic catastrophes. Maps are prepared in various parts of the national territory and a standard legend is published (1988) for small-scale maps (1:50,000).
Nineties	The methods of assessment are further standardised (SINTACS method, an evolution of the united states DRASTIC method, prepared for the Mediterranean areas); some standards begin to use the vulnerability concept ("Nitrates directive - 91/676/EEC; D.Lgs. 152/99; D.G.R.V. 615/96; standards for the application of some territorial plans").

In order to map the aquifer vulnerability, the *unified method* adopts the standard legend proposed by the VAZAR Special Programme (Vulnerability of Aquifers in High Risk Areas) of the National Group for Defence against Hydrogeologic Catastrophes of the CNR (GNDCI-CNR)[1].

In brief, for the hydrogeologic aspect the method contemplates:

1. assessment of the intrinsic vulnerability by means of a complete hydrogeologic study (based on bibliographic data available, on tests *in situ* and on measurement campaigns), with particular reference to the recharge-discharge process, drawing up intermediate maps[2] such as:

⇒ map of the permeability of the soil and of the immediate subsoil, aimed at defining the type and degree of vertical and horizontal permeability, which are necessary for defining the percolating speed of the polluting substance and the attenuating action (self purification) existing in the different soils and/or the presence of coverings with low permeability which act as protection for the underground water bodies;

⇒ map of the depth of the water table in normal flood condition or of the head of the first artesian aquifer;

⇒ maps of the principal hydrostructural elements such as underground watersheds, direction of flow, isopiestic lines, highlighting in particular the relationships existing between water tables and streams seen as potential vehicles for polluting substances.

2. Identification of the areas at risk on the basis of the intrinsic vulnerability.

The legend allows classification of the territory in 6 different vulnerability classes, two of which are incorporated, as illustrated in table 5.

Table 5

Classes of vulnerability envisaged by the CNR-VAZAR legend, by the Unified Method and relationship to the SINTACS score.

CNR-VAZAR classes of vulnerability	***SINTACS Interval***	***Unified Method classes of vulnerability (D.G.R.V. 615/96)***	***Classes of hydrogeologic suitability***
Very low	*0.80-80*		
Low	*81-105*	*Low*	*Low*
Medium	*106-140*		
High	*141-186*	*Medium*	*Moderately suitable*
Very high	*187-210*	*Very high*	*Slightly suitable*
Extremely high	*211-160*	*Extremely high*	*Not suitable*

In Italy this method has already been used in numerous areas, thus becoming a reference standard.

It should be noted that the choice of the CNR-VAZAR standard legend has the considerable advantage of also allowing the use of parametric methods, maintaining the division in the four classes listed above. In fact the standard legend (CNR-VAZAR) adopted by the unified method is applicable according to two systems, that is by means of a "zonation by homogeneous areas", by direct application of the CNR-VAZAR legend (1988), or by means of a parametric method with scores and weights ("Point Count System Model"); the SINTACS[3] (Civita, 1994). Though it should be remarked that, as the two systems were created for mapping with a different degree of detail, the results are only partly comparable (see for example: Civita, 1994).

Among the advantages of the use of parametric method there is a greater reproducibility of the result and the possibility of comparing hydrogeologic situations that may be quite different from one another (as happens in the geologic conditions of the Veneto Region). Furthermore the parameters examined are "standardised".

Parametric methods are therefore particularly suitable for the construction of maps with a low scale denominator (such as those being examined). It should, however, be specified that the parametric methods such as SINTACS have the "disadvantage" of requiring a considerable hydrogeologic data base, so they are applicable only after an in-depth hydrogeologic investigation or in areas where sufficiently complete geologic-hydrogeologic data banks are already available.

It is pointed out that, due to the scarcity of hydrogeologic data at the disposal of the Veneto Region, if the *unified method* had obligatorily chosen the SINTACS system (recently recommended, in parallel with the CNR-VAZAR, also by D.L. 152/99), it would be difficult to apply in vast areas of the regional territory.

Map of the soil suitability for the spreading of livestock effluents

From the cross-reference of the results of the two classifications, pedologic and hydrogeologic, there emerges the final judgement concerning the suitability of the soil for the spreading of livestock effluents, in the sense that the most limiting class for the use of the effluents (table 6) is assigned to each of the Units, which derive from the computerised over-mapping of the classes of suitability for spreading on pedologic bases and of the classes of suitability based on the aquifer vulnerability.

For each class of soil the regional regulation identifies the quantities of effluents that may be spread in relation to the nitrogen charge of the different animal specials (table 7).

Table 6

Classification of soil suitability for spreading of livestock effluents.

Classes of pedologic suitability	**Suitable**	**Moderately suitable**	**Slightly suitable**	**Not suitable**
Class of hydrogeologic suitability		SUITABILITY FOR SPREADING EFFLUENT		
Suitable	Suitable	Mod. suitable	Slightly suitable	Not suitable
Mod. suitable	Mod. suitable	Mod. suitable	Slightly suitable	Not suitable
Slightly suitable	Slightly suitable	Slightly suitable	Slightly suitable	Not suitable
Not suitable	Not suitable	Not suitable	Not suitable	Not suitable

Table 7

Quantity of effluent that may be spread in relation to the class of soil suitability

Class of suitability of soil for spreading livestock effluent	*Quantity of effluent that may be used (kg of nitrogen/ha/year)*
Suitable	340
Moderately suitable	250
Slightly suitable	170
Not suitable	0

Note that the Nitrates Directive contemplates a quantity of 170 kg of nitrogen/ha/year for “vulnerable areas”.

The computerisation of data

The method originates with the idea of exploiting the technological resources (G.I.S.) now at disposal for creating the above-mentioned map, so that the numerous items of information that it contains may be used and accessible even separately, considering the many further uses that the

Province or any other users may want to make.

Moreover, the application of GIS systems to the data banks allows the automatic realisation of maps with the possibility that a future integration of the data may make the map easy to update.

In order to make data more widely known, the Province of Padua has also developed a multimedia CD-Rom with an integrated search motor for consulting the maps produced with relation to the first phase of the project: the geopedologic map and the map of the suitability of the soil for the spreading of livestock effluents.

The CD-Rom, prepared by the CED of the Province of Padua, aims to replace conventional paper publications. It is proposed as an informative instrument with greater performance, as it also provided information about drillings, soil profiles and other surveyed and mapped data. This product allows interactive consultation and printing of maps and data (profile photos, campaign charts, drillings and profiles).

Still on the subject of making data known, some maps of the province of Padua may already be consulted on the web site of the Province of Padua (http://www.websit.provincia.padova.it).

3. An example of application

The provinces of Padua and Venice, which border on one another and share partly comparable territorial characteristics, are proceeding by strips of territory as contemplated by the Regional Method. The territory mapped up till now includes areas with very varied geomorphologic and hydrogeologic characteristics: it is a prevalently flat area which goes from the high plain (containing a gravelly aquifer without differentiation) to the zone of the karst springs and the low plain (with multilayer aquifers).

The area also includes as coastal and lagoon strip and a hilly area (Euganean Hills) composed of volcanic and sedimentary rocks (limestone and marl). The soil in the plain ranges in age from the Pleistocene to the present age, with various recently reclaimed zones.

The territory of these two provinces therefore includes many of the environment types to be found in the Veneto Region.

At the present state of the work, a map of the Geomorphologic Units has been prepared (author: Leda Minuzzo), which covers the whole

Province of Padua and vast areas of the province of Venice, drawn on scale 1:20,000. The pedologic measurements already taken cover vast areas of the provinces of Padua and Venice, while the work on the hydrogeologic part is currently at an advanced stage in both provincial territories.

The example presented in this note concerns two zones, one in the province of Venice and the other in the province of Padua, which include some of the most characteristic geologic types to be found in the Veneto Region.

a) The zone chosen for the pedologic aspect in the province of Venice is the southern area, including the communes of Cona, Cavarzere and Chioggia.

This is a prevalently farming area, recently created by the deposit of sediment from the rivers Po, Adige and Brenta. The area is particularly interesting since, in a few hundred square kilometres, it concentrates the alluvion of three of the major Italian rivers, the coastal strip with the shore at Isola Verde, Sottomarina and Chioggia, and the lagoon of Chioggia and Venice (island of Ca' Roman).

From a geomorphologic point of view, the mainland is divided into two areas: the inner, western area, dominated by alluvial continental morphologies, and the eastern area, dominated by delta morphologies.

The area lies prevalently below sea level and is characterised by a natural subsidence due to compaction of the recent sediments; the only portions of territory lying above sea level are:

• the alluvial rises of the Brenta (northern zone - Valli di Chioggia), of the Po (passing through Cona and Pegolotte), of the Adige and of the Tartaro around the present course of the Adige;

• the old and recent dune formations, sub-parallel to the present coastline, demonstrating how it has advanced.

In these narrow strips the sediments are prevalently sandy.

In the vast portion of the area lying below sea level, the sediments are prevalently composed of clay and peat; where peat prevails, the site plane reaches -4m a.s.l.

The following types of soil are found in the southern territory of the Province of Venice:

⇒ Alfisols

⇒ Entisols

⇒ Histosols

⇒ Inceptisols

⇒ Mollisols

They were subdivided into 33 map units, each described by at least one representative profile (for the description, see Bassan *et al.*, 1994).

To draft the map of the pedologic orientation, 6 intermediate maps were reconstructed, based on the map units found, referring to each factor limiting the spreading of livestock effluents with relation to the characteristics of the soil:

- Degree of surface cracking (%)
- Peat depth (cm) (Figure 2)
- Skeleton (%)
- Texture of the entire profile
- Depth of the permeable layer
- Classes of internal drainage.

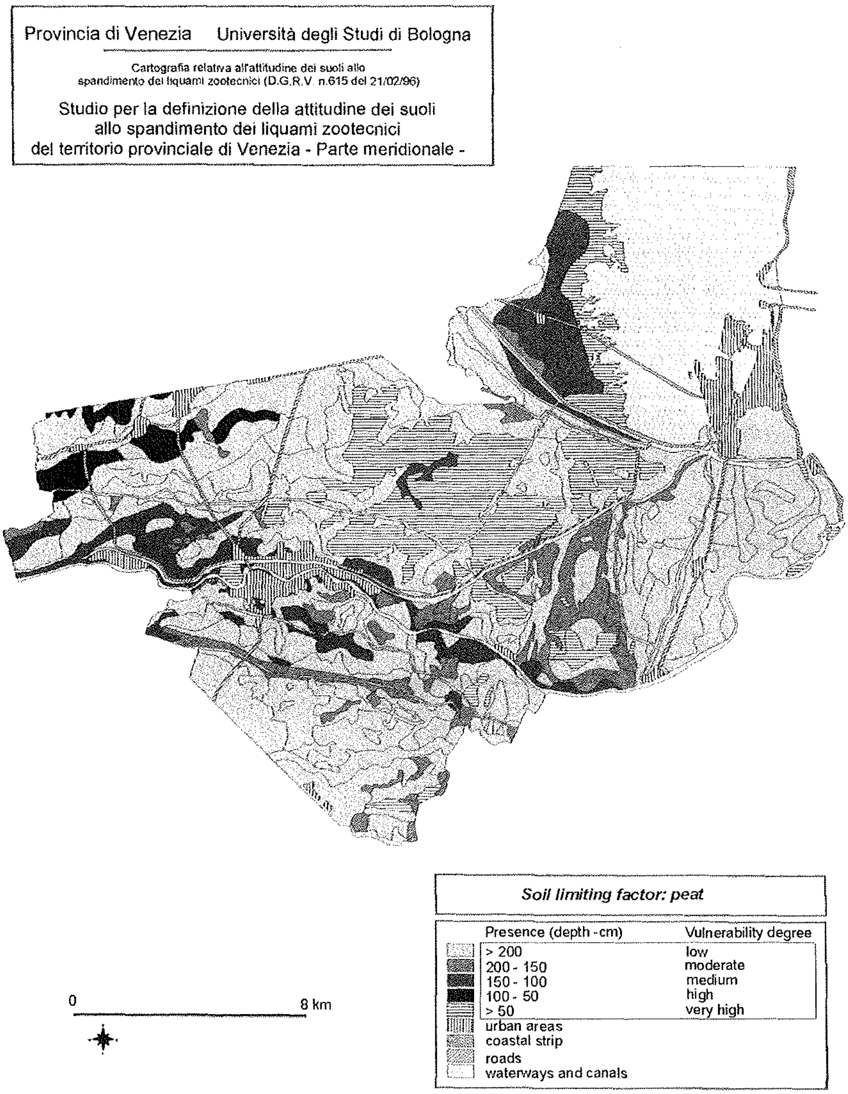
The limiting factors concerning rockiness, stoniness, slope and natural vegetation were not considered, as they do not exist in the area studied.

The sunken morphology was not highlighted as a limiting factor, as the most depressed areas coincide with the peaty areas in which the soil already belongs to the unsuitable category.

The map of the hydraulic risk drafted in the study for the Provincial Territorial Plan had also indicated the low level of risk present throughout the area, almost completely with mechanical drainage, efficiently operated by four Reclaiming Consortia. Possible flooding was not counted among the limiting factors.

Overmapping gave the map of the pedologic orientation for the spreading of livestock effluents. A large part of the territory has soil classes that are not suitable or slightly suitable: the principal limiting factors are the presence of prevalently sandy textures in the vicinity of the dunes and old dunes and of the old river beds, of peat in the most depressed areas, and of drainage that is either too rapid or too difficult.

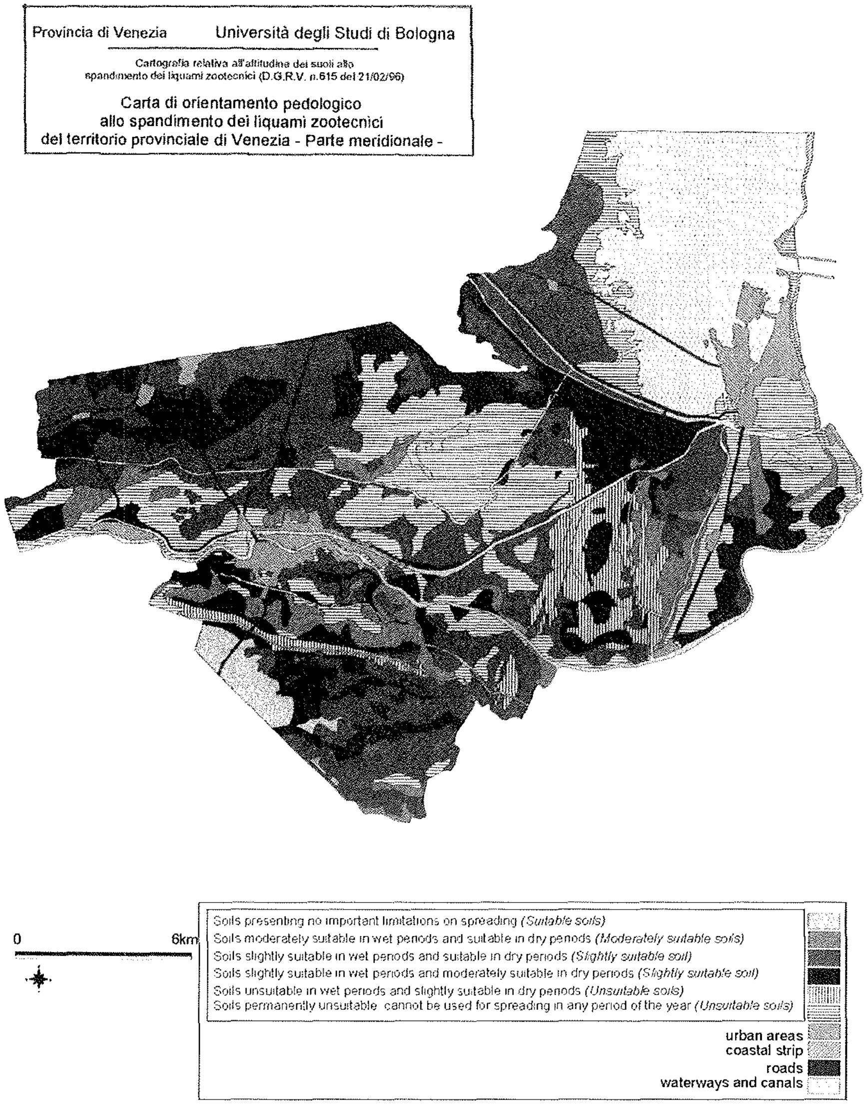
Figure 2 - Presence and vulnerability degree of a soil limiting factor: peat depth (cm)



The westernmost part of the area and the northern part have soils that are from moderately suitable to suitable from the pedologic point of view. These are clayey and slimy soils, sometimes with a certain percentage of sand, belonging to areas lying farther inland, where the reclamation is older.

The application of the FAO model, previously illustrated, was experimented in this area (Figure 3).

Figure 3 - Map of the pedologic orientation for the spreading of livestock effluents in the southern area of the province of Venice (FAO Method)



With this system a greater grading of the classes of pedologic suitability for the spreading of livestock effluents was found, with a decrease of the unsuitable pedologic units and an increase of the units belonging to the intermediate suitability classes.

As regards the hydrogeologic aspect, the application of the method to this area was complex because this part of the territory presents some peculiar characteristics (areas partly reclaimed recently, lying below sea level, with mechanical drainage, through which flow the final part of some of the major Italian rivers) and examples of limited comparison were found both in the Veneto (where, apart from a few exceptions, there is an absence of vulnerability maps on an operative scale) and in other Italian areas.

In view of the operative scale (1:10,000-1:20,000) and of the above-mentioned difficulty, the division into the classes contemplated by the CNR-VAZAR legend was made using the relationship between the SINTACS calculation model and the vulnerability classes of the CNR-VAZAR legend. The method envisages the determination and assessment, on the whole territory, of the following seven hydrogeologic parameters[4]:

- Depth to ground water (*S*oggiacenza)
- effective infiltration action (*I*nfiltrazione efficace)
- Unsaturated attenuation capacity (effetto di autodepurazione del *N*on saturo)
- hydraulic conductivity range of the aquifer (*C*onducibilità idraulica)
- Soil/overburden attenuation capacity (*T*ipologia della copertura)
- hydrogeologic characteristics of the aquifer (caratteristiche idrogeologiche dell'*A*cquifero)
- hydrologic role of the topographic slope (acclività della *S*uperficie topografica).

For each parameter, using specific comparison diagrams, a rate was assigned (variable from 1 to 10) which increased with the vulnerability. The rates for the seven mapped parameters are then multiplied by a weight related to the environmental situations of the area.

In brief, the realisation of the aquifer vulnerability map followed this pattern:

a) Collection of the data necessary to make maps representing the parameters contemplated by the SINTACS method. The diagram in table 6 illustrates, for the specific case, the type of data collected for the various parameters considered. It should be noted that for some parameters which require experimental tests (for example, permeability data), the number of data was very limited, so the maps may be improved in the future.

b) Computerised processing of the maps. Calculation of the scores according to the SINTACS method and definition of the degree of vulnerability according to the subdivision in classes contemplated by the CNR-VAZAR method (as contemplated by the *Unified Method* of the Veneto Region).

All the processing was based on precise data banks, and in particular:

- Archive of geognostic tests
- Subterranean waters monitoring network
- Archive of piezometric measurements

It would also be useful to have a data bank on hydrogeologic and infiltrometric tests, but the data currently available are not sufficient to make one.

Table 6

Type of data used to assess aquifer vulnerability

Parameter	**Data used**
Depth to ground water	Existing hydrogeologic maps (P.R.G., territorial studies); piezometric measurements in normal flood conditions; map of morphologic units, data on the monitoring network, microrelief map
Effective infiltration action	Infiltrometric tests, map of morphologic units, drillings; data on the surface texture; meteo-climatic data
Unsaturated attenuation capacity	Stratigraphies (and other geognostic and geophysical investigations) and geologic profiles
Soil/overburden attenuation capacity	Drillings, lithologic maps, P.R.G., map of morphologic units, geologic surveys, pedologic data and specially reprocessed analyses of the soils
Hydrogeologic characteristics of the aquifer	Drillings, piezometric measurements, hydrogeologic studies on a supra-communal scale
Hydraulic conductivity range of the aquifer	Collection and checking of the (few) data existing on determinations made by means of hydrogeologic tests of k n_e v..
Hydrologic role of topographic slope	Topographic data (in the example shown the slopes gradients are always close to zero and were always assessed as zero, even though a microrelief map was available).

The area show presents typical characteristics of a low plain area in which the water resources are rather poor. In fact the aquifer considered (which, as usual in vulnerability maps, is the first aquifer) has a limited thickness and potential, since the subsoil is composed of soil with a granulometry between clay and sand. In this geologic situation, the interest in the aquifer vulnerability is linked more with the connection between the aquifer and the surface drainage network (draining into the lagoon of Venice) than with the actual value of the underground water resources. In fact the underground waters are naturally unsuitable for use as drinking water ("class 0" of D.L. 152/99), besides being scarce in quantity.

In the area examined, the vulnerability is between Medium and Exceedingly High). The most vulnerable areas correspond to the areas with greater hydraulic conductivity, coinciding with old river beds and with sandy aquifers with a sub-surfacing table drained artificially by water scooping machines.

b) The zone chosen in the province of Padua is the hill and foothill area comprising the communes of Vò, Teolo, Rovolon, Torreglia, Abano Terme, Montegrotto Terme and, only in small portions, the communes of Lozzo Atestino, Cinto Euganeo, Galzignano Terme, Battaglia Terme, Carrara San Giorgio, Maserà, Albignasego, Padua, Selvazzano Dentro, Saccologo and Cervarese Santa Croce.

This is a prevalently farming area in the hill and foothill zone, where specialised vine growing is widespread, while all over the plain there are small inhabited centres which reach their greatest extent in the commune of Padua and in the three communes of Abano, Montegrotto and Torreglia, which constitute almost an urban *continuum*.

There are essentially three morphological types to be observed in the area considered:

⇒ the highest altimetric strip of the Euganean Hills, composed prevalently of older volcanic rocks from the upper Jurassic to the lower Oligocene, characterised by high acclivity;

⇒ the lower altimetric strip, characterised by marine sedimentary formations, more recent than the previous ones, characterised by limited acclivity;

⇒ the alluvial plain which surrounds the group of hills, composed of the most recent deposits of the Quaternary period.

It should be recalled that the passage from the plain to the hills is sudden. This is due essentially to the fact that at the foot of the reliefs the colluvial sheets and the alluvial cones have a very limited extent because of the burying of the piedmont strips and the lower valley parts by the alluvial materials carried mainly by the river Brenta and, to a lesser extent, by the Bacchiglione.

Due to the limited extent of the hydrographic basins of the Hills, there are very few alluvial deposits coming from the Hills themselves (Zangheri, 1990).

The hydrographic grid of the plain is practically completely a man-made environment, composed of reclamation channels, now controlled by the Reclamation Consortia.

The following types of soil are found in the territory examined (figure 4):

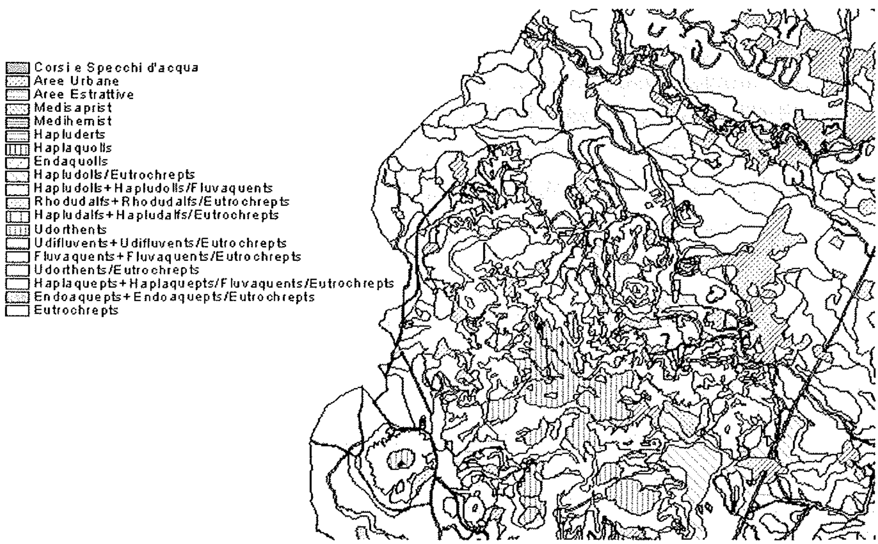
⇒ Entisols

⇒ Histosols

⇒ Inceptisols

⇒ Mollisols

Figure 4 - Map of the soils in a sector of the province of Padua



In greater detail, it is seen how the flat part is composed almost exclusively of soil with a limited pedogenetic evolution, developed from alteration processes which affect the pedogenetic substratum itself, and with the presence of carbonates which often give rise to more or less compact accumulation horizons. In some zones there are also soils with a high content of more or less decomposed organic substance in the surface layer.

The situation in the hilly area can be substantially ascribed to the two following types:

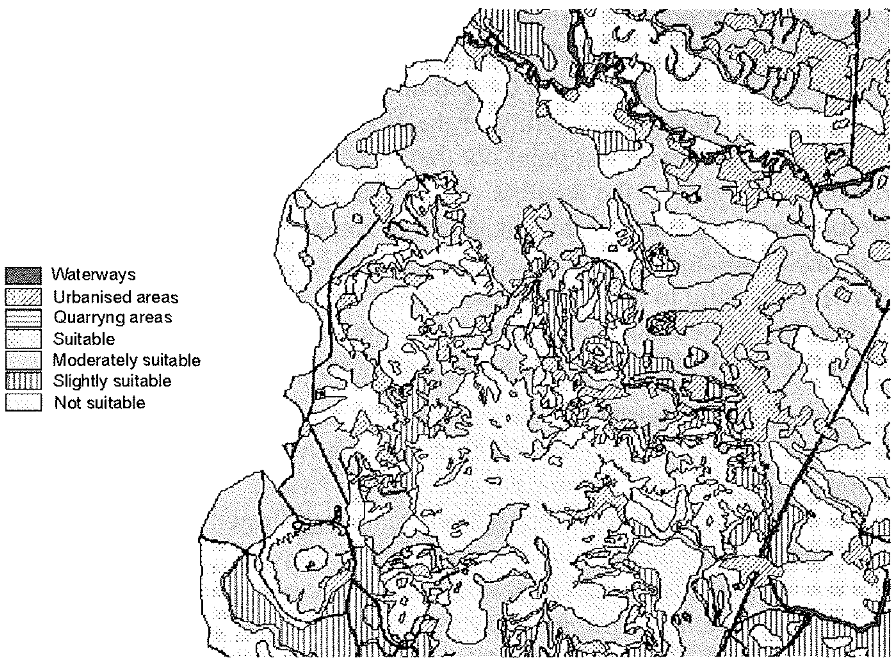
⇒ soils that are from slightly evolved to limitedly evolved, formed on lithologic substrata with a different composition;

⇒ soils that are little evolved from the pedogenic point of view, formed on lithologic substrata with a different mineralogical composition in which the content of organic substance is limited in the surface horizons and decreases regularly as it goes deeper.

With a procedure similar to the one used for the portion of territory illustrated in the province of Venice, the map of the pedologic orientation for the spreading of livestock effluents is obtained (figure 5).

The principal limiting factors are the presence of skeleton and internal drainage, as far as concerns the soil characteristics, while for the environmental characteristics they are the presence of rockiness, stoniness and slope (areas with slopes >15%).

Figure 5 - Map of the pedologic orientation for the spreading of livestock effluents in a sector of the province of Padua



4. Methodological assessments

The application of the Method carried out, which was the first in the Veneto Region, allowed the development of possible improvements to be made to the method itself.

The experience accumulated up till now has shown the usefulness of the approach, based on computerised data banks, which allows the provincial administrations to equip themselves with basic knowledge that can be updated, and allowing applications to other institutional tasks assigned to the provinces. Moreover, with limited difficulties, this theoretically also allows the application of other methods for assessing the suitability of soils for the spreading of effluents and above all a gradual improvement of maps with relation to the gradual increase of the data.

Another element that should be stressed was the necessary coordination between the various specialists involved, who often use different methods and terminology when making maps; in fact, various phases of the collection and processing of data are at least partially shared (for example, photointerpretation, microrelief, the map of the surface lithology or the analysis of meteo-climatic data).

As regards the specifically hydrogeological aspect, we must point out the difficulty in adopting reference standards in the investigating density (unlike the situation for the pedologic aspects), also in relation to the extreme hydrogeologic variability of the Veneto region. Also for the hydrogeological aspect, we must point out the difficulty in precisely assessing the vulnerability value of the aquifers on account of the extreme lack of hydrogeologic parametrisation, which is absent in some cases even in areas used to feed public water supplies! On this point, due to its relative ease of execution, it would be useful to make a first assessment of the hydraulic conductivity of the aquifer by means of widespread use of the slug test, as recently proposed (Civita *et al.*, 1999) with regard to the aquifer vulnerability map.

Also as regards the strictly hydrogeologic aspects, we must point out that the aquifer vulnerability maps provide an exclusively "environmental approach", without considering the "value" of groundwater resources. On this point the proposed assessment of "weighted vulnerability" is interesting, resulting from overmapping of the "*Intrinsic Vulnerability Map (SINTACS)*" with the "*Map of the importance of the aquifers extended to the respective hydrographic basins*", recently introduced by Braccesi and Pranzini (1999). This map, which for various aspects is linked to the well known "*risk maps*", is an interesting development of the vulnerability map.

However, its standard application should be carefully considered, as, if it is not correctly applied, it risks assimilating an aquifer with natural quality waters in class 0 with a "pollutable" aquifer. It is interesting that this map is more easily read by people who are not specialists in hydrogeology, as there is a general scarcity of this profession in Italian public bodies.

In the lack of reference experience on the overlapping of pedologic data with hydrogeologic data, the *unified method* opted for overlapping which contemplates that the soil suitability for the spreading of livestock effluents be given by the less penalising between the hydrogeologic and the pedologic vulnerability class. This is a precautionary measure for environmental protection, but it could cause needless penalisation of economic activities. So it would be important to be able to have a single matrix which, with a system of points and weights, would allow pedologic and hydrogeologic data to be crossed and their average values found. It should be noted that the SINTACS calculation model (like other parametric methods for assessing aquifer vulnerability) was created with the idea of allowing the overlapping of hydrogeologic data with certain pedologic elements. So it would be theoretically possible too modify the SINTACS matrix system, including the various elements analysed by the pedologic studies in order to have an overall assessment of the degree of water protection. However there is a lack of experience for comparison of this element at the moment, so an effort must be made in experimentation.

Bibliography

AA.VV. (1996). *I suoli dell'area a DOC dei Colli Euganei*, Serie pedologica 4. ESAV - Regione del Veneto.

BASSAN V., FAVERO V., VIANELLO G., VITTURI A. (1994). Studio geoambientale e geopedologico del territorio provinciale - parte meridionale. Provincia di Venezia.

BERETTA G.P., CIVITA M., FRANCANI V., MURATORI A., PAGOTTO A., VERGA G., ZAVATTI A., ZUPPI G.M. (1988). *Proposta di normativa per l'istituzione delle fasce di rispetto delle opere di captazione di acque sotterranee*. GMDCI-C.N.R., pubbl. 75, GEO-GRAP ed., Milan, 277 p.

BRACCESI G., PRANZINI G. (1999). Carta della Vulnerabilità Ponderata degli Acquiferi dell'Isola d'Elba. *Quaderni di Geologia Applicata* suppl. 2/99: 359-368. Atti 3° Conv. Naz. Protezione e gestione delle acque sotterranee per il III millennio. Parma 13-14-15 ottobre 1999, Pitagora Ed., Bologna.

CIVITA M. (1990). *Legenda unificata per le carte della vulnerabilità dei corpi idrici sotterranei/Unified legend for the aquifer pollution vulnerability Maps. Studi sulla vulnerabilità degli acquiferi*, 1 (Append.), Pitagora Ed., Bologna, 13 p.

CIVITA M. (1994). *Le carte della vulnerabilità degli acquiferi all'inquinamento: Teoria e pratica. Studi sulla vulnerabilità degli acquiferi*, 7, Pitagora Ed., Bologna, 325 p.

CIVITA M., DE MAIO M. (1997). *SINTACS - un sistema parametrico per la valutazione e la cartografia della vulnerabilità degli acquiferi all'inquinamento. Metodologia & automatizzazione*. Pitagora Ed., Bologna, 191 p.

CIVITA M., FIORUCCI A., PIZZO S., VIGNA B. (1999). Utilizzazione estensiva delle prove rapide d'acquifero per la valutazione della vulnerabilità degli acquiferi all'inquinamento. *Quaderni di Geologia Applicata* suppl. 2/99: 105-109. Atti 3° Conv. Naz. Protezione e gestione delle acque sotterranee per il III millennio. Parma 13-14-15 ottobre 1999, Pitagora Ed., Bologna.

ZANGHERI P. (1990). Dati paleoidrografici sulla pianura a Sud-Ovest dei Colli Euganei. *Atti e Mem. Accad. Patavina Sc. Lett. Ed Arti,* vol. CI (1988-89) - Parte II: Classe di Sc. At. E Nat., p. 175-198., Padua.

Zangheri P. (1994). Indagine sull'inquinamento delle acque sotterranee nella Pianura Veneta. *Ambiente, risorse e salute*, 2/94: 30-33, Padua

Note

1. The method is defined by the regional *unified method* with the abbreviation CNR-VAZAR; Civita (1994) defines it with the initials CNR-GNDCI. Below it will always be defined as CNR-VAZAR.

2. The *unified method* does not state the method of overmapping and/or cross-referencing these maps; below, the system used here will be described, corresponding to the SINTACS calculation diagram.

3. As is known from the specific literature on the subject (see for example: Civita, 1994), the classic United States DRASTIC method presents problems of applicability in our areas. For this reason the CNR-GNDCI has, with years of research and special calibration, now carried out in numerous hydrogeologic types, prepared a special instrument derived from the DRASTIC, known as SINTACS.

4. The initials of the seven parameters (S-I-N-T-A-C-S) form the acronym which gives the name to the system for calculating vulnerability.

LAND EVALUATION IN AREAS WITH HIGH ENVIRONMENTAL SENSITIVITY AND QUALITATIVE VALUE OF THE CROPS: THE VITICULTURAL AND OLIVE-GROWING ZONING OF THE SIENA PROVINCE

Edoardo A.C. Costantini, Lorenzo Sulli

Istituto Sperimentale per lo Studio e la Difesa del Suolo, Firenze
Piazza D' Azeglio, 30 - 50121 Firenze

Summary

In Italy there is a tendency to delegate most of the authority concerning agricultural matters, especially the ones respecting land planning and expenditure policy, to the Provincial Administrations. As Provincial Administrations seldom have all the technical expertise necessary to carry out this function, they usually rely upon free-lance professionals or Universities and Experimental Institutes. The Provincial Administration of Siena assigned the Istituto Sperimentale per lo Studio e la Difesa del Suolo of Florence the task of studying the possibilities of extending viticulture and olive tree cultivation in its territory, while at the same time safeguarding eco-compatibility, namely soil conservation, and the quality level of the products. A methodology was therefore worked out, aimed at evaluating the crop suitability of the Siena territory. This methodology requires a reasonable amount of time, is scientifically sound and can be easily applied by other Provincial Administrations. Its main qualifying aspects are the following:

i) The political and technical staff of the Administration were from the very beginning involved in defining the goals and ground rules of the study, i.e. study area, scale of investigation, meaning of the term "suitable".

ii) The study was completely computerised and compatible with the Provincial Territorial Information System.

iii) The term crop eco-compatibility was not only considered in the sense of avoiding excessive soil erosion, but also in the sense of preserving soil qualities, e.g. land capability, runoff regulation, soil suitability for producing high quality yields.

iv) The soil suitability was evaluated with reference to specific agronomic models and using a geographic soil database.

v) The evaluation was calibrated and validated with experimental plots.

vi) To assess crop requirements and soil functional characters it was set up a multidisciplinary collaboration, with researchers belonging to the different disciplines involved.

vii) In order to generalise soil information, two aspects were taken into account: how to group point information and allocate it to a soil typology, and how to extend point information to map units.

viii) Land Evaluation maps were completed with an explicit explanation of the inferences made in the evaluation process. Three indices were proposed: the "reliability" of the relationship between soil and landscape; the "confidence" of the soil suitability and the "accuracy" of cartographic information.

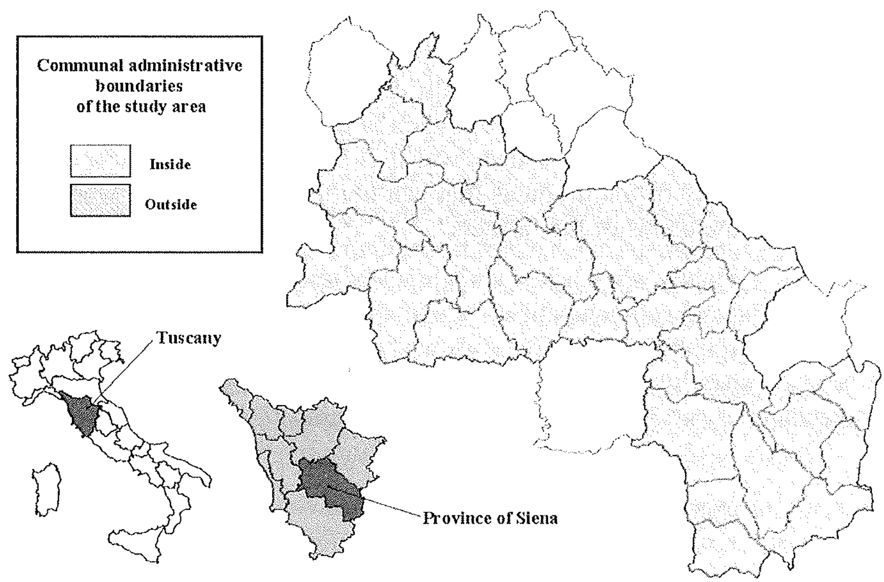
The initial outcomes of the work indicated that the areas in which it is possible to combine complete eco-compatibility and top quality production are very limited, with the current state of technology. Thus, although the study demonstrated a fair potentiality for the expanding of the two crops, the plantation and husbandry techniques would have to be modified and improved, with the adoption of appropriate soil conservation practices, specially designed to suit each site.

Introduction

On the basis of an Italian law, i.e. law 142 of 1990, regarding local government reform, several Regional Administrations are tending to delegate most of the authority on land planning and expenditure policy in the agricultural sector to the Provincial Administrations, and the region of Tuscany is very much in the forefront in terms of the delegation of this authority (viz. regional law 5/95). With precisely that low in mind, in its plan for agricultural land development, the Agricultural department of the Provincial Administration of Siena, decided to assess the possibilities of extending viticulture and olive growing in the area, safeguarding of course the eco-compatibility of the crops, especially against soil erosion. The Administration is going to use this information to define new designated origin areas for those agricultural products.

The Istituto Sperimentale per lo Studio e la Difesa del Suolo of Florence has been working on the links between soil and product quality for more than twenty years (Lulli *et al.*, 1980; Costantini *et al.*, 1985) and the lynch-pin for the methodological development has been the vine.

We moved on from studying the relationships between soil and crop yields (different soils = different grape yields; Costantini, 1987) to the correlation between soil and quality of the wine (different soils = different wine quality; Lulli *et al.*, 1989; Costantini *et al.*, 1990; Costantini *et al.*, 1991). We then compared soil and wine components, in order to provide information about the best agricultural husbandry (different soil functional characters = different wine sensorial profiles and yield components; Arcara *et al.*, 1993; Costantini *et al.*, 1996; Falcetti *et al.*, 1998; Falcetti *et al.*, 1999). Further studies regarded the interpretation of the data for viticultural zoning, according to different levels of soil parameter generalisation (Costantini, 1999). Finally, with the Province of Siena case study, we worked out a methodology to assess the territory, which would allow us to improve the local land planning policies, as well as those of the other Italian Provinces in general.



Methodological assumptions of the research, materials and methods

Established goals and ground rules

In order to meet the requirements of the Provincial Administration, it was first of all necessary to define the precise objectives of the research. This initial phase was managed in close co-operation with the technical and political staff of the Province. The first point we had to clarify was the area to be covered by the study. It was decided to consider the whole provincial territory, except the traditional areas of vine cultivation (communes of Chianti and S.Gimignano, Montepulciano, Montalcino).

Another decision that was taken had to do with the degree of precision of the survey. This was very important, because the message we wish to convey with this study is that you cannot draw conclusions for individual agricultural properties, but rather assess the probability of finding soils, which are suitable for vine and olive tree cultivation inside different areas, in the shortest time possible. Hence the scale chosen was 1:100,000, which corresponds to the reconnaissance level.

We then went on to decide what we meant with the general term "suitable". It has been quite clearly established by our studies, as well as by many others in the world, that the control of the environmental factors influencing the quality of final products (in our case wine and olive oil) is only possible with detailed studies, and that agrotechniques and fruit processing can play a major role; this is especially true at the highest level of quality (Costantini and Campostrini, 1996; Lebon *et al.*, 1997; Champagnol, 1997). In other words, at reconnaissance level it is by no means possible to guarantee the quality of the products that can be obtained, in other words "the quality is in the hands of the farmers".

Finally, we reached an agreement on the meaning of the expression "suitable and eco-compatible" which was as follow: "an area where there is a good probability of finding soils which can give satisfactory yields, both in term of quantity and quality, most years, without particularly expensive agrotechniques and an excessive risk of soil degradation, namely erosion".

The georeferenced soil database

One of the requests made by the Province was that our Soil Information System should be completely compatible with the Provincial Territorial Information System. In fact, although it is the Provincial Department of Agriculture which decides on the expenditure, general land planning is the responsibility of a different department, which deals with the storage and management of all the territorial information, including soils. When studying agricultural practices that could have an environmental impact, the Land Planning Department needs to store all this information in their database. So, the databank we have set up utilises the software Access, Arcinfo and Arcview, the same software which is used by the Siena

Province. Within our databank, soil point information is organised in soil typological units and subunits, with a specific range of variation for each soil parameter (Gardin *et al.*, 1996). Actually, our strategy was to concentrate our efforts on the most complete and appropriate characterisation of the functional properties of soil typological subunits, in our case phases of soil series (UDSA, 1993).

How to evaluate soil suitability

In order to assess soil suitability, we decided to use agricultural reference models. At the present state of the art, these models have been developed for vine cultivation, rather than for olive trees. In particular, researchers have established that the oenological result of the plant corresponds to a specific plant growth and ripening model, which is determined by agricultural practices, climate and soil conditions. So each site can be evaluated according to the difference between the actual soil conditions and the ones of the agronomic model which coincides with the desired oenological result. The rationale is based upon the observation that environmental factors influence the hormonal equilibrium of each variety, which in turn regulates the expression of the genotype (Van Leeuwen and Seguin, 1997; Costantini, 1998). The Sangiovese vine, for instance, in the most fertile soils, i.e. the ones lacking permanent limitations, gives bad viticultural and oenological results, due to the excessive productivity. On the other hand, better results can be obtained in quite fertile soils, but with some pedological limitations which induce a moderate stress. The least fertile soils, e.g. those which have been severely eroded, always produce less than the better preserved ones, but they give very variable oenological depending on the year (Campostrini and Costantini, 1996).

As reference varieties we chose the Sangiovese vine, the basic constituent of the most important wines of the area (Brunello di Montalcino, Chianti, Nobile di Montepulciano) and the widespread and highly rated Moraiolo olive.

How to establish crop "eco-compatibility"

To complete the land evaluation, we had to combine soil suitability with crop "eco-compatibility".

To define crop "eco-compatibility" we cannot avoid considering the development of Italian agricultural systems over the last few decades, and the consequences of the advent and diffusion of the so-called "unattended" and "free time" agriculture (Grillotti Di Giacomo, 1992). The former refers to the medium-large and large farms, which utilise high economic inputs and few workers, who are essentially involved in the productive process. The latter constituted by micro-landowners who occupy the rural spaces of settlements and infrastructures, but gravitate upon the city, and use agriculture as an essentially leisure-time activity.

From the point of view of this rural territory transformation and agricultural social development, what we have is the progressive disappearance of the traditional farmer way of life, with the constant presence of man on the land and his awareness of the importance of soil conservation practices ("coscienza sistematoria"). As a consequence, also in Tuscany, and precisely in those areas where specialised tree cultivation is particularly widespread, we come up against a progressive transformation of the landscapes, where the most traditional ones, namely those characterised by stone or earth terraces ("terrazzamenti") and mixed culture ("coltura mista") are gradually disappearing. The modern model of land use, designed to suit agricultural machinery, has been generally applied, without considering soil properties and in many cases it has impaired soil qualities, e.g. land capability, runoff regulation, soil suitability to produce high quality yields (Costantini, 1992; Gregori *et al.*, 1999; Costantini *et al.*, in press). Thus, the vineyard and olive tree eco-compatibility in the Siena Province implied a cultivation model which not only permitted avoiding excessive soil erosion, but which also preserved all these soil qualities. From a technical point of view, this meant that, during the evaluation process, we had to rate soil and land characteristics and set management and conservation requirements for the two crops according to the desired eco-compatible model.

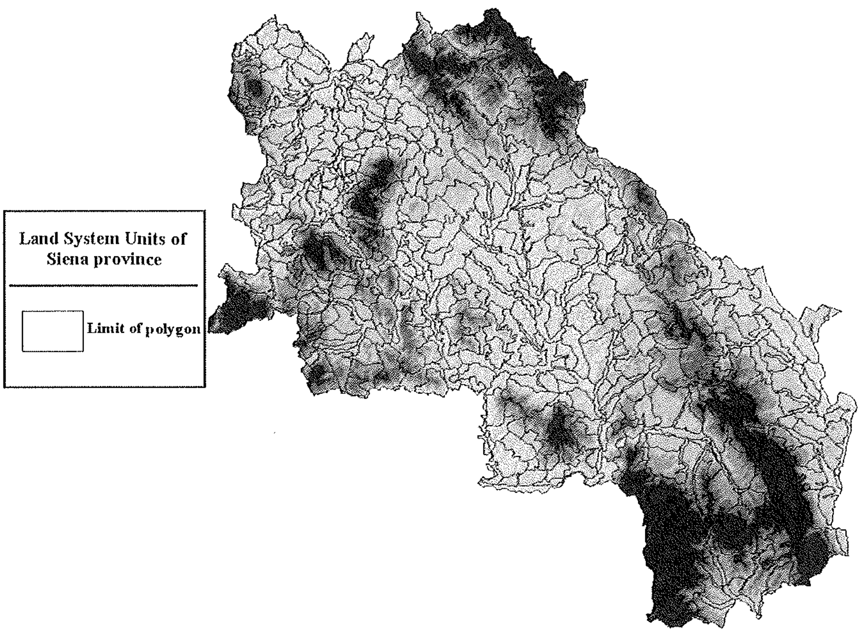
Set multidisciplinary evaluation

The methodological assumptions entail a knowledge of the relationships between soil properties and crop behaviour. This is only possible with a field check of the crop performance in the different soil conditions, as well as by means of an accurate characterisation of the soil functional parameters. For this reason, the research has involved several experts from other sectors: dr. Antonio Cimato of the CNR, Istituto sulla Propagazione delle Specie Legnose of Florence and his collaborators, drs. Simona Caselli, Lucia Tacconi and Ljiljana Petkov, researchers on olive growing, and drs. Paolo Storchi and Egon Egger, belonging to the Istituto Sperimentale per la Viticoltura of Arezzo, researchers on vine growing. They have played an essential role by suggesting crop requirements in terms of soil and climate, as well as by providing data and information from the experimental plots set up inside the study area.

The aspects related to the characterisation of soil hydrological properties and structural stability have been investigated by drs. Sergio Pellegrini and Paolo Bazzoffi of the Istituto Sperimentale per lo Studio e la Difesa del Suolo of Florence, while drs. Rosario Napoli and Lorenzo Gardin, of the same Institute, made a major contribution to the assessment of the architecture of the database (Napoli *et al.*, in press).

Data gathering, quality check and harmonisation

A large number of data were collected from different studies performed by the Istituto Sperimentale per lo Studio e la Difesa del Suolo, the Province of Siena and the Tuscany Region and this data had to be stored in the Soil Information System. The standardisation and quality check of the information was a difficult and time consuming job, because it involved technical standardisation activities (codices of the attributes, geographic reference system), quality check of the information (photointerpretation, soil classification) and soil correlation (database of the soil series). As a reference, we took the codices of the ISSDS soil survey manual and software (Gardin *et al.* 1998).



Generalising soil information

The next step was to assess the methodology for generalising the soil information. Two aspects were taken into account. Firstly how to generalise typological information, i.e. how to group point information and allocate it to a soil typology, and secondly how to spatialise geographic information, i.e. how to extend point information to map units.

The first aspect involved the creation of a catalogue of soil typological units and subunits. Thus, in our database, each soil observation has been referred to one soil unit and subunit, on the basis of soil classification, landscape characteristics and management requirements.

For the second aspect, we chose the Land System project of the Tuscany Region (Toscana. Dip. agricoltura e foreste, 1992), for the compatibility of scale, accessibility of information and because we wanted to test a methodology that could be easily extended to all Tuscany and to the other regions as well.The main advantages of the Land System lie in its open structure, which allows the input of new items and enables us to provide codified geographic information, which makes it easier to link soils with their landscape, and permits a statistical sampling of the soils on a geographic base.

The main geographical components of the Land System methodology are Land Systems, Land Units and Land Elements. Land Elements are the smallest components, which can be recognised by the photointerpretation of a characteristic geology, landform and land use pattern that can be described and codified, but not delineated on a 1:100,000 map. Land Units are recognised and delineated, even by photointerpretation, through the recognition of a characteristic arrangement of Land Elements. Land Systems group Land Units together on a physiographic and geological basis.

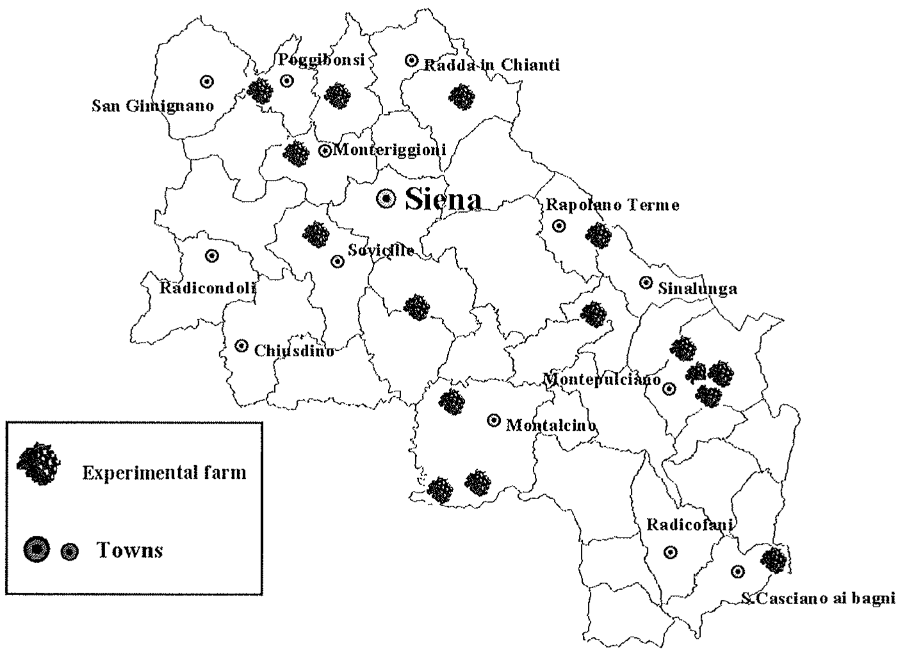
The entire Province of Siena has been covered with the Land System approach, and every soil profile stored has been referred to a Land Element. In this way, each Land Element typology may have a soil attribution, which is constituted by one or more soil subunits.

As our soil database did not have a sufficient number of observations, we decided to carry out another field soil survey on several Land Element typologies, chosen from the ones which seemed most potentially suitable for vines and olive trees, in order to provide all the Land Elements for a soil qualification.

During the field survey, every soil observation followed the recognition of the Land Element typology to which it had to be allocated.

Moreover, each observation recorded was preceded by some auger holes (generally three or four) so that only the one which appeared to be the most representative of the studied typology was taken into consideration. If a Land Element was constituted by different soils, the composition percentage was then recorded in the field file and subsequently in the database. Finally, soil information was transferred from Land Elements to map polygons, in order to produce thematic maps.

To sum up, each single map polygon belongs to one Land Unit and it is constituted by one or more Land Elements, each Land Element is constituted by one or more soil typological subunits, and every soil typological subunit has a set of observations (profiles, auger holes, mini pits) which are similar for soil classification, landscape, management requirements and crop suitability.



The evaluation process

The evaluation process took the territorial data into account first, and then the soil data. Right from the beginning, we excluded all the areas which the Tuscany Region considered to be prone to severe or very severe soil erosion, or to a very severe erosion risk, from the evaluation. We also left out water bodies and frequently flooded areas, quarries, urban settlements and dumps, all wooden lands and elevations higher than 600 m a.s.l.

The suitability of each Land Element was then established on the basis of its soil components, i.e. on each soil typological subunit present.

As the soil subunit contains several point information, we set up two expert systems, one for the vine and the other for the olive, which were able to evaluate each profile of the soil subunit on the basis of its functional parameters. The latter were taken from the previous studies (Costantini, 1987; Costantini e Lizio-Bruno, 1996; Campostrini *et al.*, 1997) and implemented in the software Access through specific algorithms.

A suitability class was attributed to every subunit by applying the expert system to all the observations referring to the soil and by taking the modal value of the resulting population; in some cases, when the population was limited in number, we took the value we thought to be the most representative.

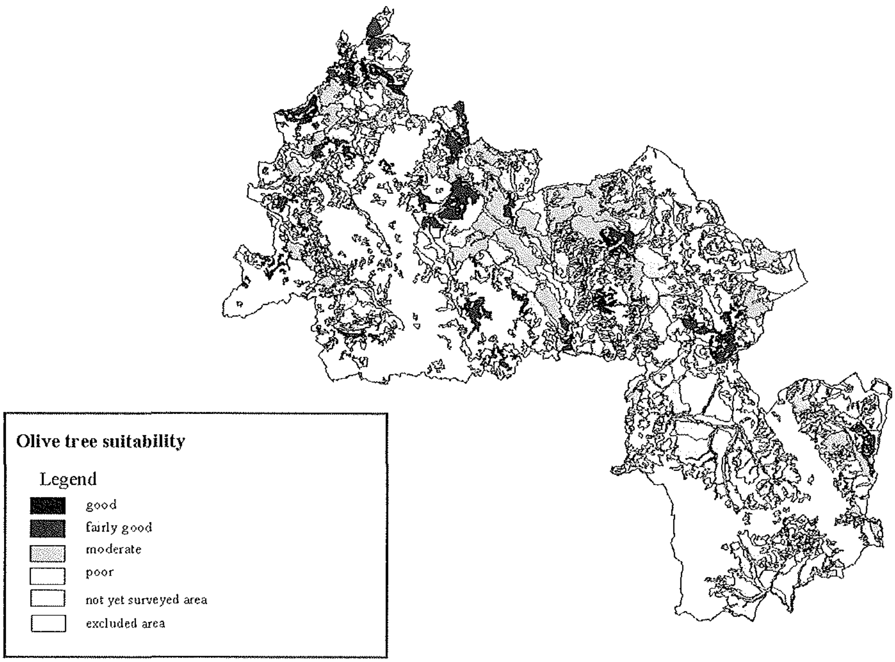
Evaluating Land Evaluation

The Land Evaluation process is the estimation of the response of a given territory to a certain utilisation. Like all classes of estimation, it is always affected by a certain degree of error, deriving from several sources. If it is not always true that the greater the inference the worse the result, nevertheless the degree of inference is seldom expressed explicit. This is a shortcoming of the Land Evaluation, because even if it is well known that political choices are not only based on technical aspects, however the users will maybe give more consideration to these aspects if they saw them as more reliable.

We tried to improve our Land Evaluation in three ways: i) by adding an experimental validation of the estimations, ii) by making the inferences we made in the evaluation process explicit; iii) by giving a geostatistical indicator of the exactness of the estimation.

As to the validation, we planned a series of experimental vine and olive plots to validate the effectiveness of the predictions and to calibrate our expert systems. In the choice of the site, we gave priority to less known soils, i.e. soils where the cause-effect relationships between environmental conditions and crop response were not so well known.

We then worked out three indices regarding the uncertainty of the evaluation, in order to qualify the information provided with each map delineation. The purpose of the indices was not only to warn stakeholders



against an over simplified use of the suitability map, but also to give information that would be useful for further, more detailed, investigations.

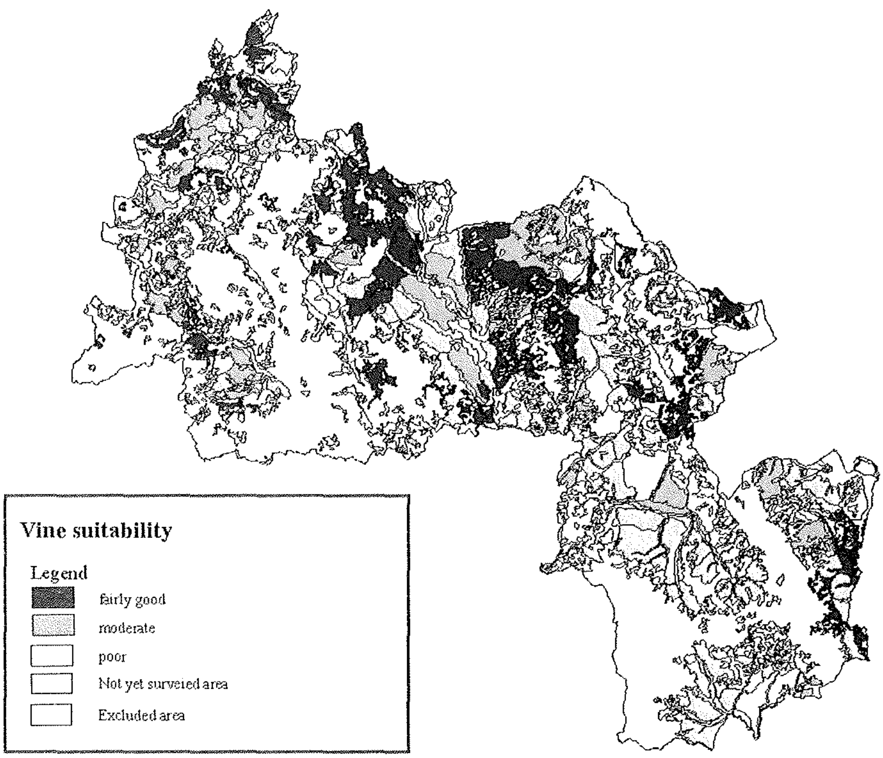
The first item we considered was related to the uncertainty about soil geography. In fact, our "soil paradigm" (Lulli e Costantini, 1992; Hudson, 1992) is based on the assumption that there should be a good agreement between soil geographic pattern, as evaluated by photointerpretation, and soil typology. For this reason we assumed that there should also be a certain degree of correspondence between Land Element and soil typological subunit. The first index therefore regards the "reliability" of this relationship. The index is based on the number and uniformity of observations per Land Element: the higher the number of observations belonging to the same typology found in a certain Land Element, the higher the probability of having the actual presence of the soil on which the evaluation has been made in a given map delineation.

In the showed map, only a first judgement in terms of "good" or "poor" reliability has been reported, but this first estimation can be easily further refined. It is to be highlighted that the areas in which the soil paradigm fails are often those where paleosols, or soil which have been deeply influenced by human activity, are widespread.

The second index refers to the uncertainty of the soil suitability. Actually, we made another "paradigm", i.e. soils with similar functional characters should give similar crop results. Thus, the more similar the soils on which the evaluation is made are to the benchmark soils, i.e. the ones of the experimental plots, the higher the probability of having crop performance akin to the estimated one. The "confidence" index expresses a judgement on this similarity.

The third index refers to the "accuracy" of the cartographic information. It simply states the percentage of each polygon constituted by Land Elements with the estimated aptitude.

Finally, before the systematic survey, we took a set of auger hole observations, to be utilised at the very end of the study, in order to compare the results of the evaluations performed on those sites using the Land Systems approach, with the ones obtained using the point soil characteristics taken. This will permit a geostatistical estimation of the effectiveness of the spatial generalisation methodology.



Initial results

Work is still underway, and the soil survey and most of the processing are not yet complete. However, to meet the specific request of the Provincial Administration, we drew up an initial draft of the two suitability maps at 1:100,000 scale.

In both maps there is a part which has been excluded, due to territorial limitations. This amounts to 57% and 49% of the total study area for vine and olive tree cultivation, respectively. A further 30% of the territory has no soil information at yet. Of the remaining surface, 4.6% and 4.0% is covered by polygons with a "poor" suitability, i.e. a very low probability of finding soils with favourable characteristics for olive and vine cultivation. Another 6.9% for the vine crop, and 12.9% for the olive tree, are constituted by areas with "moderate" suitability, i.e. areas where it is possible to have soils with an acceptable agronomic result, but with limitations in yield, product quality (only wine considered) and with a considerable risk for soil conservation.

The areas where there is a high probability of finding "fairly good" soils cover 33,326 ha (12.0%) for the vine and 12,853 ha (4.6%) for the olive tree. If many of the soils of these areas are planted and cultivated with the ordinary agro-technique, they provide better crop results and less environmental damage than the previous ones. Finally, polygons with dominant soils of "good" suitability have only been found for olive trees at the moment, and they just cover 511 ha (0.2% of the whole territory). It should be pointed out that it was possible to find soils with good suitability, i.e. giving good quantitative and qualitative results and where the crop husbandry is wholly eco-compatible, in other traits of land too, but they were too limited to be mapped at this scale.

Conclusions

The state of the art of the study does not allow us to draw final conclusions, nevertheless we can already supply the Provincial Administration with some information about the possible further diffusion of the two crops.

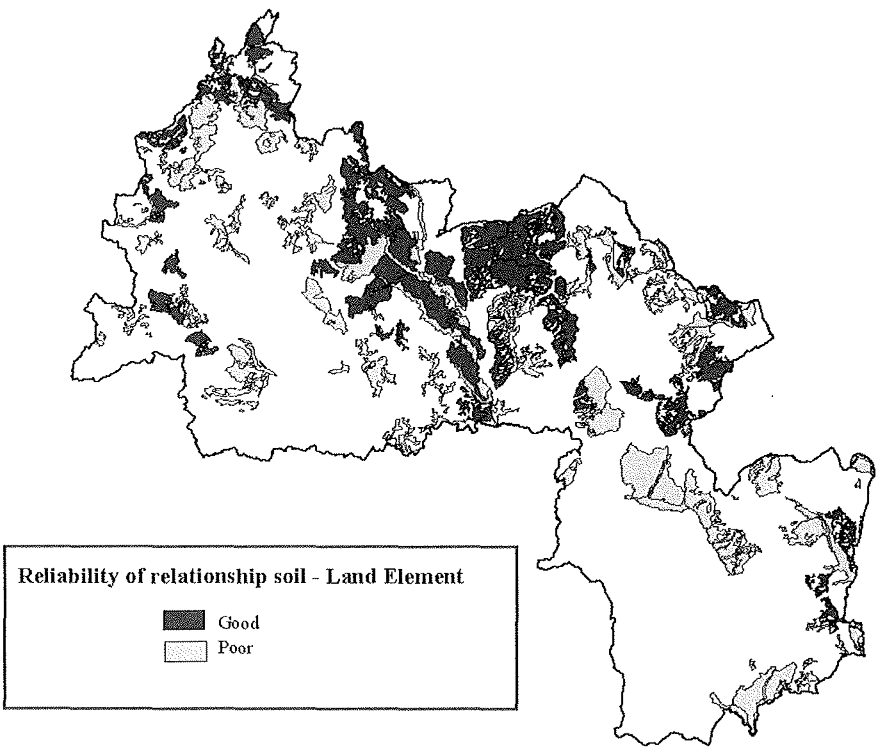
i) All in all, the area of the Province which was studied would appear slightly better suited to vine (18.9% of the study area) than to olive tree growing (17.7%).

ii) Both crops have a good diffusion potentiality, but the more profitable areas for vineyards are often the same as the ones for olive tree plantations, so there is a problem of competition between the two crops.

iii) Some vast areas, such as some belonging to the Siena, Poggibonsi and Colle Val d'Elsa communes, are fairly suitable for wine production. This suitability has already been acknowledged, and farmers can designate the origin of the wine ("Chianti dei Colli Senesi"). However, the same designation is not currently allowed for the same kind of wine produced in other areas, such as the communes of Asciano and Buonconvento, where it is possible to find soils having a similar suitability.

iv) A particularly relevant point is that the areas in which it is possible to combine complete eco-compatibility and top quality production are very limited with the current state of technology. This is due to the fact that the plantation and husbandry model normally used for these specialised crops causes environmental damage which is often not eco-compatible.

v) Therefore, there may be the potential for the expanding of the two crops, but if this is the case, the agro-technique has to be modified and improved, with the adoption of appropriate soil conservation practices.



Acknowledgements

Authors acknowledge the work of the computer technician Mario Finoia of the Istituto Sperimentale per lo Studio e la Difesa del Suolo of Florence, who greatly contributed in the setting up of the Soil Information System.

References

ARCARA P.G., CAMPOSTRINI F., CHERUBINI P., COSTANTINI E.A.C. (1993). Caratteri funzionali del suolo e risposta quantitativa e qualitativa del Vino Nobile di Montepulciano. Atti del convegno "*La ricerca sperimentale in corso per la viticoltura in Toscana*" pp. 1-3.

CAMPOSTRINI F., COSTANTINI E.A.C. (1996). Gestione del vigneto Nobile di Montepulciano per la valorizzazione delle risorse naturali del territorio. In: *Vino Nobile di Montepulciano: zonazione e valorizzazione delle risorse naturali del territorio* (F. Campostrini ed E. Costantini ed.), Regione Toscana, Firenze, pp.110-120.

CAMPOSTRINI F., COSTANTINI E.A.C., MATTIVI F., NICOLINI G. (1997). Effect of "Terroir" on quanti-qualitative paramethers of "Vino Nobile di Montepulciano". 1er colloque international "*Les terroirs viticoles*" Angers, France, INRA, pp. 461-468.

CHAMPAGNOL F. (1997). Caractéristiques édafiques et potentialités qualitatives des terroirs du vignoble languedocien. 1er colloque international "*Les terroirs viticoles*", Angers, France, INRA, pp. 259-263.

COSTANTINI E.A.C. (1987). Cartografia tematica per la valutazione del territorio nell'ambito dei sistemi produttivi. Bacini dei torrenti Vergaia e Borratello: area rappresentativa dell'ambiente di produzione del vino Vernaccia di San Gimignano (Siena). *Ann. Ist. Sper. Studio e Difesa Suolo*, XVIII: 23-74.

COSTANTINI E.A.C. (1992). Study of the relationships between soil suitability for vine cultivation, wine quality and soil erosion through a territorial approach. *Geoökoplus*, III: 1-14.

COSTANTINI E.A.C. (1998). Le analisi fisiche nella definizione della qualità dei suoli per la valutazione del territorio. I Georgofili. Quaderni 1998 III. *La normalizzazione dei metodi di analisi fisica del suolo*. Firenze, pp. 33-57.

COSTANTINI E.A.C. (1999). Soil survey and chemical parameters evaluation in viticultural zoning. Atti del 2° convegno internazionale "*Zonazione viticola*". Ass. Naz. Città del Vino, Siena, pp. 485-492.

COSTANTINI E.A.C., CAMPOSTRINI F. (1996). Vino Nobile di Montepulciano: zonazione e valorizzazione delle risorse naturali del territorio. In: *Vino Nobile di Montepulciano: zonazione e valorizzazione delle risorse naturali del territorio* (F. Campostrini ed E. Costantini ed.). Regione Toscana, Firenze, pp. 9-14.

COSTANTINI E.A.C., CAMPOSTRINI F., ARCARA P.G., CHERUBINI P., STORCHI P., PIERUCCI M. (1996). Soil and climate functional characters for grape ripening and wine quality of "Vino Nobile di Montepulciano". *Acta Hort.* 427 ISHS, pp. 45-55.

COSTANTINI E.A.C., IORI M., GARDIN L., GREGORI E., NAPOLI R. (in press). Paesaggio culturale e qualità dei suoli nella collina toscana. Atti del convegno SISS di Ischia, 1998.

COSTANTINI E.A.C., LIZIO-BRUNO F. (1996). I suoli del comprensorio vitivinicolo di Montepulciano. Le loro caratteristiche, gli ambienti, i caratteri funzionali per la produzione di Vino Nobile di Montepulciano. In: *Vino Nobile di Montepulciano: zonazione e valorizzazione delle risorse naturali del territorio.* (F. Campostrini ed E. Costantini ed.). Regione Toscana, Firenze, pp. 47-74.

COSTANTINI E.A.C., LULLI., CATONE I., PINZAUTI S. (1985). Serie e fasi di suolo sui depositi pliocenici marini del territorio di San Gimignano (Siena). Indagine preliminare per la definizione delle aree idonee alla produzione della Vernaccia D.O.C.G.. *Ann. Ist. Sper. Studio e Difesa Suolo*, XVI: 247-288.

COSTANTINI E.A.C., LULLI L., MIRABELLA A. (1991). First experiences to individuate soils suitable for the production of high quality Vernaccia of San Gimignano. Atti del simposio internazionale: *La gestione del territorio viticolo sulla base delle zone pedoclimatiche e del catasto.* S.Maria della Versa (PV) 29-30 giugno 1987, pp. 125-135.

COSTANTINI E.A.C., LULLI L., PINZAUTI S., CHERUBINI P., SIMONCINI S. (1990). Indagine sui caratteri funzionali del suolo che agiscono sulla qualità del vino. Atti del X° incontro su: *Contributi ed influenza della chimica nella produzione, conservazione e commercializzazione del vino.* Ist. Chimica org. Univer. Siena, pp. 27-40.

FALCETTI M., DE BIASI C., ALDRIGHETTI C., COSTANTINI E.A.C., PINZAUTI S. (1998). *Atlante viticolo. Il contributo del progetto zonazione alla conoscenza, gestione e valorizzazione del vigneto della Cantina La Vis.* Cantina La Vis, Lavis, Trento, pp. 214.

FALCETTI M., DE BIASI C., ALDRIGHETTI C., COSTANTINI E.A.C., PINZAUTI S., BEZZI F. (1999). Progetto di zonazione delle valli di Cembra e dell'Adige. Analisi del comportamento delle varietà Pinot nero in ambiente subalpino. Atti del 2° convegno internazionale "*Zonazione viticola*". Ass. Naz. Città del Vino, Siena, pp. 509-515.

GARDIN L., NAPOLI R., COSTANTINI E.A.C. (1996). Architettura di un database relazionale per un sistema informativo pedologico. *Bollettino SISS*, 8: 165-182.

GARDIN L., SULLI L., NAPOLI R., GREGORI E., COSTANTINI E.A.C. (1998). *Manuale per il rilevamento del suolo.* Ist. Sper. Studio e Difesa Suolo, Firenze, pp.83.

GREGORI E., COSTANTINI E.A.C., GARDIN L., NAPOLI R., SULLI L. (1999). Uso integrato di gis, database e sistemi esperti per la gestione del territorio e la conservazione del suolo. Atti del convegno: *La difesa dalle alluvioni* (M.Falciai e F.Preti ed.). Univ. di Firenze, pp. 453-472.

GRILLOTTI DI GIACOMO M. (1992). *Una geografia per l'agricoltura.* Vol. primo. Reda, Roma, pp. 367

HUDSON B.D. (1992). The Soil Survey as Paradigm-based Science. *Soil Sc. Am. J.*, 56: 836-841.

LEBON E., DUMAS V., MORLAT R. (1997). Influence des facteurs naturels du terroir sur la maturation du raisin en Alsace. 1er colloque international "*Les terroirs viticoles*" Angers, France, INRA, pp. 359-366.

LULLI L., COSTANTINI E.A.C., MIRABELLA A., GIGLIOTTI A., BUCELLI P. (1989). Influenza del suolo sulla qualità della Vernaccia di San Gimignano. *VigneVini*, 1/2: 53-62.

LULLI L., COSTANTINI E.A.C., 1992. L'uso del telerilevamento nello studio dei suoli: possibilità e limiti. In: *L'immagine nel rilievo* (C.Cundari ed.) Cangemi, Roma, pp. 388-389.

LULLI L., LORENZONI P., ARRETINI A. (1980). *Esempi di cartografia tematica e di cartografia derivata (sezione Lucignano - Foglio Firenze) - La carta dei suoli, la loro capacità d'uso, l'attitudine dei suoli all'olivo e al Sangiovese.* C.N.R., P.F. Conservazione del suolo, Firenze, pp. 127.

NAPOLI R., COSTANTINI E.A.C., GARDIN L. (in press). Metodologia di costruzione di un sistema informativo pedologico per le valutazioni agro-ambientali a scala di dettaglio e semi-dettaglio. *Agricoltura Ricerca.*

Toscana. Dip. agricoltura e foreste (1992). *I sistemi territoriali della Comunità montana Alto Mugello Mugello Val di Sieve: studio per una caratterizzazione fisica dell'ambiente mugellano (Progetto sistemi territoriali).* Giunta Regionale Toscana, Firenze, pp.198.

USDA (1993). *Soil Survey Manual.* Handbook 18, USDA, Washington D.C., pp. 438.

VAN LEEUWEN C., SEGUIN G. (1997). Incidence de la nature du sol et du cépage sur la maturation du raisin, à Saint Emilion, en 1995. 1er colloque international "*Les terroirs viticoles*" Angers, France, INRA, pp. 154-157.

Knowing the soil to protect the vulnerable and sensitive areas. The role of the National Thematic Centre for soil and contaminated sites

Renzo Barberis, Pina Nappi e Paola Boschetti

Agenzia Regionale per la Protezione Ambientale del Piemonte
Area Ricerca e Studi – Via della Rocca, 49 – 10123 TORINO

Abstract

The National Thematic Centre on Soil and Contaminated sites has the purpose of defining, collecting and organising useful data and information on soil and contaminated sites, so as to describe them on a national scale, and to direct environment protection and land use national policies according to sustainable development criteria. A correct soil use and the protection of its chemical, physical and biological properties can be easily and strictly related to groundwater pretection and to soil vulnerability and sensitivity concept.

[Key words: soil quality, soil degradation, contaminated sites, soil vulnerability]

Riassunto

Il CTN SSC si propone la definizione, la raccolta e l'organizzazione dei dati e delle informazioni sul suolo e sui siti contaminati che sono ritenuti utili per descrivere questa matrice ambientale a livello nazionale e per indirizzare correttamente le politiche di salvaguardia ambientale ed utilizzo del territorio secondo i criteri dello sviluppo sostenibile. Il corretto utilizzo del suolo e la salvaguardia delle sue qualità chimiche, fisiche e biologiche sono aspetti facilmente e strettamente collegabili con la protezione delle acque sotterranee e con i concetti di vulnerabilità e sensibilità del suolo.

[Parole chiave: qualità del suolo, degradazione del suolo, siti contaminati, vulnerabilità del suolo]

Introduction

Many different definitions of soil exist, according to the particular context, purpose, and point of view from which soil issues are approached. This report, which considers soil, with its multiple functions and impacts, as having a fundamental role in Europe's Environment, requires a broad definition such as the one adopted in 1990 by the Council of Ministers of the Council of Europe:

"Soil is an integral part of the Earth's ecosystems and is situated at the interface between the Earth's surface and the bedrock. It is subdivided into successive horizontal layers with specific physical, chemical and biological characteristics and has different functions. From the standpoint of the history of soil use, and from an ecological and environmental point of view, the concept of soil also embraces porous sedimentary rocks and other permeable materials together with the water which these contain, and the reserves of underground water." (Council of Europe, 1990).

Soil is one of the fundamental systems for agricultural food production, life and the environment, and therefore its functions and quality must be maintained in a sustainable condition. It is particularly pertinent to note that, unlike air and water, soil is relatively static. However, once its quality or functions are impaired, remediation (regeneration) can be extremely difficult and expensive.

Soil is affected in terms of "loss" or "deterioration" of its functions, and several economic sectors play an important part in contributing to soil degradation. Soil losses due to sealing and erosion can be considered in large part as irreversible in relation to the time needed for soil to form or regenerate itself. Soil deterioration due to local and diffuse contamination can be reversed, if adequate measures are taken, such as clean-up and remediation plans.

Since the regeneration of soil through chemical and biological weathering of underlying rock requires a long time, soil must be considered as a finite and non-renewable resource.

The vulnerability concept has been widely applied to groundwater and it refers to the screen effect operated from soil and unsaturated zone. From the soil point of view the problem is more complex: the soil performs different functions (biological, geological, mechanical...), and the impact spectrum that can cause to decrease or loss of these functions is very diversified and wide. Even if we consider just the chemical impacts, we find a diversified series of effects, because the contaminated soil is a source too of two fundamental kinds of pollution: the radical one (with biomass contamination) and the groundwater one (related to contaminant descent) with opposite results: for example, a soil that allows a quick descent of the pollutant can be a little vulnerable regard to vegetable contamination, and a very vulnerable, with regard to the water potential contamination.

The National Thematic Centre on Soil and Contaminated Sites (CTN SSC)

The conceptual model of SINA network (SINANet - Environmental National Informative System Network) is orchestrated on the following main subjects: the National Topic Centres (CTNs), the Regional Focal Points (PFRs), the Regions, the Ministry of the Environment (MAmb), and the Main Reference Institutions (IPRs).

Regional Focal Points (PFRs) are environmental structures appointed by Italian Regions for the regional co-ordination of activities related to the national work program. Such structures are preferably ARPAs (Regional Environment Agencies) or APPAs (Provincial Environment Agencies).

National Topic Centres (CTNs) are institutions or organisations (e.g., ARPAs) that ANPA hires to execute particular tasks on a specific topic, identified in the work program of the National Agency. The structure (and most of the topics) is similar to the European Topic Centres (ETCs) in EEA. The CTNs' activities are planned and elaborated by long-term basic programs. CTNs are centres of excellence on specific themes and play the role of National Reference Centre in the EIONET network for the respective theme. They can also become components of the correspondent ETC of the EIONET network.

Main Reference Institutions (IPRs) are institutions or organisations possessing, at National level, relevant knowledge regarding environmental science, monitoring or modelling.

The SINANet components are shown in the Figure 1.

Main activities of CTN SSC are:

- the inquiry on soil matrix, as derived from directives, conventions, laws and norms at European and National level;
- the choice of useful indices and indicators to describe the soil

matrix;

• the development of guidelines for the construction of these indices and indicators;

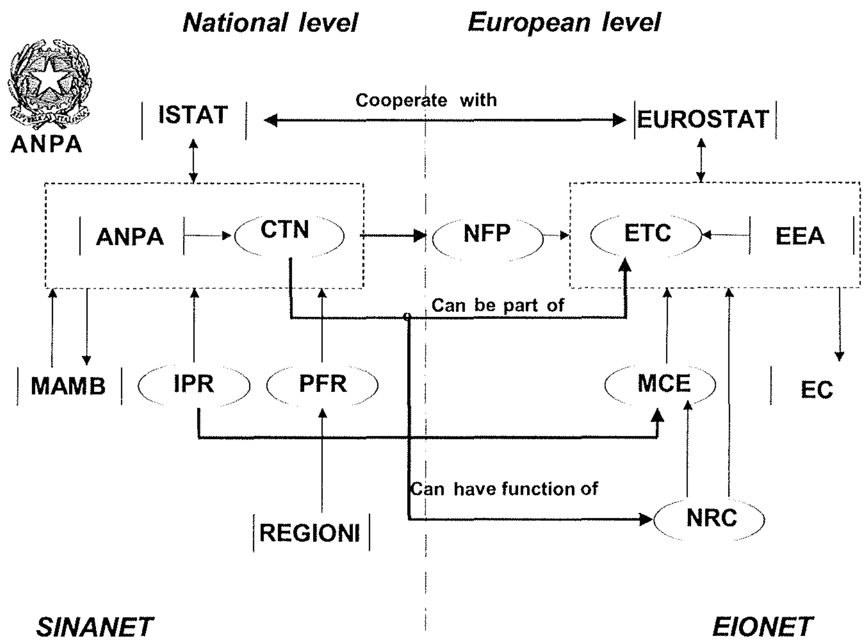
• the census of the sources of necessary data for the formulation of indicators and indices and the acquisition of the available data;

• the validation and the integration of these data.

Besides many other correlated activities, the CTN SSC deals with the standards of environmental quality, and with the technical guides on analysis methods.

Figure 1

The SINANET and EIONET organisation



To face the approach to such a complex matrix like soil, four different themes were defined to represent four particular soil aspects, broadly correlated:

1. *Soil quality* - it concerns soil representation through its intrinsic properties, that best characterise it as a natural matrix able to perform its numerous and well-known functions. Soil quality definitions currently follow

two concepts: the first is the "capacity of the soil to function" and the second is "fitness for use". Capacity of the soil to function refers to inherent properties of soil formation, which include climate, topography, vegetation and parent material. These are measured in soil surveys by characteristic such as texture, slope, structure, and soil colour. Fitness for use is a dynamic concept and relates to soils as influenced by human use and management. This concept is often termed soil health or condition. Measures of soil quality such as land capability and prime farmland are thought to reflect the inherent properties of soil and are based on crop production. Other criteria are needed for other uses of land. The potential capacity of soil to function must be assessed before soil's fitness for use can be measured. Measures of land and soil quality should also account for scale, both spatial and temporal. Scale is important because soil quality change over time and is different by region.

2. *Physical and biological degradation of soil* - it considers the degradation aspects of soil matrix that, mainly during last century, determined or risk to determine both a soil loss and a deterioration of part of its functions, because of phenomena that could be considered irreversible, at least in the human temporal scale. Human activities such as agriculture, industry, urban development and tourism give rise to soil degradation, the extent of which is determinated, among other things, by the physical, chemical and biological properties of the soil. The most severe causes of soil degradation in terms of irreversibility are erosion, desertification and soil pollution.

3. *Diffuse Contamination* - it considers those qualitative soil aspects that could be progressively compromised by soil use, above all by man, in ways that do not respect the natural recovery times, or better such as to jeopardise the soil's biological filter function. The diffuse contamination affects the soil functions most in its buffering, filtering and transforming capacity. Currently the most important problems are soil acidification, mainly due to emissions from vehicles, power stations and other industrial processes. Heavy metals, high concentration of which may occur due to high lithological contents or be due to anthropological influences, causing threats to the food chain. Nutrient surplus is mainly due to overapplication of fertilisers, with high phosphorous and nitrogen contents leading to eutrophication of ground water, waterways or coastal systems through soil erosion or surface run-off.

4. *Local contamination of soil and contaminated sites* - it considers one of the most worrisome phenomena of last decades, the increase of strong soil contamination situations by human activities on well-defined areas, needing reclamation interventions that, often, cannot restore soil functionality. Local contamination is characteristic of regions where intensive in-

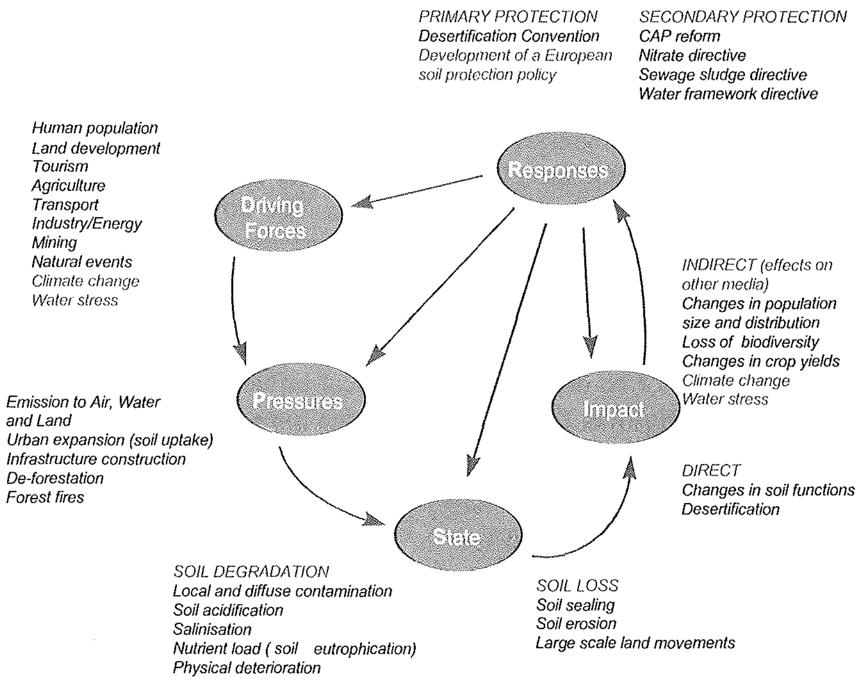
dustrial activities, inadequate waste disposal, mining, military activities or accidental pose a special stress on soil. If the natural soil function of buffering, filtering and transformation are overexploited, a variety of negative environmental impacts arise.

List of relevant indicators

The concept of multiple soil function and competition is crucial in understanding current soil-protection problems and their multiple impact on the environment. Accordingly, a conceptual assessment framework has been developed applying the DPSIR approach adopted by EEA to soil issues (see Figure 2). This approach requires the development of policy relevant indicators on soil issues which describe the interconnections between economic activities and society's behaviour affecting environmental quality.

Figure 2

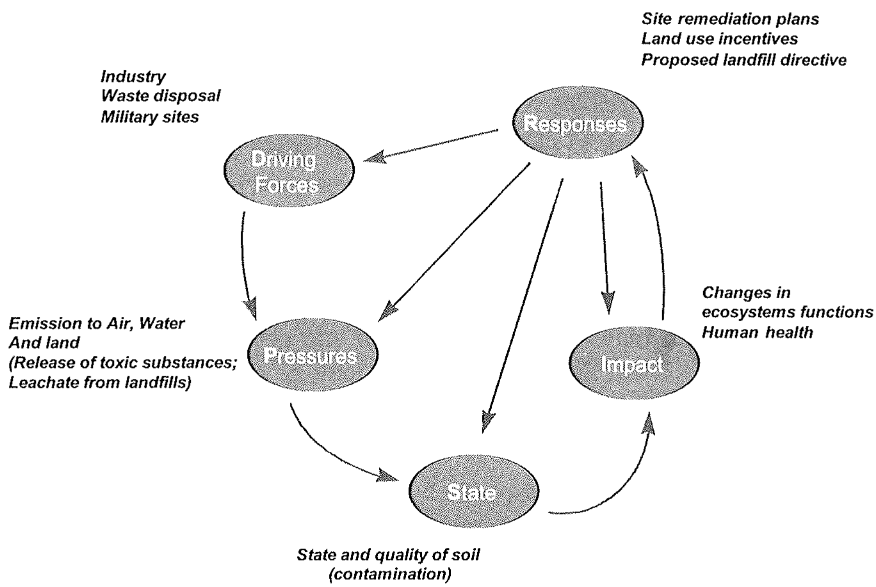
DPSIR assessment framework applied to soil



The problem of soil degradation and soil loss is mainly driven by activities such as intensive agriculture or by increases in human population, which lead to pressures on the environment, e.g. emissions to air/water/land, urban development, or deforestation. As a consequence, these pressures directly affect the state of the environment, for example, in terms of a degradation of the soil quality due to emission of hazardous substances or top soil loss due to erosion. Hence, information about these pressures on the environment are of great importance. Changes in the state may lead to impacts (changes in the population size and distribution, changes in crop yields), finally resulting in society's responses, such as the reform of the Common Agriculture Policy or the UN-CCD Convention. In turn, these responses will again affect each part of the DPSIR assessment framework (Figure 2 and Figure 3).

Figure 3

DPSIR assessment framework applied to contaminated sites



The identification of suitable indicators, representing specific environmental matrix, is based on the utilisation of patterns able to put the exercised pressions in touch with the status of the matrix and with the responses still existing or conjecturable for the future.

In this particular case, the referring pattern is the DPSIR model that describes the issues Driving forces, Pressures, States, Impacts and Responses. This scheme has been developed by the EEA (European Environmental Agency) to a proposed general reference framework and a integrated approach in the reporting processes on the environmental status, conducted at every national or European level. It permits to represent all the elements and relations that characterise any theme or environmental phenomena, putting it in touch with all politics effected on it.

The component of the DPSIR framework can be defined as follows:

- **D**riving Forces. A "driving force" is a need. Example of primary driving forces are the need for shelter, food and water, while examples of secondary driving forces are the need for mobility, entertainment and culture. For an industrial sector a driving force could be profit and to produce at low cost, while for a nation a driving force could be the need to keep unemployment levels low.

- **P**ressures. Driving forces lead to human activities such transportation, and result in meeting a need. These human activities exert pressures on the environment, as a result of production or consumption processes, which can be divided into three main types: excessive use of resources, change in land use and emissions.

- **S**tates. As a result of pressures the state of the environment is affected; that is, the quality of the various environmental compartments in relation to the functions that these compartments fulfil. The state of the soil is thus the combination of the physical, chemical and biological conditions.

- **I**mpacts. The changes in the physical, chemical and biological state of the soil may have environmental and economic impacts on the matrix. In other words changes in the state may be referred to the functioning of the ecosystem, to the human health and to economic and social performance of society.

- **R**esponses. A response by society or policy makers is the result of an undesired impact, and can affect any part of the chain between Driving Forces and Impacts. An example of a response related to pressures is a regulation concerning permissible heavy metal levels in contaminated soils.

The indicator choice to define the soil quality in all its components (chemical, physical and biological) and to define diffused or punctual pressures must be related to an accessory information set; this one must be able to describe, in the best way, the continuous change of principal soil characteristics through relationships between indicators and specific territorial topographic references.

The soil quality indicators may be considered as tools to evaluate the soil status but also as an incentive to start a management change for growers, producers, technicians and politicians. The trend evaluation on soil health status appears fundamental to evaluate the current activities on soil use and to project planning in order to preserve the resource. That means a productive advantage for today and a guarantee for future generations. Indeed a sustainable use, compatible with the own characteristic of the resource and of the environment, is careful and attentive of processes and times for the soil regeneration.

The draft list of the suggested relevant soil indicators can be found in Table 1.

Vulnerability and soil monitoring framework

Among different quality soil indicators, in order to evaluate the area vulnerability, soil erosion needs careful attention, as it removes topsoil, reduces organic matter levels and contributes to the soil structure breakdown. Erosion, as already said before, removes surface soil, which often has the highest biological activity and greatest amount of soil organic matter. This causes a loss in nutrients and often creates a less favourable environment for plant growth.

Also the compaction must be considered carefully, because it decreases pore size, increases the proportion of water filled pore space at field moisture, and decreases soil temperature. This affects the activity of soil organisms by decreasing the rate of the composition of soil organic matter and the subsequent release of nutrients. Soil compaction occurs in response to pressure exerted by field machinery or animals. Compaction decreases infiltration and thus increases runoff and the hazard of water erosion.

The evaluation of heavy metal content connected to industrial activities, vehicular traffic or agricultural activities is important for chemical soil degradation. For example, the soil vineyards always show high copper values.

Another important indicator is the pesticides content that soil can filter, buffer, degrade and stop by means of its own characteristics. The buffering capacity, in particular, is the attitude of soil to immobilise a substance both for root absorption and for vertical migration. When the soil conditions change (land use, acidification...) the buffering capacity may became no more efficient and may start a phenomenon called “chemical time bomb”.

Table 1

The draft list of relevant indicators for soil and contaminated sites

Indicator	DPSIR	Priority
Soil quality		
pH	S	Yes
Cation Exchange Capacity - CEC	S	Yes
Texture	S	Yes
Organic matter	S	Yes
Available P and K	S	
Total heavy metals	S	Yes
As	S	
Cd	S	
Cr	S	
Cu	S	
Hg	S	
Ni	S	
Pb	S	
Zn	S	
Heavy metal availability	S	
Pesticide use	S	
Nutrient-balance of the soil (nutrient input/output)	S	Yes
Nitrate in groundwater	I	Yes
Pesticide in groundwater	I	Yes
Surface water total P	I	
N and P contribution to rivers and seas	I	
Protected areas	R	Yes
Electric conductivity - EC	S	
Physical and biological degradation		
Population density	D	Yes
Urbanisation and infrastructures	D	Yes
Compaction risk - tractors number and power	P	Yes
Wetland loss through drainage	P	Yes
Large land movements in rural areas	P	Yes
Soil organic humic matter	S	
N Mineralization	S	
C e N in microbial biomass	S	
Biomass C/ total organic C	S	
Soil respiration	S	Yes
Respiration/biomass	S	
Microbial biomass	S	
Enzymatic activity	S	
Biodiversity	S/I	
Soil porosity	S	
Hydraulic conductivity	S	
Compaction level and compaction susceptibility	S	
Compacted layers along soil profile	S	
Soil crusts and its forming susceptibility	S	
Soil cracking	S	
Structure loss	S	
Erodibility	S	Yes
Sediments release from rural areas	I/P	Yes
Soil depth	S	Yes
Water retention capacity	S	
Soil slope	S	
Water erosion	S	Yes
Wind erosion	S	Yes
Salinization	S	

Forest fires	S	Yes
Desertification risk	S	Yes
Contamination from diffused fonts		
Farm number and dimensions (size)	D	Yes
Land use	D	Yes
Farm total areas (ST)	D	
Area of agricultural land (SAU)	D	
Relation SAU/ST	D	Yes
Agricultural employment	D	
Agricultural workers income	D	
Working days of agricultural assigned	D	
Use of mineral fertilizers (N, P, K)	P	Yes
Use of organic fertilizers	P	Yes
Heavy metals content in mineral and organic fertilizers	P	
Use of pesticides (herbicides, fungicides and insecticides)	P	Yes
Head of livestock	P	Yes
Manures and sewages production	P	
Heavy metals content in manures and sewages	P	
Area used for intensive arable agriculture	P	Yes
Change in traditional land use practice	P	Yes
Area of agricultural set-aside (Reg.CEE 1094/88)	R	
Farms adhering to environmental measures (Reg.CEE 2078-2080/92)	R	
Farms adhering to biological agriculture (Reg. CEE 2092/91)	R	
Use of quality organic matter in agriculture	R	
Sale of agricultural machines for fertilisers location	R	
Sale of agricultural machines for herbicides location	R	
Land use change	R	
Areas of sustainable farming management systems	R	Yes
Local contamination and contaminated sites		
% of workers in productive activities	D	Yes
Area for productive activities	D	
Potentially contaminated sites	P	Yes
Really contaminated sites	P	Yes
Industrial derelict areas	P	Yes
Waste treatment and disposal	P	
Activities at risk of important accidents	P	Yes
Storage systems outdoor and underground	P	
Number and locations of productive systems for potentially polluting typology	P	
Use of organic and inorganic toxicant from productive activities	P	
Mines	P	Yes
Quarries	P	Yes
Industrial and mixed water releases	P	
Toxic waste production	P	
Scattering areas for sewage releases	P	
Polluting Organic matter in soil	S	
Limitations in land use	S/I	
Major accidents occurred	I	Yes
Accidental spilling events on soil	I	Yes
Heavy metal contents in groundwater	I	
Organic pollutants in groundwater	I	
Inorganic pollutants in groundwater	I	
Regional plans for land reclamation	R	Yes
Reclaimed sites	R	Yes
Companies adhering to environmental management systems (EMAS and/or ISO 14000)	R	Yes
Estimated costs for reclaimed activities	R	Yes

A "chemical time bomb" may be defined as an unforeseen chain of events resulting in the delayed and sudden occurrence of harmful effects due to the mobilisation or chemical transformation of chemicals stored in soil and sediments in response to saturation or alteration in certain environmental conditions.

A soil wich could be defined "few vulnerable" in conventional terms could be, consequently, "highly vulnerable" in terms of chemical time bomb.

This underlines the importance of investigating on soil knowledge to find any possible vulnerability factor that will permit to evaluate the soil deterioration risks about a particular impact and about a particular soil function.

Information already existing on soil is patchy, dissimilar and not always easily available among Regions. This reflects the diverse interests Regions have for their own particular soil problems. Another reason is that information on issues concerning soil are wide-ranging, from mining and waste disposal to land use planning, agriculture and bio-diversity. The information is therefore often held by a variety of organisations/authorities and the distribution of information within each region may be organised quite differently. This makes collation and evaluation of soil concerns especially difficult at the National level.

The development of a national monitoring and assessment framework for soil is needed to combat limitations and gaps of present programmes, information and data on soil at the National level. There is little National and EU legislation that directly addresses the problems of soil degradation and loss, unlike air and water (EEA, 1999a). Several directives are in place (e.g. nitrates, sewage sludge) which protect soil to some degree, but they have been set primarily to protect other environmental compartments (water and the food chain) than soil.

The objectives of this framework will:

• identify priorities of soil problems (agreement on set of indicators)

• identify data availability and data gaps

• provide for integration of relevant information from other environmental compartments and economic influences

• produce information by development of indicators and integrated assessment

• enable a more comprehensive reporting on the state of soils in Italy.

VALUTAZIONE DELLA FUNZIONE PROTETTIVA DEI SUOLI A SUPPORTO DELLE DECISIONI NELLA REGIONE LOMBARDIA

Stefano Brenna, Romano Rasio

ERSAL, The Regional Board for Rural Development in Lombardy
Palazzo Canova Milano 2 - 20090 Segrate (MI)

Il suolo svolge negli ecosistemi terrestri diverse funzioni ecologiche, per le quali vari autori hanno proposto nel tempo definizioni e classificazioni. A fini pratici, è tuttavia possibile identificare ed attribuire alle coperture pedologiche tre principali funzioni:

- Produttiva, correlata con il concetto di fertilità e, quindi, con la capacità dei suoli di sostenere e favorire la produzione di alimenti.
- Protettiva, correlata con la capacità dei suoli di agire da barriera e da filtro nei confronti di potenziali inquinanti e, quindi, di proteggere, in particolare, le risorse idriche.
- Naturalistica, correlata con il ruolo che i suoli hanno nel formare gli habitat naturali, nel proteggere la biodiversità e nel conservare importanti patrimoni culturali per l'umanità.

Il comportamento e le risposte attese dai suoli in relazione alle forme di gestione e di utilizzazione a cui sono sottoposti dipendono dal grado di espressione delle funzioni sopra ricordate.

Le interpretazioni pedologiche consistono così in criteri di valutazione della funzionalità dei suoli che permettono l'elaborazione di supporti conoscitivi, cartografici e metodologici, per l'attuazione delle politiche agricole, ambientali e territoriali in genere.

ERSAL, che da una quindicina di anni ormai conduce programmi finalizzati al rilevamento sistematico dei suoli lombardi a scale diverse e all'allestimento del Sistema Informativo Pedologico regionale, da sempre opera con questa priorità.

Numerose interpretazioni pedologiche sono state conseguentemente elaborate in questo periodo.

Tuttavia, soprattutto negli ultimi anni, si è manifestato un interesse crescente, in particolare, per le interpretazioni riferibili a valutazioni della funzione protettiva dei suoli.

Ciò è da mettere, evidentemente, in relazione con la sempre più vasta sensibilità nella società odierna per i problemi connessi con lo smaltimento dei rifiuti e dei residui di origine civile o generati nei cicli produttivi agricoli ed industriali, emergenze ambientali, queste, che in pianura padana ed in Lombardia sono tra l'altro particolarmente sentite.

D'altra parte, anche nel settore agricolo, le politiche agroambientali comunitarie mirano da alcuni anni ad orientare l'agricoltura verso funzioni non esclusivamente produttive e l'attenzione si è così prioritariamente rivolta alle problematiche connesse con la tutela dell'ambiente e con la riqualificazione del paesaggio rurale.

ERSAL attualmente allestisce routinariamente e mantiene aggiornate quattro interpretazioni pedologiche che trattano della funzione protettiva dei suoli:

- Attitudine dei suoli allo spandimento agronomico dei liquami zootecnici (Fig.1).
- Attitudine dei suoli allo spandimento dei fanghi di depurazione urbana.
- Capacità protettiva dei suoli nei confronti delle acque profonde (Fig.2).
- Capacità protettiva dei suoli nei confronti delle acque superficiali (Fig.3).

Le carte dell'Attitudine dei suoli allo spandimento dei liquami, pubblicate in numerosi rapporti di rilevamento editi dall'ERSAL, sono ormai da tempo un riferimento cartografico e metodologico utilizzato dai tecnici nella redazione dei Piani di Utilizzazione Agronomica (PUA) dei reflui zootecnici previsti dalla L.R. 37/93 che, in Lombardia, è anche strumento di recepimento della Direttiva CEE 676/91 concernente la protezione delle acque dall'inquinamento da nitrati.

Le carte dell'Attitudine dei suoli allo spandimento dei fanghi di depurazione urbana vengono a loro volta proposte, nel quadro normativo di riferimento definito dal D.L.vo 99/92, a supporto della redazione di piani di spandimento che siano realmente integrati all'interno di piani di gestione della fertilità dei suoli, in modo tale da considerare insieme l'uso di fanghi, liquami, acque reflue, compost ed ogni altra sostanza eventualmente distribuita sui terreni agricoli.

Fig.1 - Attitudine dei suoli allo spandimento agronomico dei liquami zootecnici.

Attitudine dei suoli allo spandimento agronomico dei liquami

(inventario pedologico ERSAL a scala 1:250.000)

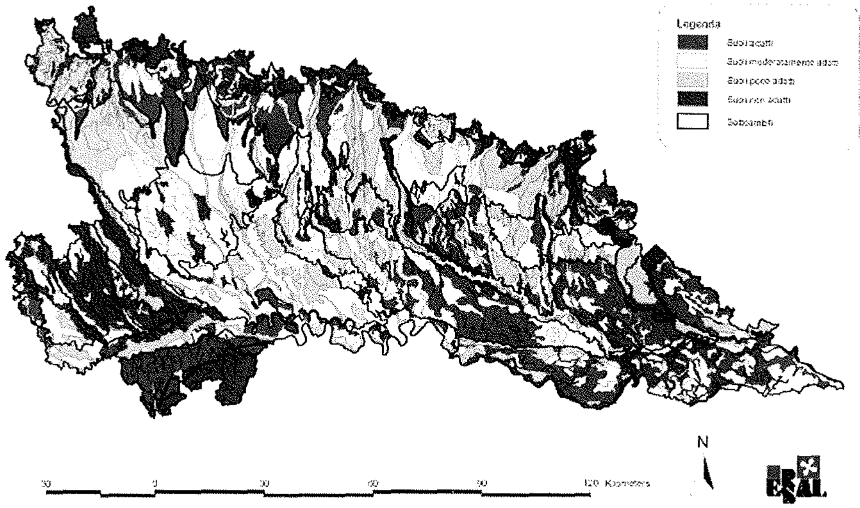


Fig.2 - Capacità protettiva dei suoli nei confronti delle acque profonde.

Capacità protettiva dei suoli nei confronti delle acque profonde

(inventario pedologico ERSAL a scala 1:250.000)

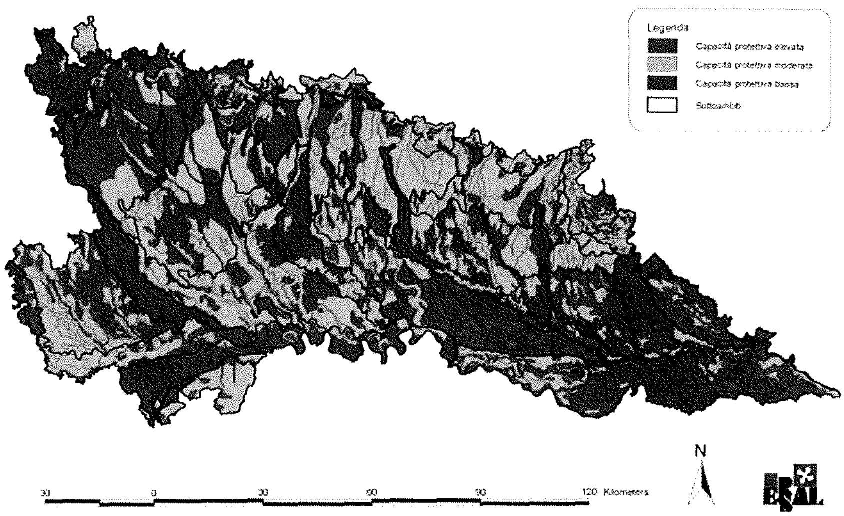
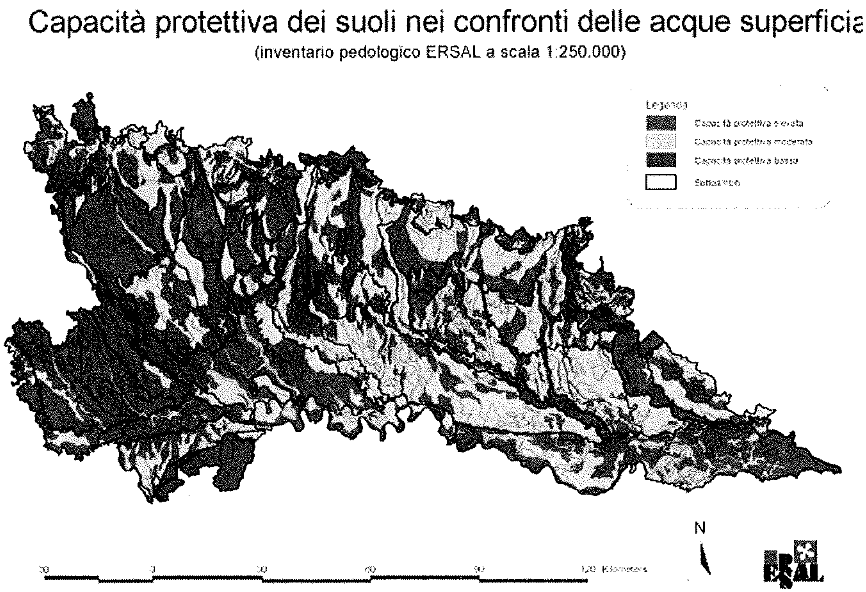


Fig.3 - Capacità protettiva dei suoli nei confronti delle acque superficiali.



La prima concreta applicazione della Capacità Protettiva dei Suoli è invece avvenuta in campo agroambientale; la cartografia, elaborata in quella occasione a piccola scala, venne utilizzata, insieme ad altre informazioni ambientali e socio-economiche, per la zonazione del territorio regionale nel Programma Agroambientale della Lombardia in attuazione del Reg. CEE 2078/92.

A cinque anni di distanza, la stessa interpretazione, ma applicata agli inventari a scala 1:250.000 e 1:50.000, è divenuta uno degli strumenti conoscitivi di riferimento adoperati nella valutazione degli effetti ambientali dell'applicazione del Programma Agroambientale in regione.

La funzione protettiva dei suoli è poi stata considerata nell'ambito delle azioni indirizzate all'analisi del destino ambientale degli antiparassitari previste nel "Piano Regionale di Sorveglianza Igienico-Sanitaria e di Prevenzione dei Rischi da Antiparassitari", che ha, fra gli altri, anche lo scopo di fornire supporti conoscitivi per l'applicazione del D.L.vo 194/95, che a sua volta recepisce la Drettiva CEE 91/414 di regolamentazione dell'uso dei fitofarmaci.

Allo scopo di ottenere, in presenza di un set di dati limitato, prime indicazioni sul potenziale rischio di percolamento di residui di antiparassitari, sono state realizzate, a partire inizialmente da inventari pedologici a scala 1:250.000, una carta della capacità protettiva dei suoli riferita al sistema delle acque sotterranee ed una carta della vulnerabilità degli acquiferi, redatta secondo una metodologia proposta dal Prof. J. Hollis (Cranfield University, UK); il confronto tra le carte ha mostrato un'ampia correlabilità tra le classi evidenziando la generale coerenza interpretativa tra i due metodi.

Nonostante il grande patrimonio conoscitivo sui suoli allestito in Lombardia appaia ancora relativamente poco sfruttato rispetto alle potenzialità informative che contiene, va segnalato che l'interesse e l'attenzione per la risorsa suolo e per le opportunità che la sua conoscenza offre a supporto delle decisioni sono sempre più diffusi.

Un segnale innovativo di grande importanza a questo proposito è contenuto nel recente D.L.vo 152/99 "Testo Unico sulla Tutela delle Acque" che attribuisce a quella che viene definita "capacità di attenuazione del suolo" un significato importante nella individuazione, in integrazione con altri strati informativi, delle zone vulnerabili a nitrati e fitofarmaci.

Per quanto riguarda i nitrati sono in corso di definizione, sia a livello regionale, che di Autorità di Bacino del Po nell'ambito del Piano Stralcio sull'Eutrofizzazione, programmi finalizzati all'elaborazione di cartografie pedologiche interpretative della funzione protettiva dei suoli; per questa azione si prevede un'armonizzazione informativa tra le Regioni del bacino padano in sintonia anche con il progetto di realizzazione della carta pedologica nazionale a scala 1:250.000 (Programmi Interregionali "Agricoltura e Qualità").

ERSAL, inoltre, è da quasi un anno impegnato nella realizzazione di un progetto LIFE-Ambiente cofinanziato dalla Commissione Europea che si propone di allestire un sistema di supporto alle decisioni inerenti l'uso sostenibile dei fitofarmaci in agricoltura, operativo a tre scale diverse tra loro integrate concettualmente ed informativamente. L'obiettivo, a livello regionale, è di sviluppare una metodologia di integrazione di basi informative relative a suolo, clima ed antiparassitari per l'individuazione delle aree vulnerabili nel contesto di quanto stabilito dal D.L.vo 152/99; a livello provinciale, lo scopo è invece di produrre informazioni di maggiore dettaglio a supporto delle decisioni che devono essere prese in merito ad azioni di monitoraggio, controllo ed assistenza tecnica; a livello aziendale, infine, il sistema di supporto alle decisioni consentirà di programmare strategie di difesa delle colture più consapevoli sotto il profilo ambientale.

Infine, nella consapevolezza che i processi decisionali richiedono supporti conoscitivi sempre più approfonditi e documentati, ERSAL sta dando carattere permanente ad attività finalizzate alla caratterizzazione fisica ed idrologica dei suoli e alla selezione ed applicazione di pedofunzioni di trasferimento e modellistica ambientale, in modo tale da rendere sempre più ampie e complete le valutazioni delle funzioni dei suoli e di quella protettiva in particolare.

Aspects of soil sensitivity and vulnerability in Southern and Insular Italy

A. D'Antonio[a], D. Tosco[a], G. Aramini[b], F. Bellino[c], F. Guaitoli[d], G.A. Di Lisa[e], M.G. Matranga[d], G. Loj[f], M. Perciabosco[d], A. Pumo[d], T. Reale[g], L. Viviano[h]

[a] Regione Campania, Assessorato all'Agricoltura, Se.S.I.R.C.A

[b] Regione Calabria, Agenzia Regionale Sviluppo e Servizi in Agricoltura

[c] Regione Puglia, Assessorato all'Agricoltura, Servizi di Sviluppo Agricolo

[d] Regione Sicilia, Assessorato all'Agricoltura

[e] consulente dell'ERSA della Regione Molise

[f] ERSAT-Regione Sardegna, Settore Difesa del Suolo

[g] ERSA del Molise, Laboratorio Cartografico-Pedologico

[h] Regione Basilicata, Agenzia Lucana di Sviluppo e Innovazione in Agricoltura

Introduction

As the soil is the natural superior part of the earth crust, it is an open system with continuous flow of matter and energy. Owing to natural and anthropic factors, it has to undergo to a number of processes which modify the structure and its functional aspect (Tosco and D'Antonio, 1995). Such processes "according to the degree of soil reactivity to the solicitations produced from external agents of perturbation (sensibility), determine some modifications until a point limited by the tendency to reveal degradation either in one or more of its chemical, physical and biological functions (vulnerability)" (Sequi and Vianello, 1998).

Although the soil sensibility is determined by the type, the degree and the speed of interaction between soil and modifying agent, thus introducing the concept of vulnerability, man creates due to his specific demands or necessity the level or the threshold over which a soil is defined as such (Lulli, 1996). In other words, the level of vulnerability is a quantity or a quality of the modifying agent which has nothing to do with the inner aspects of the soil system, rather than a functional tool to human use.

Therefore, only the knowledge of the soil's components and its spatial organization (structural aspect) together with all the processes and the understanding of the inside mechanisms (functional aspect), makes it possible to evaluate its sensibility.

Then in order to define the vulnerability of the soil and its level of degradation, it is necessary to identify the factors which caused the external modifications. For this reason, although with a high degree of generalization, the natural factors ascribable to the catastrophic and prolonged geological processes and those attributable to climatic, chemico-physical, geomorphological, salification and alkalinitation events as well as contamination due to heavy metals have to be identified. The modifications affecting the hydraulic order, the coastal lines, the induced hydrogeological disarrangement, the process of erosion and of chemical-physical lack of balance induced by agronomic activity, organic contamination or caused by heavy metals can be attributed to the anthropic factors (Sequi and Vianello, 1998).

The aim of of the present note is to highlight the aspects of soil sensibility and the vulnerability of some environments of southern and insular Italy which clearly appeared during the last years; the possible scenarios and the main issues that, in the fields of the degradation and the protection of the soil should be taken into account in the next years are also highlighted in this paper.

Factors of soil degradation in the Mediterranean environment

As it is known Southern Italy is characterized by mediterranean climatic conditions: there is a sharp contrast between winter and summer temperatures with rain especially in autumn and winter. Other peculiarities are represented by climats over years with little or huge amounts of rain and by the intensity of rain which can be so elevated that it determines most of the annual precipitation concentrated in only few events.

Insofar Southern Italy as every other Mediterranean environment manifests its specificity for some soil degradation processes: among these we have the water erosion. There are different predisposing and outbreaking factors for the intense erosion process in these environments (Torrent, 1995): *in primis* the erosivity of the rains with intense and brief rainy events, sometimes also extreme during the end of summer periods; then the erodibility of the soil generally poor in organic matter, sometimes connected to morphological aspects as the exposure of the slopes (Panicucci and Maletta, 1987) thus determining a different erosion (the surfaces directed to south are more subjected to erosion than those oriented to north); finally the use and the management of the soil in the agrarian and forest systems not correctly performed.

Another important factor of degradation common to the regions of the south of Italy, as for the whole Mediterranean area is represented by the fires of the pastures, which is used like real agronomic practice (cleaning of the pastures) (Pulina *et al.*, 1997), as well as the areas covered by woods. A part from having an immediate effect on the erosive phenomena, especially in the slopes where the soil losses can also increase 34 times (Talamucci, 1984), the fire has indirect effects that are not less dangerous, as the drastic reduction of organic matter due to pyrolysis with possible production of hydrorepellent substances in the subsurface forming an impermeable film where the water flows away sideways (Talamucci, 1984; Torrent, 1995), thus increasing the vulnerability of the soil to erosion.

Consequently the environments characterized by a "Cs" climat according to Köppen's classification, attributable to the Mediterranean basin, have a sediment removal value equal to 832 ts km^{-2} $year^{-1}$, which is very low compared with that of the tropical environment, but very high if compared with the center and northern Europe environment (Torrent, 1995).

Another important aspect of soil degradation in the Italian south and island areas is represented by salinity, both natural and induced, often due to the use of irrigating waters of low quality. Even in the case of a fresh water irrigation containing 0.5% of salts and considering that for a crop m^3 to 4,000÷5,000 ha^{-1} $year^{-1}$ are supplied, this introduces 2-2.5 ts to the soil ha-1 of salts which, if not washed away with the autumn-winter precipitations result in dangerous gathering.

Despite the well-known relevance of the phenomenon, it is not possible to determine precisely the extension of lands affected by salinity or sodium content in Southern Italy. This is not only due to the increased irrigated areas in these last decades, but also due to major use of low quality, if not anormalous water (Fierotti, 1999). On the other side, the effects of high concentrations of electrolytes on the soil and crops are well known (Aringhieri, 1999; Fierotti, 1999).

Molise region

In Molise it is possible to identify three principal environmental systems: the system of the center-southern Appennine mountains, the one of the high and medium hill (central Molise), the coastal and low hill system lowering towards the Adriatic sea (Reale *et al.*, 1999).

The mountain area (150,000 hectares) is characterized by calcareous lithologies with connecting subsystems, and from the soil vulnerability point of view this aerea is not subjected to any particular phenomena thanks to its geopedological structure, its surfaces used for wood and pasture purposes and thanks to the introduction of the "regional paesisticis laws" which contributed to its integrity.

Degenerative phenomena due to erosion are found to a large extent in the high and medium hill system (230,000 hectares), where formations flinty-marl, complex flyscioidis marly-sandstone and marly-clay are known with the terms of the "Argille Varicolori" which means multicoloured clays (Patacca *et al.*, 1991). The main factors are: the nature of the rocky body (clayey lithotype), the inclination of the slopes, the irregular distribution of the rain during the year, and the wrong agricultural tillage. In particular, the presence of the "multicoloured" or scaly clays, causes unstable soils, and frequently wide landslides also in slopes with weak inclination, as well as erosions forming "calanchi" (badlands, peculiar erosion forms). Such phenomenon hinders especially in the slopes the normal chemico-physical alteration of the minerals and the soil formation process.

Furthermore, the negative choices in "agricultural planning" contributed in meaningful way to increase the degradation. The increase in agricultural mechanization also in slopes contributes naturally to the slipping, causes a bad general situation and all attempts of hydraulic-forest setup (reforestation, bioengineering, etc.), are bound to be unsuccessful as the erosion and hydrogeological disarrangement has already compromised the stability of the slopes. In such areas it should be advised to use "political choices" capable to increase spontaneous or seminatural vegetation in such a way not to expose the clay surfaces to the action of atmospheric agents, and so allowing the re-equilibrium of the rock-soil-vegetation system.

The coastal and low hill system (64,000 hectares), where clayey formations and sandy-conglomerats are alternated to the river terraces of the valleys of the Biferno and Trigno rivers, is always subject to an intensive agricultural use and to great use by the industrial and handicraft sectors.

The problem of sensibility and vulnerability of these soils is also due to erosion. Further to the natural eronsion phenomena, there are problems due to the tillage techniques of some types of soils: in fact, in many areas the presence of calcium carbonate (crusts of pulverulent limestone) which is brought in surface by trenching provokes a notable deterioration of the soil. It can be hypothesized that in such areas, previously to these tillages, the soils belonged to a larger extent to Mollisols with good chemico-physical characteristics without much limitations to use; subsequently the high content in total and active limestone present in the superficial horizons also strongly limitated the choice of cultivation (Cocchiarella *et al.*, 1996; Cocchiarella *et al.*, 1997).

Finally, the excessive use of nitrogen fertilizers and pesticides can sometimes affect the groundwater quality and the rivers at the sea. Here the soil vulnerability must be faced in terms of "chemical pressure", as partly carried out by the Molise region with the application of the EEC Regulation n. 2078/92. The permeability of the soils and the presence of superficial water also makes it necessary to pay greater attention in evaluating the "ability of soil weakening".

Campania region

Climatic and lithologic factors make the soils of Campania between the most fertile of the agricultural regions of the South of Italy: the land profitability - 3,512 euro per hectare of SAU (utilized agricultural surface) - is not only the biggest compared to all the other regions of the Southern Italy, but is even higher than the national average - 2,169 euro per hectare of SAU - (Istituto Nazionale di Economia Agraria, 1999).

In fact, the soils are strongly influenced by the volcanic districts of Campania (Roccamonfina, Flegrei fields, Somma-Vesuvio and the island of Ischia), even if not direcly from vulcanic origin: almost anywhere in Campania one can find soils with more or less evident characteristics and properties inherited from this origin and therefore manifest an elevated natural fertility (Lulli, 1999).

Yet the phenomenon of vulnerability which also the Campania soils is subjected, is not very different from that of the Mediterranean area; in some cases they are even more evidenced. The process of erosion, the decrease of fertility, the increasing phenomena of salinization and the strong urbanization of the coastal band are bound to be the primary cause of degradation.

With reference to the erosion process, the most sensitive environmental system is certainly that of the calcareous reliefs (Appennine mountains) that is not characterized by the soils originated by the underlying calcareous rock but by fallen pyroclastic and volcanoclastic deriving from the volcano districts (D'Antonio *et al.*, 1992; Di Gennaro *et al.*, 1995). This area is supposed to be more than 500,000 hectares of the total Campania territories.

The actual landscape of such environmental system, the southern slopes having xerophilous vegetation with outcrop rock and woody northern slopes, represents the process of irreversible loss of soils in the past, but which it is still in action. Upon termination of the volcanic action, the strong anthropic pressure together with the intense deforestation in Roman and medieval age (also this still continuous) has caused intense erosive phenomena due to the elevated soil erodibility (mostly sandy) and rains (Campania is among the southern regions with major rainfalls). However, the degree of erosion is different according to the exposure of the slopes and consequently diversity of evapotranspiration. Therefore, some soils in the north with more water availability due to morphological and climatic conditions, have a quicker reconstritution (coppice is the used most) compared to the slopes exposed to the south (D'Antonio *et al.*, 1992). In such way the antierosive vegetation effect allows to check more effectively the erosive losses of the northern slopes whereas the southern slopes being more exposed to the rains, progressively lose the original thickness until completely eroded.

Such development is in progress, sometimes also with movements of catastrophic masses, but which is to be considered absolutely common for these lithologies (Del Prete *et al.*, 1998): the soils are at a maximum degree of vulnerability, as the material is almost consumed (unless natural events renew the pyroclastic cover), and therefore have to be managed with all useful conservative practices in order to maintain the erosion at natural levels.

Another point is the vulnerability of the wide plains near to the coast between the volcanic area and the calcareous reliefs which formed deep soils on pyroclastic, volcanoclastic and ignimbrite deposits of about 146,000 hectares (Terribile and Adamo, 1999). Here the urbanization and the intensive agricultural development are the main causes of degradation, although the soils are able to resist to strong anthropic pressures, except for the process of imperviousness due to urban expansion.

Only in the area of Naples, the urbanization and industrialization have diminished from 1961 to 1991 more than half of the SAU (Di Gennaro *et al.*, 1995).The same dramatic effects can be seen in the plains of the Volturno and Sele rivers, especially along the coastal bands of the dunes and the area around which notoriously is an extremely vulnerable environment. Nowadays, such expansion is underlined by big infrastructures (port areas, big commercial centers, highspeed railways) with always more soil "consumers". All this not only determines the irreversible loss of soil, but causes in the areas where the urban ecosystem meets the agricultural system causes a series of negative outcome and, often, degenerative effects like soil pollution from non-agricultural source or abandoning of conservative agricultural farms (Tosco and D'Antonio, 1995).

Finally, the increased agriculture due to exceptional soil fertility and water availability, gained elevated qualitatively and quantitatively production, whose impact on the soil starts nowadays to be evident. The type of agriculture of the coastal plains is intensive, at continuous cycle with high value industrial crops (horticulture and orchards, associated with protected floriculture): In order to obtain this, different technicical means (mineral fertilizers, pesticides and irrigated waters) are employed: data coming from the Campania Region confirm the observations of other authors (Postiglione, 1995), according to which the nitrogen quantities used in some plain areas can reach and overcome the value of 1 ts ha^{-1} $year^{-1}$. The effects of such intense agriculture are frequently seen as a marked organic reduction causing loss of biological activity. This determines further physical degrade, such as superficial crusts due to elevated values of silty soils.

A part from this, there is an increase of the salinization areas, not only along the coastal band but also in the area behind the dunes where the soils contact directly the groundwater manifesting a conductibility of 10 dS m^{-1}; also in the more internal areas there were an elevated number of wells collecting intensively groundwater thus determining an increase of sea water infiltration.

Puglia region

Puglia is one of the regions mostly subjected to the problem of soil alkalization and salinization. Different factors contribute to the phenomenon: the length of the coasts (around 500 kms) which not only determines an large contact surface between the fresh water strata and sea water, but also salt deposition due to winds at the coast; geological formations, mainly calcareous-dolomites along with hollow and undersoil rivers contacting fresh with salty water; the strong use of groundwater for agricultural, industrial and civil purposes determines the front withdrawal towards the inner land; the long periods of drought.

The main areas interested by salinization are the coastal band of the area called "Murgie baresi" and the "Murgie salentine" (about 400,000 hectares).

In the Murgie baresi which are characterized by a moderate high ground, a large coastal plain and various highlands, intense agricultural activity is performed which involves the withdrawal of large quantities of groundwater from wells 700-800 metres deep that means deeper than sea level. In this situation, the front of salty water also proceeded some kilometres towards the hinterland also considerably depending from theraininess during the year. This causes near the coast the withdrawal in many wells of salty water with water conductibility values from 1 to 4 dS m^{-1}.

Due to the moderate high grounds and being surrounded by the sea, in the Murgie salentine the phenomenon is even more stressed.

The soil degradation is evident above all due to the deterioration of the structure caused by deflocculated clay. The most sensitive soils are those deprived of carbonate and with clayey texture. In Puglia these soils are present all over the Murgia's territory: these are commonly denominated "Terre rosse" (Rodoxeralfs according to the Soil Taxonomy). The heavyest damages can be observed in the areas where intensive horticulture is made as well as olive groves, vineyards and orchards. Due to this reason the farmed started to introduce appropriate techniques to correct these soils: deep trenching to increase permeability, soil recarbonating, introduction of organic matter and of sulphur in order to facilitate sodium washing.

In Puglia the attention is draw on serious problems of heavy metal soil pollution following the introduction of the national law 99/92 referring to the clearance of muds deriving from the urban depurators. In many cases the bad application of the quantitative limits foreseen by law and the depurator income of extraurban waste also increased this situation. The surfaces interested by this problem have never been quantified, but it is estimated to be more than 2,000 hectares. The greatest damages have occurred to the olive groves with difficult vegetation and low production which in the most serious cases have led to the death of the plant. Notable damages can also be observed on other arboreal crops (vine, almond tree, cherry and peach tree), while plant panthology has not been notified on the grassy crops. This problem causes particular concern due to the presence of heavy metals on the clayey part.

In the areas of the Alta Murgia barese where the production investments are not high and prevailing crops are wheat and colza, a technique of soil transformation is used which might cause soil losses. This consists in the removal of the rocks and in the grinding of the first 10 cms of the substratum (calcareous rock). In this way the soil is subjected to very serious erosive phenomena as the surface is leveled and without asperity. Following the erosion of the thinnest particles, the soil remains with a very rich calcareous skeleton. In these environments the risk of desertification is extremely elevated in consideration of the slow pedogenesis of the calcareous substrata. According to estimation this phenomenon interests an area of around 100,000 hectares.

Basilicata region

Two are the environmental systems of the Basilicata in which meaningful problems of soil vulnerability have to be underlined: the environment of the Ionian alluvial plain and that of the plio-pleistocenic clays.

The soils of the Ionian alluvial plain area, originated from the enlargement of the local rivers on the coastal deposits following the sea regression in the ancient Quaternary, rappresenting Basilicata's area of most agricultural interest, is affected by the phenomenon of salinization. Even if it is not possible up-to-now to quantify the surface interested by this process, nor to describe its intensity, the strong limitations of its use by the major part of agrarian crops appears. This is due to concurrant factors: the materials deriving from erosion of the sea terraces, due to the nature of its pedogenetic substratum (plio-pleistocenic clays) is rich of soluble salts, particularly of sodium, the infiltration of sea waters and also the soil texture in that area where it results to be finer determines a salt accumulation along the profile. These areas are locally defined as "burnt land" and is spread along the whole coastal band which goes from Policoro to Scanzano right up to Metaponto, and involves for about 1 km a band that stretches to the hinterland (around 4,000 hectares). In the valley bottom of the Cavone river (MT), for instance, soils with values of EC1:2 of 3 dS m^{-1} to 40 cms of depth can be found. Currently the waters for irrigation coming from the local Consortium of Reclamation results of good quality, while only low quantities of irrigated water come from local wells representing danger due to elevated salt content.

An intense constitutional sodium salinity is also typical for the soils of the environment of the plio-pleistocenic clays which interests a surface of around 200,000 hectares in the south-oriental part of the region. Yet the problems of such environment are of other nature: in fact, the "calanchi" formations are very widespread. On the Entisols of the slopes exposed to south and on the rounded off ridges, the warm and dry summers open a net of cracks, whose depth is in relationship with the geographical orientation. This is the reason of the strong surface increase subject to the aggression of summer and autumn rains and, therefore, an elevated erosion: from 2 to 20 mm $year^{-1}$ according to sloping (Viviano and De Donato, 1995). On the other hand vertic inceptisols are found on the surface levels or with weak inclination, where the intensity of the surface demolition process is lower.

Together with the difficulties of the management due to the particular morphological conditions, this area has a marginal productivity; for this reason, according to the recent community directives, the effects of a new and intense alignment towards extensive agriculture and productive forestation (Marano *et al.*, 1996) is felt. For instance, with the EEC Regulation Nr. 2078/92, widespread surfaces are foreseen to a twenty-year withdrawal of the sown lands, as economically more convenient for the farmers compared to the actual use.

Yet, this has caused strong erosive processes channeled-type like in soils which were already extremely vulnerable to such phenomena. In fact, due to the absence of correct soil tillages which interrupt the preferential sliding ways of the water, furrows and rivulets are deepened and turn out to have branches determining a quick loss of the first superficial horizons and the formation of the calanchis afterwards.

The same quoted EEC Regulation adds further "damage" to the environment of the plio-pleistocenic clays. In order to benefit of the community contributions, the farmers try to increase their available surface levelling the "calanchi" areas: this determines not only the loss of their thin soil, furthermore it results useless as such formations have a stability and a high resilience (Ceccanti *et al.*, 1995).

Also the rules that foresee forestation (like EEC Regulation Nr. 2080/92) can determine in these environments phenomena of mass erosion, exactly due to the nature of the substratum. In fact, the introduction of wood, on one side decreases the superficial erosion, on the other side it increases the soil permeability and overloading the slopes during development; these factors can contribute to the instability of the slopes themselves (Viviano and De Donato, 1995).

Calabria region

Until the first half this century, in Calabria the most vulnerable environmental system was represented by the hills and the inner mountains of the Sila, the Serre, and the Aspromonte Mountanis.

The strong anthropic pressure (deforestation, fires, excessive pastures, non conservative crop systems) together with morphological (very steep slopes) and climatic conditions (high erosivity of the rains) which were particularly predisposing, determined a high risk of soil erosion. The progressive degradation of this ecosystems frequently caused alluvial events of extreme severity in the downstream valley areas.

In the fifties a strong action of environmental restoration with the reconstitution of 153,000 hectares of wood in the areas risking great vulnerability started. The results in terms of soil protection and water control were soon visible. From a pedological point of view a clear change in the evolutionary address of the soils happened. From strong degrade situations with slopes to a large extent bared or thin soils characterized by truncate profile to the reforested areas with more stable situations in which the presence of a superficial horizon enriched of organic matter is the distinctive element.

The evident increase of water retention of the soils and the ability to regulate the outflows from the woods has determined in these areas positive outcomes on the superficial and deep hydrology. From the analysis of the chronological sequence of the alluvial events verified in a period from 1920 to 1990 a substantial change emerges. In fact, from an average of six alluvial events per decade occurred since 1920 to 1960, the actual number of events is one per decade in the following period (Aramini *et al.*, 1998).

Especially this last data underlines the important change: as a matter of fact, the alluvial events of the last years have interested almost exclusively the coastal areas. The emergency therefore trasnferred from the inner areas to the environmental system of the silty-clay pliocenic hills of the Ionian slopes, an area of around 250,000 hectares. At the beginning of the sixtees, the social-economic transformations and the politics of supporting the income have stimulated the modelling of the slopes, the strong mechanization and radical change of destination of use: from pasture to the cereal coltivation according to traditional criteria of cultivation leaving the surface of the soil without vegetable coverage especially in the period of the year in which the maximum precipitations happen. In a stressed Mediterranean climate with vulnerable soil typologies not appropriate for productive processes, serious phenomena of disarrangement have been provoked with accelerated water erosion and dislocation.

Soil surveys have underlined average values of organic matter of 0.7% in the epipedon of the soils most exposed to erosive phenomena (particularly serious condition if one considers that this soils are only used to crop since a few decades) compared to 1.6% found in more preserved soils. Such differences evidently reflect that the crops with different growth has now become typical of the landscape. Often one can see soils without productive ability and with serious disarrangement phenomena which are abbandoned. Low production soils (pastures) which are fundamental for the equilibrium of the agrosystem, due to bad management have been transformed in a few years irreversibly in unproductive areas. A part from the direct damages to the agricultural sector this also has consequences to the landscape degradation and damages to the infrastructures.

Sicilia region

In Sicily different processes of soil degradation are found which are typical for the Mediterranean area: among these water erosion is the most important and widespread.

Research conducted by different authors (Dazzi and Raimondi, 1989; Fierotti and Dazzi, 1989) on soil samples of clayey hilly environment (vertic Inceptisols and Vertisols) have been realized with a rain simulator and have underlined that in the Vertisols one rainy event at high intensity (around 70 mms h^{-1}) is enough to reach abundantly the tolerable maximum limit of soil loss (T factor), fixed by Hudson in 12.5 ts ha^{-1} $year^{-1}$. In the case of average (around 46 mms h^{-1}) and low rain intensity (around 28 mms h^{-1}), it has been observed that 6÷8 rainy events are enough to exceed the T factor and our environment is frequently subjected to this situation during the rainy season. These observations on the high soil erodibility of the clayey hilly environment have found further confirmation in the results of a research realized by Dazzi (1993) on the K factor of USLE equation of the Belice basin soils.

The vulnerability of the hilly environmental system is also determined by agriculture: the prevailing use of the soil is represented mostly by simple sown land, based on the alternation wheat-fallow-pasture, and from the wheat-fodder rotation; in this crop system the soil tillages are realized according to irrational techniques (generally by up and down tillage) and are not finalized to limit erosive phenomena. For this reason the agricultural technical assistance service of Regional Administration is working in order to improve arable land management techniques towards more conservative ones.

From the above it results evident how this environmental system, and mainly the hilly landscapes of the Miocene and Pliocene clays (around 700,000 hectares), as well as the landscapes of the Gessoso-solfifera Formation (around 150,000 hectares), presents a high degree of vulnerability and the urgent need for interventions in line with the new directives of community agricultural politics.

Also the environmental system of the plains, and particularly that of the coastlines, shows worrisome signals of soil degradation. In Sicily the plains are 14% of the regional surface, and technically and economically more advanced agriculture is here assembled. In some cases, the intensive use has determined the degradation of the chemico-physical soil characteristics. In the alluvial plains of Gela and Licata and in some alluvial plains of small extension, which are all characterized by the presence of clayey texture soils and by an irrigated agriculture that often uses anomalous waters, particularly as far as the salt content is concerned, soils have been found with irrigation-induced salinity. Currently these areas are investigated by the regional administration with the collaboration of the University of Palermo, with the purpose of checking-up the salty soils which, according to Dazzi and Fierotti (1994), occupy in Sicily a surface of around 250,000 hectares (including the soils that evolved the Gessoso-solfifera Formation), and to provide a correct irrigating and agronomic management of anomalous water, especially the salt pans.

In the landscapes of the calcarenitic marine terraces typical of the coastal bands (around 120,000 hectares) it has been observed, particularly along the south-western band, on soils of elevated agronomic and environmental value (deep alfisols, proper to sustain crops of esteem), phenomenona of strong structural degradation of the superficial layer (hardsetting) that hardens strongly during the phase of soil droughteness and structure collapse in soil saturation conditions. Such phenomena are probably due to the combined effect of particular soil sensibility of repeated superficial tillages with rotating utensils, often perform in optimal conditions determining the pulverization of the epipedon as well as the impoverishment of the organic matter. Often the structural degradation is accompanied by the sealing of the soil surface and consequently its superficial sliding of rain waters. The serious consequence of this complex of erosion phenomena is observed following strong intensity rainy events and that it often determines the removal of the more fertile superficial layers.

Sardegna region

In Sardinia the pasture has represented the destination of prevailing use for all those areas where morphology, climate, vegetable coverage and soil made it unsuitable to any intensive agricultural use (Madrau *et al.*, 1999).

Up to the sixties, these areas almost always situated in high and medium hills, during the summer season were subject to the pasture of the stubbles or were interested by biennial to quadrennial rotations, in which a rest turn anticipated the pasture. In the following decades the migration towards the continent, especially those towards the metropolitan and industrial coastal areas, have brought above all to the abandonning of large agricultural surfaces: From 1961 to 1991, a progressive diminution of the surface occupied by the pastures has been recorded, which lowered from 1,482,629 hectares in 1961 to 789,499 hectares in 1991, espectively from 61.5% to 32.8% of the regional surface.

At the same time, regional politics finalized to the creation and the extension of the direct land ownership was carried out with huge public financings and has favoured the sheep-farming technological level growth, determining the increase of the number of animals burdening on the pastures passing from 3,059,301 in 1961 to 3,923,080 in 1991 with an 28% increase.

The intensive cultivation has conducted to the permanent necessity of fresh forages for most part of the year, particularly of pasture grasses, forcing the breeder to maintain pasture grassy and to extend the surface interested through the classical practices of the ploughing and use of fire; this last matter in particular is the reason why in Sardinia of the areas to pasture are those subjected to the major incidence of surface destroyed by fire (Aru *et al.*, 1998).

The overgrazing, erosion, fire and the improper use of areas to the intensive-type agriculture, consequently brought to desertification in over 50% of the total surface of the pasture areas in Sardinia, above all the hardly alterable substrata (quartzites, granites, dolomies), which do not allow the reconstitution unless in long times of the partially or totally eroded soils (Aru *et al.*, 1998).

It has to be underlined that the failure of many attempts of improvement made in the past, brought the public administration nowadays to dispense financings in the agricultural sector in areas where it is possible to associate the maximum productivity to the maintenance of the soil fertility (Madrau *et al.*, 1999).

Another important aspect is represented by the change of soil characteristics to the prolonged irrigation. This not only refers to the problem of salinization of some soils in the coastal areas (Cagliaritano, Muravera), but also to soil saturation with water as well as to the formation of calcic horizons in areas which originated from calcareous substrata (Aru *et al.*, 1998).

Future scenarios

The analysis made in the whole region has allowed to characterize the large soil systems which have shown more than others to be vulnerable to natural and anthropic factors. This allows us to us elaborate meaningful and quantitative data: in Southern Italy a surface equal to around 3.7 million hectares is currently or potentially interested by evident and various forms of degradation.

According to our opinion, in the middle and long term new problems might occur concerning the soil degradation not only from the use of no traditional human organic sources as solid urban residuals, but also from muds of purification and the use of waste water and low quality waters.

Particularly this last item appears to be an aspect of great importance, due to the peculiarity of the environment, as on one hand the water competition from other parts (industrial and civil) and on the other hand the decreased general water availability. Therefore, agriculture has more need in non-conventional water resources. Following the necessary treatments, their use must be evaluated with attention not only considering the benefits for fertility and with the hope that the soil will work as a dynamic and vital filter (Senesi and Brunetti, 1995), but above all, in the long period the risk of degradation might reduce the quality of the soil. This should be done with a global and integrated approach improving in particular the criteria of soil evaluation with reference to the irrigating goals (Baldaccini, 1999; Fierotti, 1999; Pereira *et al.*, 1995).

With reference to the fires, more research should be conducted on the vegetation-soil relation in order to study the formation of hydrorepellent substances, not only for the effects that determine in forest or pasture areas, but also in agriculture which still uses the practice of controlled fire as mean of agronomic improvement.

It has to be underlined how almost all the surfaces interested by phenomena of soil degradation act on the crop systems, agrarian and forest, directly increasing or possibly solve many problems.

In fact, the new guidelines of community agricultural politics, as expressed by "Agenda 2000", transfer the productivity and social agriculture of the "Trattato di Roma" to a new multifunctional role: to produce more healthy food with increased quality respect to environment and consumer health, and towards the maintenance of the interacting environmental and territorial resources (Istituto Nazionale di Economia Agraria, 1999). Therefore the concept of a sustainable agriculture is being accepted.

In a similar scenery it is difficult to establish whether agriculture in the Mediterranean area countries, above all the non irrigating areas will evolve towards middle input and middle-high output systems or towards lower input and middle-low output: this will depend to a large extent from the economic, environmental and social factors that will have to be resolved at regional and local level (Torrent, 1995).

Agriculture seems to return to more conservative management systems and this will be more feasible in the regions of Southern Italy. Practices that have already been used for many centuries in the long agricultural history in the countries of the Mediterranean basin (around 8,000 years) will come back into fashion, as for instance terrace-cultivation, crop rotations, green manure, organic enrichments together with tillages of recently conception (minimum tillage, no tillage, ripper-tillage, etc.).

Nevertheless, with reference to the above mentioned it is evident that at least for some environments of Southern Italy the application *tout court* of the community rules foreseeing the introduction of extensive crop systems, can be a degrading factor in areas with particular characteristics. Such introduction should be evaluated with attention in order to establish suitability and environmental impacts arising in future. Experimentally this has been shown by by different authors (Landi, 1984; Pagliai and Vignozzi, 1996). For this reason the realization of the 1:250,000 Italian soil map can be useful for the recognition of these soilscapes and consequently be used for the introduction of more proper agricultural politics taking into consideration the environmental and social context and surpass the exclusive logic of the market.

English version by Patricia Benke.

References

ARAMINI G., COLLOCA C., COREA A.M., PAONE R. (1998). Il ruolo della copertura vegetale nella conservazione del suolo e nella tutela degli eventi alluvionali: l'esempio della Regione Calabria. *Genio Rurale*, LXI, 2, 52-55.

ARINGHIERI R. (1999). Salinità e struttura del terreno. *Boll. Soc. It. Scienza del Suolo*, 48 (2), 305-314

ARU A., BALDACCINI P., DESSENA M.A., FANTOLA F., LAI M.R., LODDO S., MADRAU S, PUDDU R., SERRA G., TOMASI D., VACCA A., VACCA S. (1998). La qualità del suolo per un ambiente sostenibile: il caso Sardegna. In Atti del Convegno Annuale SISS "La qualità del suolo per un ambiente sostenibile", Roma, giugno 1997. *Boll. Soc. It. Scienza del Suolo*, 47 (3), 311-334.

BALDACCINI P. (1999). Definizione della risorsa "suolo" ai fini della sensibilità dei territori all'irrigazione. In Atti del Convegno "Un programma di valorizzazione territoriale per il meridione d'Italia", Lagopesole (Potenza), 15-16 luglio 1997. *Boll. Soc. It. Scienza del Suolo*, 48 (1), 149-157.

CECCANTI B., MASCIANDARO G., GARCIA C (1995). Bio-monitoraggio e funzionalità dell'ambiente. *Boll. Soc. It. Scienza del Suolo*, 5, 53-71.

COCCHIARELLA A., PRIMAVERA F., REALE T. (1996). *Carta pedologica in scala di semidettaglio dei comuni di Campomarino e Portocannone*. ERSAM.

COCCHIARELLA A., PRIMAVERA F., REALE T. (1997). La carta pedologica in un'area del Basso Molise. *Genio Rurale*, LX, 9, 31-37.

D'ANTONIO A., INGENITO M.R., MARSEGLIA G., TODERICO L. (1992). *I suoli della media valle del Volturno*. Monografia FORMEZ, Napoli.

DAZZI C. (1993). Erodibility factor-K values of Belice watersheed soils. Workshop su "*Soil erosion in Semi-Arid Mediterranean areaas*", ESSC-CSEI, Taormina.

DAZZI C, FIEROTTI G. (1994). *Problems and management of salt-affected soils in Sicily. Soil salinization and alkalinization in Europe.* Ediz. Misopolines, European Society of Soil Conservation.

DAZZI C., RAIMONDI S. (1989). Prove di erosione con simulatori di pioggia. Nota II: Effetti di diverse intensità di pioggia simulata sulla perdita di suolo e di elementi nutritivi in un Chromic Pelloxeret dell'interno collinare siciliano. *Quaderni di Agronomia* n. 12, Palermo.

DEL PRETE M., GUADAGNO F.M., HAWKINS A.B. (1998). Preliminary report on the landslides of 5 May 1998, Campania, southern Italy. *Bull. Eng. Geol. Env.* 57, 113-119.

DI GENNARO A., D'ANTONIO A., INGENITO M.R., MARSEGLIA G., TERRIBILE F., TODERICO L. (1995). *I suoli della provincia di Napoli.* Studi sul Mezzogiorno, Camera di Commercio di Napoli, CUEN Ed., Napoli.

FIEROTTI G. (1999). I suoli di fronte all'irrigazione con acque anomale. In Atti del Convegno "Un programma di valorizzazione territoriale per il meridione d'Italia", Lagopesole (Potenza), 15-16 luglio 1997. *Boll. Soc. It. Scienza del Suolo*, 48 (1), 179-199.

FIEROTTI G., DAZZI C. (1989). Prove di erosione con simulatori di pioggia. Nota I: Effetti di diverse intensità di pioggia simulata sulla perdita di suolo e di elementi nutritivi in un Typic Xerochrept dell'interno collinare siciliano. *Quaderni di Agronomia* n. 12, Palermo.

Istituto Nazionale di Economia Agraria (1999). *La riforma della PAC in Agenda 2000.* Roma.

LANDI R. (1984). Regimazione idraulico-agraria e conservazione del suolo. Riv. di Agron., 18, 3/4, 147-174.

LULLI L. (1996). Può un suolo essere sensibile? Boll. Ass. It. Pedologi, 2, 11-12.

LULLI L. (1999). Lo studio del vulcanico e la sua importanza per le aree mediterranee. In Atti del Convegno "Un programma di valorizzazione territoriale per il meridione d'Italia", Lagopesole (Potenza), 15-16 luglio 1997. *Boll. Soc. It. Scienza del Suolo*, 48 (1), 121-123.

MADRAU S., LOJ G., BALDACCINI P. (1999). Modello per la valutazione della attitudine al miglioramento dei pascoli dei suoli della Sardegna. Studio realizzato nell'ambito del Programma Operativo Plurifondo (POP), Regolamento 2052/88. Misura 8.5.3. Sottoprogetto "Valorizzazione delle risorse naturali. Censimento dei terreni a pascolo. Valutazione della attitudine al pascolo dei suoli della Sardegna" e del MEDALUS III. Progetto 1 UE contratto n. ENVA-CT95-0115.

Marano B., Coppola E., Lauria M.C., Pariti L., Buondonno C., Buondonno A. (1996). Caratterizzazione dei suoli delle zone calanchive della valle del medio Basento. Indagine preliminare. In Atti del Convegno "Contributi della Scienza del Suolo allo studio e alla difesa dei territori montani e collinari", Milano, 17-19 giugno 1996. *Boll. Soc. It. Scienza del Suolo*, 8, 205-206.

Ministero per le Politiche Agricole (1999). *Rapporto interinale "Programmazione fondi strutturali"*. Roma, marzo 1999.

PAGLIAI M., VIGNOZZI N. (1996). La prevenzione della degradazione del suolo attraverso attività agricole a basso impatto ambientale. In Atti del Convegno "Contributi della Scienza del Suolo allo studio e alla difesa dei territori montani e collinari", Milano, 17-19 giugno 1996. *Boll. Soc. It. Scienza del Suolo*, 8, 207-219.

PANICUCCI M., MALETTA M. (1987). Erodibilità del suolo in relazione all'orientamento dei versanti. Nota II - Rilievi in ambiente meridionale. *Annali Istituto Sperimentale per lo Studio e la Difesa del Suolo*, Firenze XVIII, 145-156.

PATACCA, SCANDONE P., BELLATALLA M., PERILLI N., SANTINI U. (1991). La zona di giunzione tra l'arco appenninico settentrionale e l'arco appenninico meridionale dell'Abruzzo e nel Molise. *Studi Geologici Camerti* vol. spec, (1991/2), CROP 11.

PEREIRA L.S., GILLEY J.R., JENSEN M.E. (eds) (1995). *A Research Agenda on Sustainability of Water Resource Utilization in Agriculture.* NATO Advanced Research Workshop, 21-26 Marzo 1994, Vimeiro, Portogallo.

POSTIGLIONE L. (1993). Agricoltura e problemi ambientali in area mediterranea. In Atti del corso di aggiornamento "*Tecniche per la difesa dall'inquinamento*". Giugno 1993, Ed. BIOS, Cosenza.

PULINA G., D'ANGELO M., DETTORI S., CAREDDA S., ENNE G. (1997). Attività agropastorali e degrado ambientale del bacino del Mediterraneo. *Genio Rurale*, LX, 6, 48-53.

REALE T. (1999). *I suoli delle aree irrigue del Molise*. ERSAM, in stampa.

SENESI N., BRUNETTI G. (1995). Riutilizzo delle acque reflue in agricoltura. Interazioni tra reflui urbani di depurazione e suolo adibito ad uso agricolo. *Boll. Soc. It. Scienza del Suolo*, 5, 27-51.

SEQUI P., VIANELLO G. (1998), a cura di. *Sensibilità e vulnerabilità del suolo*. Franco Angeli Ed., Milano.

TALAMUCCI P. (1984). Cotiche erbose e conservazione del suolo. *Riv. di Agron.*, 1984, 18, 3/4, 182-198.

TORRENT J. (1995). Genesis and properties of the soils in mediterranean regions. Università degli Studi di Napoli Federico II, Dip. di Scienze Chimico-Agrarie, Napoli.

TERRIBILE F, ADAMO P. (eds) (1999). *Cost Action 622 Scientific Program and Guide for the Excussions*. Napoli, 27-30 maggio 1999.

TOSCO D., D'ANTONIO A. (1995). La conservazione del suolo nell'esperienza della Campania. In Atti del Convegno "*L'Informazione pedologica nella prospettiva di un Servizio Reginale del Suolo*", 26-27 ottobre 1994, ERSAL-Regione Lombardia, Milano, 53-59.

VIVIANO L., DE DONATO V. (1995). *I suoli delle aree irrigue del medio Sinni*. Regione Basilicata, Dipartimento Agricoltura e Foreste, Ufficio Sviluppo Agricolo, Potenza.

INTERDISCIPLINARY STUDIES FOR THE MANAGEMENT OF A SENSITIVE NATURAL AREA

Gian Tommaso Scarascia Mugnozza*, Aleandro Tinelli**, Anna Benedetti***

*Accademia delle Scienze detta dei XL

**Segretariato Tenuta Presidenziale di Castelporziano

***Istituto Sperimentale per la Nutrizione delle Piante - Roma

Abstract

Protected areas are of extreme interest in terms of both the evaluation and the intervention on the land regarding soil vulnerability and sensitivity, particularly in consideration of the valuable environmental and landscape characteristics which define such areas.

In particular, studies aimed at monitoring parameters for the identification of soil and environmental quality are being more frequently conducted in protected areas. A set of interdisciplinary studies was planned and carried out over the last five years on the Tenuta Presidenziale di Castelporziano "Reserve" in a Mediterranean environment affected by numerous human activities. The monitoring program took into consideration the relative aspects of atmospheric, soil water, vegetation and fauna quality as well as evaluating the human impact on the estate. In order to implement such a program, an Integrated Informative Territorial System for the archiving of data and the elaboration and subsequent information management was developed. In the course of the project, approximately 900 sites on the estate, both permanent and temporary, were kept under control; specifically, 42 atmospheric samples, 145 fauna samples, 63 hydrogeologic samples, 130 samples related to human impact, 22 samples for SITAC, 91 soil samples, 187 vegetation samples and 162 samples from the swimming pools were collected in total.

Regarding the soil and a definition of its vulnerability and sensitivity, parameters qualifying atmospheric pollution such as heavy metal fall out, acidity, humid and dry atmospheric depositions, as well as strata pollution with excessive nutrients, etc. were determined.

The monitoring program correlated soil vulnerability with wild and domestic animal activity (ungulate grazing, wild boar rooting, farm animal stomping), and identified soil sensitivity in the areas where human activity

had multiple effects (agricultural cultivation, pasture rotation, traffic, air pollution, etc.), both on and off the estate.

In a protected area, soil vulnerability needs to be addressed in terms of forest management so that appropriate soil cover as a function of erosion susceptibility is guaranteed and so that forest renovation is favored.

Integrated elaboration of the obtained data allows for the identification of the most opportune and ecocompatible practices by highlighting those activities suited to naturalistic aspects such as sustainable agriculture, the reuse of biomass residue for fertilization, forestry and proper wild animal management.

The monitoring program on the Reserve of Castelporziano allowed for the identification of general criteria which could also be applicable in other protected areas managed by the Ministry of the Environment and by the Regions.

Several examples of integrated interpretation of results for the evaluation of the impact of air pollution, wild animal pressures as well as reforestation on the soil are provided in the report.

1. Introduction

The number of protected areas in our country which have been established at the national and regional levels is growing steadily in addition to those managed by environmental associations. After the first operation, addressed in Law 394/92, aimed at identifying areas, which thus created protected areas, the knowledge of the natural characteristics of ecosystems was enriched. In addition, the aspects of environmental education have been investigated in depth, resulting in the creation of visitor centers, expository panels and popularized materials. Currently, there is a pressing need to examine the mode of management so that traditional, economic and nature conservation aspects can be pursued, even with regard to European Community indications concerning the rescue of ecosystems in danger.

Furthermore, environmental problems are continuously acquiring a supernational dimension as a function of the problems which could be felt on a global level. Such a possibility was brought up at the Rio Convention (regarding biodiversity rescue, pollution-producing agents and environmental damage) and at the Kyoto Convention, in which the global relationship between carbon dioxide and forests, was emphasized. Thus, it appears more necessary and more opportune than ever to initiate studies which could furnish the most complete data in order to define the state of the environment.

Consequently, even aspects of soil vulnerability and sensitivity in protected areas are characterized by specific study conditions. Herein, we report observations of soil vulnerability made during an interdisciplinary scientific investigation, which contributed to the creation of a well-organized monitoring program for the Reserve of Castelporziano a Mediterranean environment affected by numerous human activities.

The reserve has notable importance at the naturalistic level since the presence of artificial plant formations as well as of natural and semi-natural associations, representative of ancient coastal vegetation (Bruno 1979), can be found on the grounds. In particular, according to the phytosociological scheme proposed by Lucchese and Pignatti (1990), the following units have been distinctly recognized on the Lazial coast: a patch of *Juniperetum macrocarpae-phoeniceae* on mobile dunes, *Holoschoenetalia*, elophytic vegetation in the interdunal swamp depressions, and coastal *Lecceta litoranea* in its various aspects *Asplenio-Quercetum ilicis*. It seems more difficult, however, to assign a meso-hydric forest formation positioned on a limited area of consolidated dune (Lunghini and Quadraccia, 1990). This is ascribable to by Hydrophilans back-dune relict forest wood *Lathyro-Quercetum cerris*, but there are scattered infiltrations of xerophilous elements, probably due to changes previously carried out by humans, as well as areas dominated by *Laurus nobili*, likely relevant to wrecked wood, and by the lauriphile, *Lauro-Carpinetum betuli*.

The estate is on an area of the Lazial coast, whose climate was defined by Blasi (1993) as follows: inferior Mediterranean thermotype, superior-dry/inferior-subhumid ombrotype and xerotic region (thermomediterranean/mesomediterranean sub-region). Summers are hot and are characterized by dry spells which last about 3 months, while winters are characterized by mild conditions. Precipitation is generally low and distributed irregularly over the course of'the year.

Seven different teams (Atmosphere, Hydrogeology, Soil, Vege-tagion, Fauna and Human Impact) collaborated in order to produce an Infor-mative Territorial System (SITAC) to be used in the management of the estate.

2. Studies on soil vulnerability

The necessity to identify simple instruments for the immediate interpretation of data regarding the definition of soil state is well known; while ecologists speak of ecosystem rescue, farmers prefer to consider soil health and quality. For quite some time there has been substantial alarm regarding the effects, both certain and hypothesized, of human activity on the equilibrium of the delicate chemical, physical and biotic complex found in the soil and upon which the homeostasis of the whole planet depends, as we know today.

There are many causes of soil degradation and consequent loss of fertility, but certainly soil pollution due to the introduction of undesired substances has been a problem of fundamental interest in the recent past, not only to researchers but also to individual citizens. Anthropic pressure on the soil generates continuous alarm situations which range from abusive dumping, to poorly managed water purification systems, to chemical product abuse in agriculture to atmospheric pollutant fall-out, etc. There are principally two types of soil pollutants: inorganic and organic. Among the inorganic agents, the heavy metals such as Cu, Ni, Cd, Zn, Cr and Pb are by far the most important. Once these elements are introduced into the soil, they remain there for extremely long periods since their half-lives, although different for each metal, are several thousand years. The organic pollutants are more difficult to evaluate, with respect to the inorganic ones. This is basically due to the fact thousands of different organic compounds exist, some of which are constantly being immersed in the soil ecosystem while others only sporadically. Furthermore, it is necessary to distinguish between "stress agents" and "pollutants". The first cause small or transitory changes, while the second have more persistent and more serious effects. One characteristic of the organic pollutants is that they can be metabolized into carbon dioxide and other inorganic substances which the plants, themselves, are able to use. For this reason, following the fate of such compounds in the soil becomes a complex undertaking.

The microorganisms in direct contact with the soil are, for many reasons, ideal sensors for pollution monitoring since they have mass and their activity can be measured, and thus are useful in evaluating vulnerability in terms of ecosystem functionality. Perhaps the best criteria were proposed by Domsch (1980) and Domsch *et al.* (1983), who emphasized the effects of stress which act naturally on the microbial population of the soil and on their activity. Fluctuations in temperature, water potential, extreme pH values, variations in the soil's physical characteristics due to anthropic pressures, reduced gas exchanges, the decrease in the amount of nutritional elements available, the increase in the number of inhibitors and the fluctuations in the predatory and antagonistic microorganism populations are only a few of the factors which influence the metabolism and the physiology of the microbial populations in the soil ecosystem.

Each of these phenomena, either independently or in synergy, can have marked effects on both the dimension and the activity of the microbial community. According to Domsch (1980) and Domsch *et al.* (1983), whatever alteration, due to natural agents or pollutants, which allows for a complete recovery of the examined microbiological properties within 30 days, can be considered within the norm of natural fluctuations. On the other hand, those alterations which result in a 60-day delay are to be considered tolerable, while those which result in a 90-day delay are truly stress agents.

Nevertheless, no single microbiological parameter can be universally used as an indicator of soil pollution. Considering, however, that the two major activities are carbon and organic nitrogen mineralization and that inhibition of these activities has consequences for the entire ecosystem, it would seem reasonable to direct particular attention to these two biological processes in defining the potential of microbiological properties as indicators of soil health.

Powlson and Jenkinson (1976) affirmed that microbial biomass is a much more sensitive indicator of the changes in soil conditions than the total content of organic matter. Thus, the biomass can serve as a "pre-alarm" for such changes; in fact, other methods are less effective in this sense. However, all studies carried out in the natural environment to determine, for example, the environmental impact of heavy metals, have been hindered by the difficulty in obtaining analytical results comparable to uncontaminated control soils (Brookes 1993).

CRITERIA TO BE EMPLOYED IN THE CHOICE OF MICROBIOLOGICAL PROPERTIES TO BE USED AS SOIL POLLUTION INDICATORS

1. The parameter must be accurately measureable, above all in a wide range of soil types and conditions.
2. It is preferable that the parameter be easily and economically measureable since a large number of samples must be analyzed.
3. The nature of the parameter must allow measurements of the control to be carried out so that the polluting agent's effects can be precisely determined.
4. The parameter must be sensitive enough to detect pollution, and robust enough not to generate false alarms.
5. The parameter must have a general scientific value, based on reliable scientific knowledge.
6. If the reliability of an individual parameter is low, it is preferable to choose two or more independent parameters. in this case, their inter-relations in unpolluted environments must be known.

The soil is an environmental compartment which normally interacts with all other compartments, and by nature is a junction of environmental equilibria. A practical example of the interrelations that can be formed between the soil compartment and the other compartment was provided by the collaboration of the Soil Work Group and the other work groups during the course of the monitoring project. Studies were carried out by researchers in the following areas:

1. **Atmosphere** - soil vulnerability in relation to the critical acidity and heavy metal levels introduced by dry and moist atmospheric depositions.

2. **Hydrogeology** - to evaluate water erosion of the soil.

3. **Vegetation** - correlating erosion, plant associations and soil type, and identifying carbon dioxide absorption capacity.

4. **Fauna** - for wild boar rooting activity.

5. **Anthropic Impact** - for the evaluation of soils in the areas subjected to domesticated animal grazing and forest management and in areas affected by fires.

From this interdisciplinary research carried out on a large base of samples, the following results were obtained.

2.1 Soil and atmosphere

Studies concerning the impact of acidification by dry and wet depositions on the soil were conducted by the Atmosphere Working Group.

Environmental monitoring during the period 1992-1997 allowed for the determination of the excess of wet and dry atmospheric depositions with respect to critical acidity levels. The critical level (CL) is the quantity of a given substance which an environmental compartment can tolerate without experiencing negative effects. The CL commonly expresses a quantity of a polluting substance, related to a surface and a period of time, and is applicable to most atmospheric pollutants. The term excess indicates the excess of atmospheric depositions with respect to the critical levels. The critical levels are subdivided into 5 classes with increasing sensitivity levels: >2000, 1000-2000, 500-1000, 200-500 and 0-200 eq H^+ ha^{-1}. Deposition excesses are divided into 6 classes of increasing excess: <0, 0-200, 200-500, 500-1000, 1000-2000 and >2000 eq H^+ ha^{-1} $year^{-1}$.

Soil quality and its possible state of degradation have prevalently been characterized by chemical parameters (organic matter contents and parameters related to humification used to verify the soil's capacity to preserve biological fertility) and biochemical indicators which allow possible alteration situations to be revealed, since these indicators are sensitive to stresses (percent ratio between microbial biomass carbon and total organic carbon, TOC, which represent an internal control of the soil ecosystem, and specific biomass respiration). The excess acidity of the atmospheric depositions with respect to the critical levels falls within the first three classes, with minor introductions in Mediterranean Scrub and Ilex areas, and major introductions in the Pine area. The Pine area was found to be the most vulnerable, and the metabolism of the soil microorganisms appears to be altered, thereby causing an increase in the ecosystem's vulnerability.

Regarding the heavy metals introduced in the soil due to dry and wet atmospheric depositions, it was observed that the plant cover can present a strong retention power for these pollutants. Nevertheless, the heavy metal concentrations, identified by means of analysis of run-off away water from *Quercus ilex* trees, reveal an enrichment, especially of lead, corresponding to sites adjacent to highly trafficked roads with respect to less exposed sites located deeper within the estate (Table 1).

Table 1

Average heavy metal concentrations in tree wash away water (μg/l).

	Spagnoletta	Ortaccio	Scopone	Capocotta	Fontanile nuovo
Pb	10.2	5.2	7.2	3.4	3.2
Cd	0.02	0.04	0.10	0.04	0.04
Cr	2.8	1.8	1.6	1.0	0.9
Ni	3.7	3.1	3.3	2.0	1.5
Cu	3.2	3.4	3.9	4.8	0.4

Despite the heavy metal content in the analyzed soils, which falls within the range of values commonly measured for Italian soils, it is noteworthy how in the Ortaccio area, bordering Pontina Road, an increase in Ni, Mn and Pb contents was observed from 1995 to 1996 (Pinzari *et al.*, 1998). Careful inspection of the data regarding heavy metal contents reveals that the Ortaccio area is definitely more involved in fall-out phenomena with respect to the Ortaccio soil located in the estate's interior. In particular, the value for lead in the superficial layer (0-20 cm) is at least three times higher

(98.0 ppm) than the value corresponding to the soil layer not bordering the road (32.0 ppm) which served as the control. However, the Spagnoletta and Scopone areas, far from busy roads, do not seem to have alarmingly high lead content values.

From the analysis of the data from the study of the organic matter turnover in the Ortaccio sites, it can be seen that these sites are not particularly lacking in soil organic matter, and the values for humification parameters guarantee a sufficient stabilization of the extractable fractions of organic matter. Nevertheless, in the case of the land bordering the Via Pontina Road, a decrease in humification in the surface layer 0-20 cm was detected; in fact the marked mineralizing activity of the microbial biomass could be ascribable the high levels of heavy metals, which should be able to induce a state of metabolic hyperactivity. Such elements could cause the depletion of soil organic resources over time, as can be seen from the comparison of the organic matter values of the two areas examined.

The multidisciplinary nature of these studies allowed for an evaluation of the ecosystem for which the vulnerability to acidification and soil quality are only one aspect.

2.2 Soil and Hydrology

Erosion is considered another aspect fundamental to soil monitoring and to the identification of soil vulnerability. The investigations carried out in this area allowed us to develop a Thematic Map of Superficial and Water Erosion of the Soil. The parameters considered in this case include:

- rain intensity
- soil morphology and characteristics
- use of the soil
- layout of the land
- management of the area

The erosion classes with soil loss expressed in mm/year are greater in cultivated areas where activities which take advantage of environmental resources have intensified (> 4 mm/year), thus emphasizing a serious loss of the humus surface layer and of organic matter with relative depletion.

The consequent variation in environmental and landscape characteristics approaching degradation indicate aspects linked to soil aridity, which therefore need continual intervention without, however, reducing dangerous erosion levels. In contrast, the thematic map shows that the areas with sufficient forest cover are able to guarantee maximum soil protection (< 0.5 mm/year).

2.3 Soil and Vegetation

For better monitoring, a Map of the Interaction between the Natural Vegetation and Erosion was prepared, superimposing the vegetation thematic map and the erosion thematic map. Soil vulnerability to erosion is shown by means of a "degree of soil erosion in relation to plant associations", delimiting zones of low, medium and high erosion which were identified mainly in cultivated areas and areas used for pasture. The following two areas were marked:

Area 1 (influenced by morphological factors with fragmented vegetation and small landslides);

Area 2 (with erosive phenomena provocated by human activity).

The interrelation of scientific studies between soil chemists, pedologists, geologists, farmers and forest rangers allowed soil vulnerability to be represented in cartographic form so that over time the state of the environment can be monitored, thereby identifying management problems.

In the forest areas, a close correlation between soil quality, practical aspects of the microbiological ecosystem and plant cover was found. This should be kept in particular consideration in the case that reforestation be implemented. The pine forest, artificially planted, has brought about progressive soil acidification and has profoundly altered soil microbiological life. The presence on the estate of older pine forests, all of the same age, facilitate this type of study.

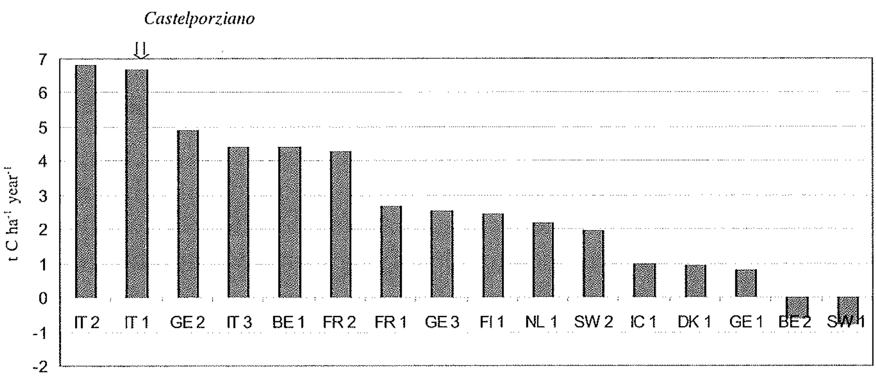
Among the activities which required the synergy of botanists, forest rangers and soil and air chemists, were those concerning the absorption of carbon dioxide by the vegetation, indicated in hectares/year parameters (Seminar Acts III 1996).

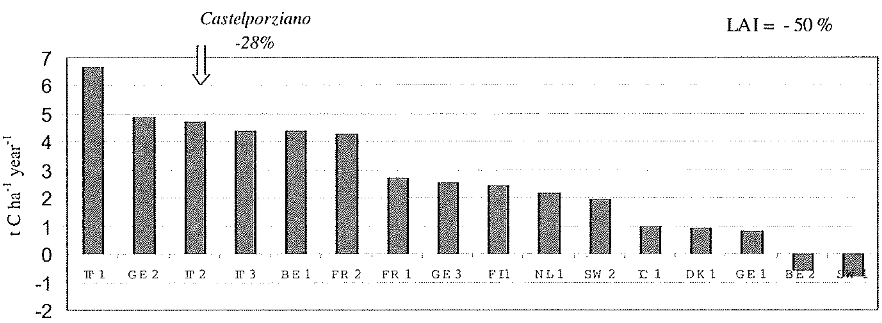
The International Geosphere Biosphere Programme is the result of a global network composed of 65 stations (4 in Italy) representative of various vegetational types. Thus, the Castelporziano site, which is among 16 European forests in Germany, France, Finland, Holland, Sweden, Denmark and Belgium subject to monitoring, was found to be in second place with a value of 7 tons of carbon absorbed/hectare/year.

The revealed maximum absorbency efficiency, with contributes to the globally important mitigation of the greenhouse effect, must be preserved with accurate and targeted forest interventions, so that such a high level can be maintained. Furthermore, it was found by means of a simulation hypothesis that the reduction of tree cover (between 25 and 50%) would produce a loss of absorption efficiency that would cause the estate to fall to third place in the European classification (figure 1).

Figure 1

C absorption in 16 European forests (up); prediction of the loss in efficiency of absorption, caused by a 50% hypothetic reduction in cover of the forest in Castelporziano (down).





2.4 Soil and Fauna

Since Castelporziano is a protected area where populations of numerous species of wild Mediterranean fauna are present, integrated studies between the Soil and Fauna Working Groups were developed in order to evaluate the impact of wild boar (*Sus scrofa majori*) rooting on soil vulnerability. Following an accurate mapping of wild boar movements, from which it was possible to make a specific thematic map, reliefs in the six transepts characterized by high, medium and low rooting, were made. Soil samples were subjected to determinations of physical parameters such as porousness, density, etc. as well as micromorphology using image analysis, chemical parameters (organic matter, organic C and N), biochemical parameters (mineralization kinetics) and microbiological parameters (total biomass dosing, activity etc.). Regarding the physical parameters, it was found that wild boar rooting totally destroys soil structure and favors the rapid decomposition of organic materials. From the thin sections obtained from the undisturbed control soil samples (unaffected by wild animal activity), a system of interconnected pores which allows for good soil aeration and for the accumulation of organic substances, which incorporate and cement quartz granules (sand) is clearly visible. The images obtained from sites affected by wild boar rooting, however, show, especially in the superficial part, that soil degradation is evident since the soil seems disaggregated with totally dissolved quartz granules, and thus the presence of large empty spaces almost entirely absent of organic matter.

Regarding chemical, biochemical and microbiological characteristics, the differing grazing intensities suggest the hypothesis that the different soil organic matter contents could be one of the discriminating elements for the wild boars' choice of rooting area. Nevertheless, from the data obtained it can be seen that rooting can be made responsible, especially where it is particularly intense, for the degradation of organic horizons, rendering them indistinguishable among each other. This seems due to an acceleration in the soil organic matter turnover, which directs metabolic mechanisms of the microbial biomass principally towards the mineralization of organic materials, to the detriment of those slow and complex processes which bring about the formation of soil humic substances. The kinetic trend obtained for the less degraded sites suggests that the microorganisms proceed towards the synthesis of macromolecular organic structures, such as humic substances, which become stratified in the deepest horizon, in contrast to what occurs in the sites largely affected by rooting, which show a more limited capacity to "preserve" matter and energy, and therefore a higher environmental vulnerability at the level of biological fertility. Comparison of the biochemical indices confirms the above stated conclusions by indicating a higher metabolic activity, active biomass being equal. In fact, a higher stability of the microbial community in the soils not subjected to rooting is made apparent (Trinchera *et al.*, 1998).

2.5 Soil and Human Impact

The level of soil sensitivity and vulnerability in numerous areas of the estate was also evaluated in areas where "human activities" are carried out for the utilization of the soil for equine and bovine grazing and for cultivation. In the areas fit for seed, a loss of global fertility was found with respect to the areas of environmental restoration (previously fit for seed).

Erosion in areas reserved for farm animals is a very incisive phenomenon. A comparison between the areas within the estate (natural, for grazing, for degraded grazing and affected by animal stomping) and those beyond the estate's borders was carried out. The preselected parameters in the 33 monitored sites are as follows:

- mechanical resistance to soil cutting (kg/cm^{-2});
- apparent density (g/cm^{-3});
- porousness (%)
- index of soil structure stability.

Examination of the data reveals that problems of structure stability and resistance to cutting are rather high, especially in the degraded grazing areas, in the areas subjected to domestic animal grazing and in the areas outside the estate (Seminar Acts IV 1997) (figure 2). The impact on these soils appears very high, and therefore constant monitoring is necessary for the definition of those interventions which lower "soil stress" levels by removing the causes.

Soil vulnerability was also the object of an investigation regarding the risks of fire (figure 3) by means of a "Fire Map". Areas severely struck by this malicious phenomenon were identified by correlating these data with rainfall and other meteorological factors, with tree and shrub cover and the species' flammability. The major risk areas and the state of the plant cover were indicated by means of a series of transepts, and soil vulnerability was assessed through soil sampling and analysis. The investigations carried out in an area recently affected by fire show a state of soil stress manifested by the soil's incapacity to preserve organic resources and thus biochemical fertility (microbial biomass values severely reduced, and corresponding excessive mineralization activity). In this case, the monitoring forms part of a more complex management picture which sees to specific actions for fire prevention and environmental upgrade intervention to recuperate areas affected by fire.

Figure 2

Soil shear strength: ■ surface - □ 10 cm under the datum

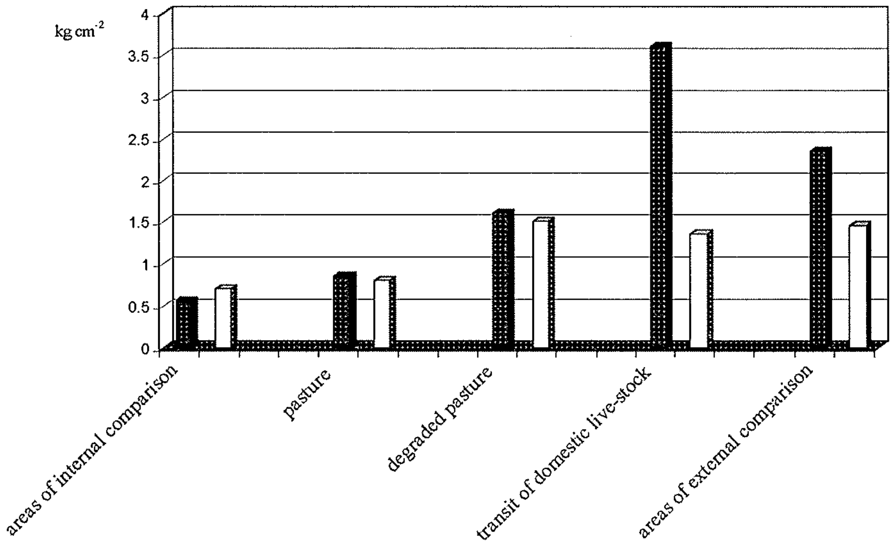
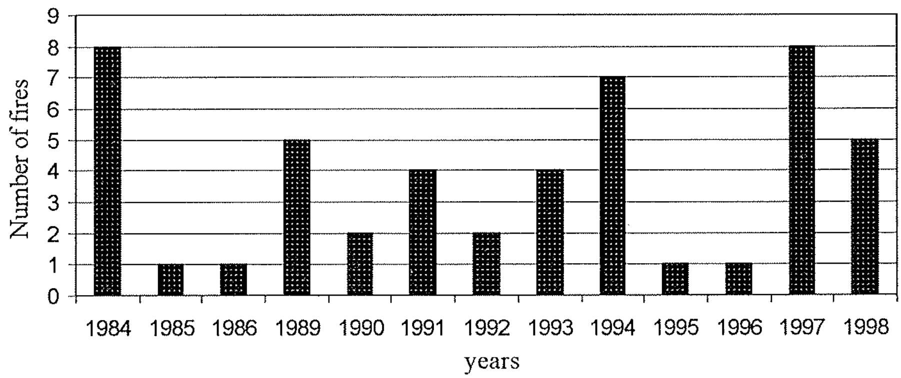


Figure 3

Monitoring of fires in the Park from 1984 to 1998.



3. Conclusions

The ensemble of interdisciplinary studies in a sensitive natural area has furnished general criteria which could be useful in analogous studies in other locations. Using the Monitoring Project for soil, it is possible to identify vulnerable zones on the estate with regard to physical, chemical and biological fertility for different causes.

The study conducted on the effect of wild boar rooting confirms that a large number of animals can compromise soil fertility by accelerating organic matter mineralization processes with subsequent fertility degradation over time. It would be opportune to control organic carbon and soil respiration values by taking samples annually with the aim of standardizing and validating these fertility indices.

The analysis of forest tree run-off in the five permanent sites allowed the impact of atmospheric pollution on the soil and plants to be monitored. The Ortaccio site was found to be highly vulnerable to heavy metal pollution in comparison with other stations on the estate.

Finally, it should be noted that the area of the estate shows intrinsic vulnerability connotations linked to the type of pedologic substrate, to the typically Mediterranean climate, to the site's previous history (having been reclaimed), and currently for its condition as a natural "island" inserted in a highly antropization.

The above considerations declare the absolute need for continued monitoring of soil quality, since the soil is considered an essential part of the environment, aimed at soil preservation and renewal.

References

Seminar Acts III (1996). Progetto di Monitoraggio Ambientale della Tenuta presidenziale di Castelporziano.

Seminar Acts IV (1997). Progetto di Monitoraggio Ambientale della Tenuta presidenziale di Castelporziano.

BLASI C. (1993). Carta del fitoclima del Lazio. Regione Lazio, Roma.

BROOKES P.C. (1993) The potential of microbiological properties as indicators in soil pollution monitoring. Workshop on "Soil Monitoring: Methods for Early Detection and Surveying of Soil Contamination and Degradation", Monte Verita - Switzerland, 18-23 October 1992. It is also published in Soil Monitoring (eds R. Schulin, A. Desaules, R. Webster and B. von Steiger) with permission of Birkhauser Verlag (Publisher).

BRUNO F. (1979). Carta della vegetazione della tenuta di Castelporziano. Istituto di Botanica - Università di Roma. CNR: AQ/1/36 (Programma finalizzato "Promozione della qualità dell'ambiente". Tema di ricerca: "Rilevamento cartografico della vegetazione").

DOMSCH K.H, JAGNOW G, ANDERSON TH (1983). An ecological concept for the assessment of side- effects of agrochemicals on soil micro-organism. *Residue Reviews* 86, 65-105.

DOMSCH K.H. (1980). Interpretation and evaluation of data. In: Recommended tests for assessing the side-effects of pesticides on the soil microflora. *Weed Research Organization Technical Report* N. 59, 6-8.

Legge quadro sulle aree protette 6 dicembre 1991 n. 394. Supplemento ordinario della G.U. n. 292 del 13/12/1991.

LUCCHESE F., S. PIGNATTI (1990). Sguardo sulla vegetazione del Lazio marittimo. *Quaderni Accad. Naz. Lincei*, 264: 5-48.

LUNGHINI D., L. QUADRACCIA (1990). Contributo alla conoscenza degli Ifomiceti demaziacei della tenuta presidenziale di Castelporziano (Micoflora del Lazio III). *Quaderni Accad. Naz. Lincei*, 264: 121-132.

PINZARI F., TRINCHERA A., BENEDETTI A. (1998). Studio della fertilità biologica di un pascolo inquinato da metalli pesanti. Atti XV Convegno Nazionale della Società di Chimica Agraria. Patron Editore, 169-178.

POWLSON D.S., JENKINSON D.S. (1976). The effects of biocidal treatments on metabolism in soil II.Gamma irrdadiation, autoclaving, air-drying and fumigation. *Soil Biol & Biochem* 8,179-188.

TINCHERA A., PINZARI F., BENEDETTI A. (1998). Valutazione dell'impatto del pascolamento di cinghiali (*Sus scrofa* L.) sulla fertilità del suolo in area mediterranea. *Bollettino della Società Italiana della Scienza del Suolo*, n. 2, 295-303.

Acknowledgments

We thank all the researchers who contributed to bringing about the Monitoring Project. Special thanks are due to Prof. Morselli and Dr. Francaviglia for the Atmosphere part, to Dr. Focardi for the Zoogeography part and to Dr. Biondi for the Human Impact part. Finally, we thank all the Work Group researchers for having provided experimental data reported in this study.

THE SINA PROJECT IN THE PADANO-VENETO BASIN

C. Calzolari[1], F. Ungaro[1], E. Busoni[1], N. Filippi[2], M. Guermandi[2], P. Tarocco[2], S. Brenna[3], G. Michelutti[4], M. Piazzi[5], I. Vinci[6]

[1] CNR IGES

[2] Regione Emilia Romagna - Servizio Cartografico e Geologico

[3] E.R.S.A. Lombardia - Servizio del Suolo

[4] E.R.S.A. Friuli Venezia Giulia

[5] I.P.L.A. Torino - Settore Suolo

[6] ARPAV Veneto, Centro Agroambientale

Abstract

Recognising soil a key role as regulator of energy and matter flows within agro-ecosystems has led to a growing concern to assess its quality and vulnerability for different applications and to an increasing use of simulation models as tools for environmental planning and management. These models often require as inputs physico-hydrological soil parameters which can be difficult to retrieve in the ordinary soil surveys. The research in soil data applications has lead in recent years to the definition of pedotransfer functions (PTF) i.e. algorithms capable to link these complex parameters to basic soil properties, such as texture, organic matter content or bulk density. Once the physico-hydrological behaviour of a particular soil is known and the model outputs are obtained, the areal generalisation of the results needs a careful assessment of the spatial variability of the functional soil properties.

In the frame of the three years project *SINA (National Environ-mental Information System) - Soil Mapping in Areas at High Environmental Risk*, funded by the Ministry of Environment and co-ordinated by Regione Emilia Romagna-Ufficio Pedologico-Servizio Cartografico, a research on soil properties capable to influence ground water quality has been carried out. In this research, co-ordinated by CNR IGES with the co-operation of all the Regional Agencies responsible for soil survey and management in the Pianura Padano-Veneta, the coupled models Macro/SoilN have been used, in order to evaluate the soil nitrate leaching potential risk. All the diverse steps in models application have been preceded and supported by a careful data quality assessment, both as model inputs and outputs.

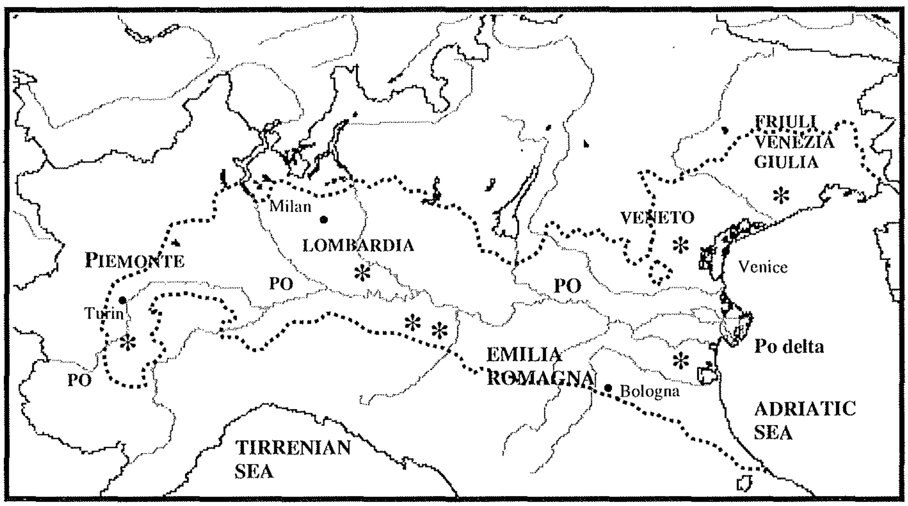
The guiding lines and the objectives of the project are briefly described and discussed, together with some of the preliminary results at different scales.

Introduction

The project "SINA (National Environmental Information System) - Soil Survey in Areas at High Environmental Risk" is an inter-regional research project with relevant practical applications, funded by the Ministry of Environment and co-ordinated by Regione Emilia Romagna-Ufficio Pedologico-Servizio Cartografico. The project involves the Regional Agencies responsible for soil survey and management in the Pianura Padano-Veneta (IPLA-Piemonte, ERSAL-Lombardia, ARPAV-Veneto, ERSA-Friuli Venezia Giulia, Regione Emilia-Romagna) and different research institutions (CNR-IGES, MiPAF-ISA, MiPAF-Experimental Institute for Soil Study and Protection, European Soil Bureau -JRC-Institute for Remote Sensing Applications, ARPA-Servizio Meteorologico Regionale).

Figure 1

SINA project study areas.



The area interested by the project, the Pianura Padano-Veneta, is among the most industrialised and densely populated regions in EU and the main agricultural district of Italy. Here the consequences of an increasing environmental pollution, affecting soil, air and water resources, have been in the recent years particularly severe (figure 1). The estimated nitrogen supply from manure and fertilisers in the Pianura Padano-Veneta ranges from 170 to 250 kg Nha^{-1} per year, the highest in southern European countries (Stanners and Bourdeau, 1995).

The project is divided in the following subprojects: subproject 1: "*Soil Survey and Mapping at 1: 50.000 Scale in pilot zones of Areas at High Environmental Risk*"; subproject 2 "*Models and Pedotransfer Functions for the Evaluation of Soil Qualities Affecting Groundwater Vulnerability*" and subproject 3 "*Soil Data Base*".

This paper briefly describes the guiding lines and the objectives of the subproject 2, together with some of the preliminary results at different scales.

SINA subproject 2 "Models and Pedotransfer Functions for the Evaluation of Soil Qualities Affecting Groundwater Vulnerability": description and aims

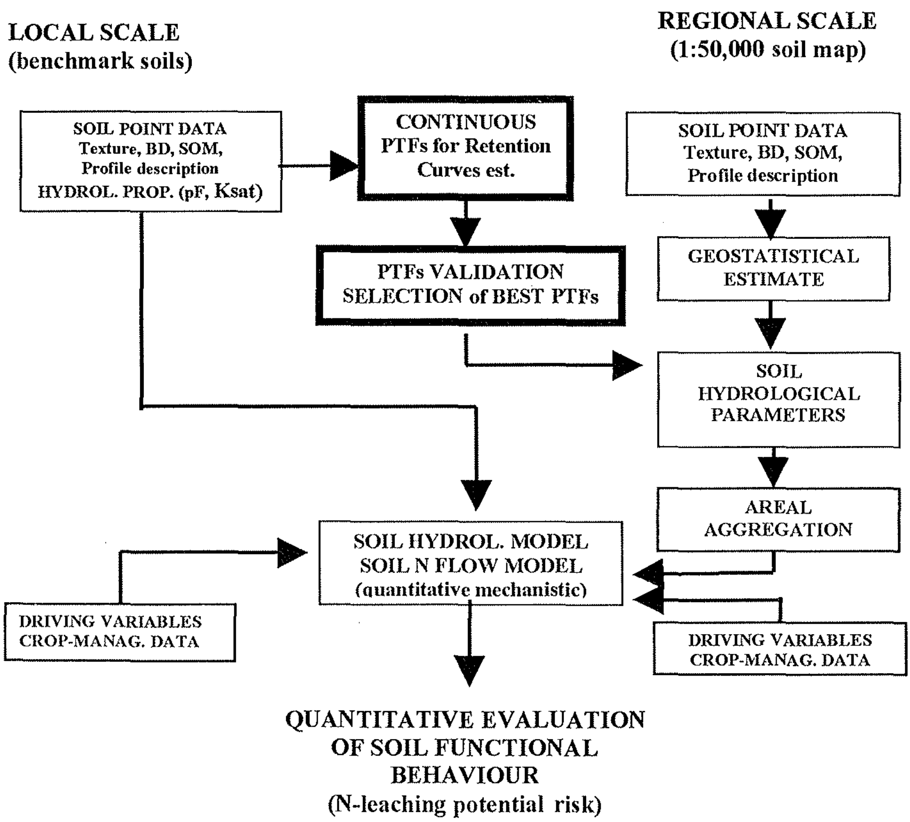
Among the main objectives of the research there are: a) Utilisation of simulation models for water-heat and solute transport in layered and structured soils focused mainly on soil physico-hydrological properties, in order to quantitatively evaluate soils in terms of nitrate leaching potential risk; b) the definition and evaluation of existing pedotransfer functions, selected according to the level of information currently available in the existing soil databases, to derive parameterised soil hydrological properties to be used as input for the simulation models whenever direct measurements of such properties were not available, and for better characterising the hydrological behaviour of representative benchmark soils of the Pianura Padano-Veneta. To achieve these objectives a number of milestones have been defined in the early stage of the programme, and results periodically discussed in workshops.

An initial screening of some of the most diffused models describing water and solute flow in the soil have been done. The different models have been described in terms of input requirements, working scale, both in space and time and functional equations (Ungaro, 1997).

Any quantitative mechanistic model needs a high number of input data, given a certain set of driving variables, i.e. crop and management data. At local scale regional data bases can provide soil data, such as texture, bulk density, organic matter content, soil structure and hydrological properties. Usually these last are measured only for a reduced number of soil profiles: the use of pedotransfer functions (PTF) can provide the missing data (Bouma, 1989). In order to identify the most reliable ones, existing algorithms have been tested during the research on the basis of available measurements from local soils.

Figure 2

Project flow diagram.



For most applications model outputs are usually needed at a scale larger than that at which the model was developed but being models scale specific (Heuvelink and Pebesma, 1999), particular attention must then be paid to how any change of scale is carried out. The same holds for most pedotransfer functions: due to their non-linearity they are scale dependent and then should be used only at the scale at which the data used to derive the PTF were collected. For this reason any transfer of information among different scales and any method for spatially aggregating soil information demands awareness of both measurements scale and model development and validation scale. Beside a traditional aggregating methodology, based on soil mapping units, an experimental procedure was followed capable to take into account all the information existing in the local soil data base and to avoid the application of PTFs, and model, at a wider scale than that at which they were developed and consequently the upscaling of model parameters. The flow process of the research can be summarised in figure 2.

Selection and evaluation of model

According to a set of statements defined with the regional soil services involved in the project, a certain number of N leaching models were evaluated (Ungaro, 1997). The guidelines followed for the model choice were:

1. inputs requirements as compared to inputs availability;
2. importance of soil hydrological properties;
3. flexibility and reliability
4. possible European reference

In order to avoid problems due to scale factor, a punctual model was also to be preferred to a basin scale one, also considering the fact that soil information over the Pianura Padano-Veneta is not homogeneous, neither in quantity nor in quality.

To date a common European reference model does not exist. Some of these models, as DAISY, ANIMO, SWATR, etc, have been evaluated and compared in European Projects (Commission of the European Communities, 1991), while others have been developed within EU research project (i.e. Euro-ACCESS I e II, Loveland *et al.*, 1995) but each of them satisfies the particular exigencies it has been developed for and none of them can be considered an accepted reference.

Recently the MACRO (Jarvis, 1994) model has been considered a possible European reference for simulating hydrological balance with particular reference to pesticides movement and transformations in the soil, and its recent linkage with SOILN model (Eckersten *et al.*, 1996; Larsson *et al.*,

1996) for nitrogen balance in the soil, makes it suitable for a quantitative assessment of nitrogen potential leaching risk in the frame of SINA project.

One of the requirements of the chosen model should be the possibility to run it with soil, crop and climate input data, which can be commonly retrieved by the regional soil services. In the MACRO model necessary input data can be summarised as follows: a) climate data: daily precipitation, maximum and minimum temperature, potential evapotranspiration; b) crop: phenological calendar, roots and canopy characteristics; c) soil: the Brooks and Corey soil water retention parameters (the saturated water content of the micropores, the equivalent pressure head and the pore size distribution index), the saturated hydraulic conductivity of the micropores, the macropore size distribution index, the saturated hydraulic conductivity of the macropores and the *effective diffusion pathlength* (i.e. aggregate half width). In terms of crop growth simulation, the MACRO model is rather simple and consequently the parameters to describe are quite few, as compared to other models. On the other side the model describes in detail the soil medium. Water balance is simulated subdividing soil in two different water flow domains: macro and micro-porosity. Each domain is characterized by its own water content, water potential and hydraulic conductivity, while the lateral exchange between the two domains is largely influenced by the parameter d, the *effective diffusion pathlenght* (mm), which affects the entity of flow in the macro pores domain. The value of the factor d is strictly linked to size, shape and degree of the soil aggregates.

In the micro-pores domain the water flow is described using Richard's equation, deriving water retention curve parameters from Brooks and Corey equation and Mualem equation for hydraulic conductivity K, while in the macropore region water flow is modelled as a kinematic flow.

Selection and evaluation of pedotransfer functions for estimating the water retention curve

There are many approaches to derive functional parameters describing soil water relationship over a range of matric potential or to estimate water contents at specific values of potential, generally referred to as pedotransfer functions (Bouma, 1989). All these models can be divided into two general groups: 1) models based on functional relationships between particle size distributions and pores geometry; 2) models derived from empirical multiple regression equations. A review of pedotransfer functions models is given by Tietje and Tapkenhinrichs (1993).

Table 1. Selected pedotransfer functions.

Reference	Input variables	Output variables	Principles
Saxton *et al.*, 1986	Sand (50 - 2000 μm) % Clay (< 2μm) %	Soil water contents at selected matric potentials	3 equations according to tension range; not valid for all textural ranges
Rawls and Brakensiek, 1985	Sand (50 - 2000 μm) % (valid range 5-70%) Clay (< 2 μm) % (valid range 5-60 %) Bulk density (g cm^{-3})	van Genuchten equation parameters θ_r, θ_s, α and n	4 regression equations; not valid for all textural ranges; van Genuchten m = 1-1/n
Rawls *et al.* [a], 1982 (model 1)	Sand (50 - 2000 μm) % Clay (< 2μm) % Bulk density (g cm^{-3}) Organic matter %	Soil water contents at 12 fixed values of soil water potential	12 regression equations valid for all textures
Scheinost [b] *et al.*, 1997	Gravel (2-63 μm) % Sand (50/63-2000 μm) % Silt (2-50/63 μm) % Clay (2-0.04 μm) % Bulk density (g cm^{-3}) Organic carbon (g g^{-1})	van Genuchten equation parameters θ_r, θ_s, α and n	4 regression equations valid for all textures; van Genuchten m = 1
Vereecken *et al.*, 1989	Sand (50 - 2000 μm) % Silt (2 -50 μm) % Clay (< 2 μm) % Bulk density (g cm^{-3}) Organic carbon (g g^{-1})	van Genuchten equation parameters θ_r, θ_s, α and n	4 regression equations valid for all textures; van Genuchten m = 1
Jarvis *et al.*, 1997	Sand (63 - 2000 μm) % Silt (2 -63 μm) % Clay (< 2 μm) % Bulk density (g cm^{-3}) Organic carbon (g g^{-1})	Brooks and Corey equation parameters θ_s, λ and ψ_b	3 regression equations valid for all textures; Brooks and Corey $\theta_r = 0$
Rawls *et al.* [a], 1982 (model 2 and model 3)	Sand (50 - 2000 μm) % Clay (< 2 μm) % Bulk density (g cm^{-3}) Organic matter % Water content at -33 k Pa and at -33 and -1500 kPa	Soil water contents at 12 fixed values of soil water potential	12 regression equations valid for all textures

[a] Rawls *et al.* (1982) pedotransfer functions are referred to as model 1, model 2 and model 3, depending on the input variables required for the estimation of the soil water content in correspondence of the following values of matric potential (kPa): -4, -7, -10, -20, -33, -60, -100, -200, -400, -700, -1000 and -1500. For model 1 the input variables requested are: sand, silt, clay, organic carbon and bulk density; for model 2 and model 3 the inputs are the same with the addiction of the water content at -33 kPa tension, and of the water content at -33 and -1500 kPa respectively.

[b] The number of textural fractions required to derive the particle size distribution parameters necessary as input for the PTF of Scheinost *et al.* (1997) depend on data availability; in this study three (sand 50 -2000 μm, silt 2-50 μm and clay 2-0.04 μm) and five (coarse sand 100-2000 μm, fine sand 50-100 μm , coarse silt 50-20 μm, fine silt 2-20 μm and clay 2-0.04 μm) fractions were used as input; the validation results are referred to as Scheinost 3 and Scheinost 5 respectively.

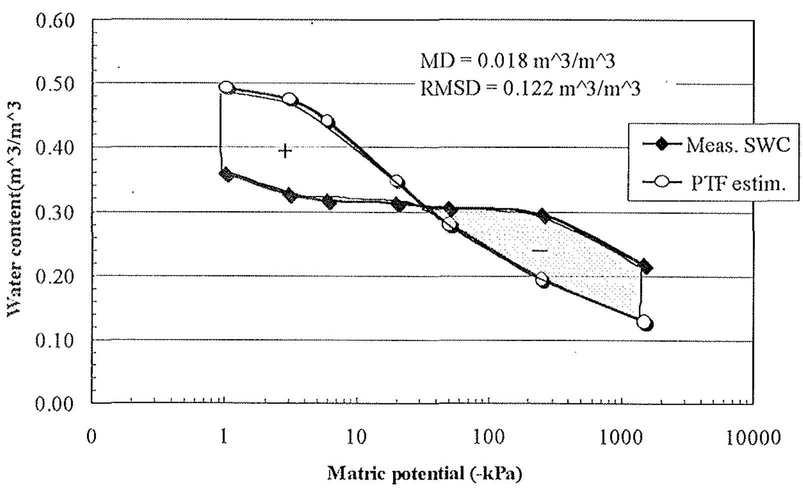
Models requirements for simulating solute transport in soils include quantitatively defined hydrological parameters for each soil horizon. Several pedotransfer functions for estimating soil hydrological parameters were published in the eighties and nineties. In table 1 the general characteristics of selected PTFs are reported. In some cases (point regression methods, eg. Rawls PTFs) the outputs are water contents at specific matric potentials, while in other (functional parameter regression methods, eg. Jarvis PTFs) the outputs are the functional parameter necessary to the full characterisation of the retention curve accordingly to well established models such as van Genuchten's (1980) or Brooks and Corey's (1964).

In order to identify the most reliable ones, selected algorithms were tested on the basis of available measurements from local soil data bases.

A data set of 140 soil horizons from local soil databases was used for which a full description of soil properties and soil water retention characteristics was available: soil texture (the number of particle size fractions varies from a minimum of three to a maximum of eight), organic carbon content, bulk density and water contents at different matric potential (from pF1.01 to pF 4.18). A total of 1035 paired observations of water content vs. matric potential were available for PTFs validation.

Figure 3.

Differences (shaded areas) between measured (Meas. SWC) and PTF estimated (PTF est.) soil water contents along a hypothetical retention curve: MD mean difference (m^3m^{-3}); RMSD: root of the mean squared difference (m^3m^{-3}).



In order to quantify the prediction accuracy of the pedotransfer functions the estimated retention curves were compared with the experimental ones using the mean difference (MD) and the root of the mean squared difference (RMSD) between measured and estimated water content for any given matric potential (figure 3). The differences were calculated with numerical quadrature of the following integrals (Tietje and Tapkenhinrichs, 1993):

$$MD = \frac{1}{b-a}\int_a^b (\theta_p - \theta_m)\, d\log h \qquad (1)$$

$$RMSD = \left[\frac{1}{b-a}\int_a^b (\theta_p - \theta_m)^2\, d\log|h|\right]^{\frac{1}{2}} \qquad (2),$$

where h is the matric potential (hPa) and θp and θm are the predicted and the measured water contents (vol. %) at that potential, and a and b values define the pF range over which the experimental curve is defined. The definition of the two indices is necessary because we are not comparing single values of water content but more values within a specific tension range. In our case the range is from pF 1.01 to pF 4.18. MD is used to indicate weather a PTF overestimates (MD>>0) or underestimates (MD<<0) the water content , while RMSD, always positive, can be viewed as the continuos analogue of the standard deviation over the whole retention curve, providing therefore an absolute error index (Tietje and Tapkenhinrichs, 1993).

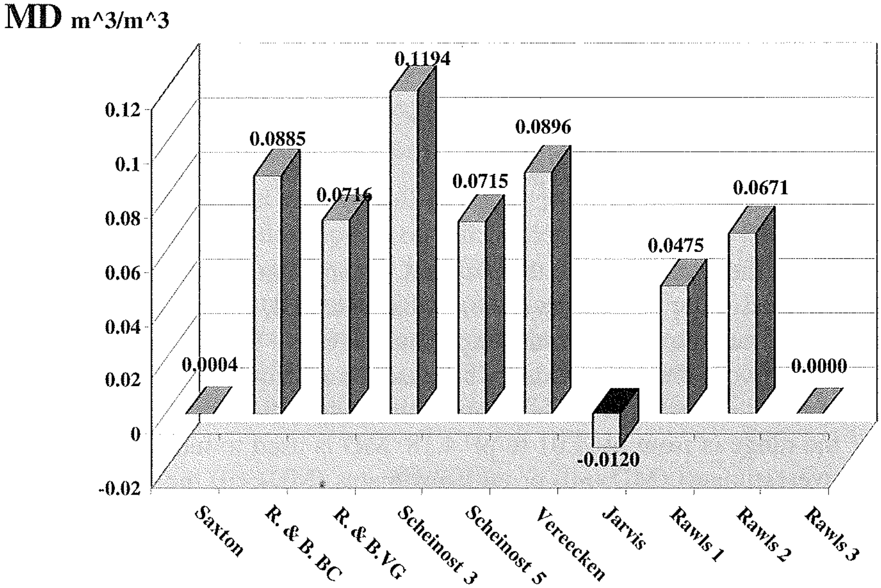
In order to define ranges for optimal usage of the different PTFs, the two error indices were computed not only for the whole data set, but also for different subset of data defined according to the following criteria: USDA textural classes, organic carbon content, bulk density and matric potential (Ungaro and Calzolari, 1998).

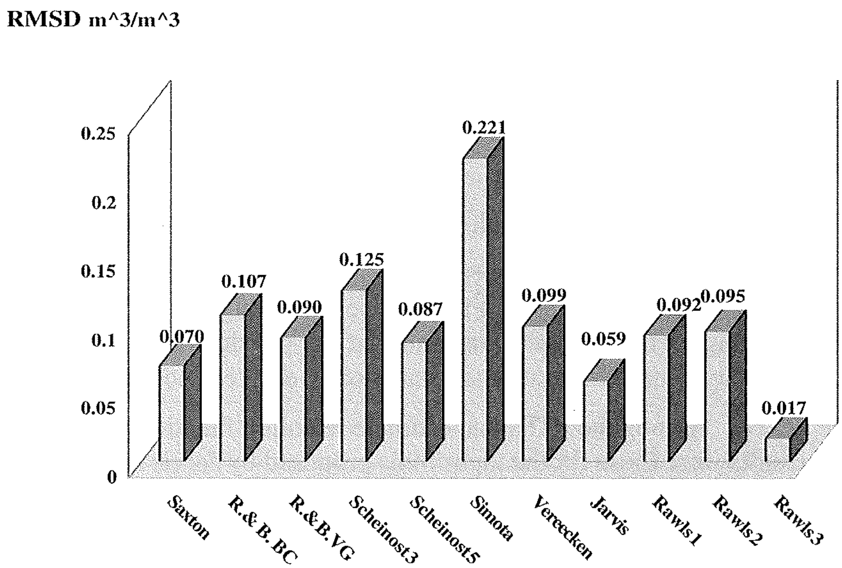
In figure 4 the results of the validation process for the whole data set are reported.

The results showed that the best accuracy is not necessarily related to a higher number of inputs and that the physically based models are not necessarily more accurate than statistically derived models.

Among the PTFs that estimate retention function parameters the best results were those for the algorithms proposed by Jarvis *et al.* (1997) for the Brooks and Corey retention model, whose RMSD was 0.059 m^3m^{-3}; among the PTFs that estimate the van Genuchten parameters, the most accurate prediction were those derived from Scheinost *et al.* (1997) PTF with five textural fractions as input (RMSD 0.087 m^3m^{-3}); if only three fractions are given as inputs, then the best results were those for the algorithm proposed by Rawls and Brakensiek (1985) and Vereecken *et al.* (1989), whose RMSD were 0.088 and 0.099 m^3m^{-3} respectively.

Figure 4. Pedotransfer functions validation results for the whole data set. MD: mean difference (m^3m^{-3}); RMSD: root of the mean squared difference (m^3m^{-3}).





Fairly good results, considering also that the required inputs are only clay and sand %, were obtained for the prediction of Saxton *et al.* (1986) PTF, with a RSMD of 0.07 m^3m^{-3}; in this case however for modelling purposes, functional parameters must be further derived for the estimated retention curve. The same holds for the three algorithms proposed by Rawls *et al.* (1992), whose RMSDs are respectively 0.092, 0.095 and 0.017 m^3m^{-3} for Rawls 1, Raw3ls 2 and Rawls 3. For this last PTF then the RMSD is the lowest of the whole set, but it must be noted that the inputs requirements are rather demanding, since in this case the soil water contents at -33 and -1500 kPa tension are required.

Control of model performances

The model MACRO was calibrated and validated in controlled situations by Istituto Sperimentale Agronomico-MiPAF (1999), and then used for the simulation of water balance in some sites for which control data were available (table 2).

Table 2

Soil	years	Crops	Control data	Meteo Station
SINA P1-RSD	1996-1997	beet-maize	Moisture profile*	San Pancrazio (MO)
SINA P1-RSD	1996-1997	beet-wheat	Moisture profile*	San Pancrazio (MO)
SINA P4 -RNV	1996-1997	wheat	Moisture profile*	Ozzano (BO)
SINA P6- CON	1996-1997	maize-maize	Moisture profile*	Gariga (PC)
SINA P6- CON	1996-1997	wheat-tomato	Moisture profile*	Gariga (PC)
Pilastri (con falda)	1994-1995	wheat	Moisture profile†	Villanova d'Arda (PC)
Pilasti (senza falda)	1994-1995	wheat	Moisture profile†	Villanova d'Arda (PC)
Le Contane	1994-1995	alfalfa - wheat	Moisture profile†	S.Pietro Capofiume (BO)
Barco	1994	maize	Moisture profile†	Gariga (PC)
Confine	1994	maize	Moisture profile†	Gariga (PC)
Liqu-34	1994-1996	barley-maize-maize	Water balance	Fossano
Liqu-43	1994-1996	ryegrass-maize	Water balance	Fossano
Liqu-44	1994-1996	ryegrass-maize	Water balance	Fossano
Liqu-45	1995-1996	maize-barley-maize	Water balance	Fossano
Liqu-46	1995-1996	maize-maize	Water balance	Pralormo
Liqu-47	1995-1996	grassland	Water balance	Pralormo
Liqu-49	1995-1996	grassland	Water balance	Lanzo
Liqu-50	1995-1996	maize-maize	Water balance	Lanzo
Liqu-66	1995-1996	maize-maize	Water balance	Carmagnola

†: data from I.ter, 1996;*: data from CRPV, 1998.

In table 3 some common indexes, used for model performance evaluation (Janssen and Heuberg, 1995) are reported.

Table 3. Error indexes adopted for model performance evaluation. *Pi* and *Oi*: predicted and observed values respectively; *P* and *O*: predicted and observed mean values; *P'i* and *O'i* : differences between predicted and observed values and respective mean values.

Index	Symbol	aCalculation
Average error	AE	$\frac{\sum_{i=1}^{N}(P_i - O_i)}{n} = \overline{P} - \overline{O}$
Normalized average error	NAE	$\frac{(\overline{P} - \overline{O})}{\overline{O}}$
Root mean square error	RMSE	$\sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}}$
Normalised RMSE	NRMSE	$\frac{RMSE}{\overline{O}}$
Index of agreement	IoA	$1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}\left(\lvert P_i' \rvert + \lvert O_i' \rvert\right)^2}$
Alternative index of agreement	AioA	$1 - \frac{\sum_{i=1}^{N}\lvert P_i - O_i \rvert}{\sum_{i=1}^{N}\left(\lvert P_i' \rvert + \lvert O_i' \rvert\right)}$
Mean absolute error	MAE	$\frac{\sum_{i=1}^{N}\lvert P_i - O_i \rvert}{N}$
Normalised mean absolute error	NMAE	$\frac{MAE}{\overline{O}}$
Modelling efficiency	ME	$\frac{\left[\sum_{i=1}^{N}(O_i - \overline{O})^2 - \sum_{i=1}^{N}(P_i - O_i)^2\right]}{\left[\sum_{i=1}^{N}(O_i - \overline{O})^2\right]}$

Table 4. Simulations error indexes: * significative at 5%; ** significative at 1%.

Soil	crops	n.. obs.	obs mean	obs. Var.	AE	NAE	RMSE	NRMSE	IoA	AIoA	MAE	NMAE	ME	r
SinaP1- RSD- PTF	beet-maize	93	0.403	0.005	0.007	0.017	0.068	0.170	0.702	0.507	0.055	0.136	0.233	0.499**
SinaP1-RSD-meas.	beet-maize	93	0.403	0.005	0.022	0.053	0.079	0.195	0.623	0.463	0.062	0.154	0.047	0.411**
SinaP1 - RSD- PTF	beet-wheat	96	0.356	0.008	0.020	0.057	0.066	0.186	0.809	0.625	0.052	0.146	0.380	0.723**
SinaP1 - RSD- meas.	beet-wheat	96	0.356	0.008	0.044	0.124	0.087	0.244	0.706	0.533	0.066	0.185	0.125	0.590**
SinaP4 - RNV-PTF	wheat	98	0.343	0.004	0.024	0.071	0.074	0.216	0.682	0.527	0.058	0.170	-0.323	0.481**
SinaP4 - RNV-meas.	wheat	98	0.343	0.004	0.016	0.048	0.058	0.170	0.772	0.559	0.049	0.142	0.056	0.615**
SinaP6- CON- PTF	maize-maize	80	0.302	0.006	0.041	0.135	0.098	0.324	0.601	0.485	0.072	0.237	-0.343	0.357**
SinaP6- CON- meas.	maize-maize	80	0.302	0.006	0.022	0.074	0.069	0.228	0.696	0.562	0.048	0.160	0.412	0.558**
SinaP6- CON- PTF	tomato-wheat	79	0.293	0.007	0.022	0.075	0.082	0.278	0.769	0.581	0.067	0.227	-0.257	0.615**
Sina P6-CON- meas.	tomato-wheat	79	0.293	0.007	0.019	0.065	0.067	0.229	0.775	0.580	0.054	0.185	0.397	0.662**
Pilastri (f.)- Criteria	wheat	35	0.392	0.002	0.051	0.129	0.074	0.188	0.611	0.386	0.067	0.171	-2.825	0.346*
Pilastri (s.)-Criteria	wheat	30	0.420	0.002	-0.107	-0.255	0.129	0.307	0.335	0.218	0.110	0.262	-8.527	n.s.
Le Còntane- Criteria	alfalfa-wheat	70	0.459	0.053	0.015	0.032	0.189	0.411	0.750	0.591	0.121	0.263	0.497	0.581**
Barco-Criteria PTF	maize	29	0.327	0.002	0.009	0.027	0.083	0.255	0.270	0.201	0.067	0.205	-1.273	n.s.
Barco- Criteria meas.	maize	29	0.327	0.002	0.008	0.024	0.077	0.234	0.172	0.167	0.060	0.185	-0.476	n.s.
Confine-Criteria PTF	maize	23	0.319	0.004	0.001	0.002	0.072	0.227	0.624	0.437	0.058	0.181	-0.539	0.411*
Confine-Criteria meas.	maize	23	0.319	0.004	-0.023	-0.072	0.065	0.203	0.765	0.556	0.050	0.157	-1.145	0.682**

These indexes measure in a quantitative way the difference between the model predictions and the observed values. Error indexes were calculated and results are reported in table 4.

The results are fairly satisfactory, also considering the fact that both the control data and the driving variable were collected in other previous research projects, outside the SINA framework.

Results of simulations

Once the model performance has been controlled it is planned to use it for simulating water balance in two different situations: a) benchmark soils scattered in the entire study area, from Piedmont to Friuli; and b) soil map sheets of selected pilot areas.

In the first case the role of the different soils and of their properties in affecting water balance, and then the potential leaching risk had to be assessed, given similar climate and management inputs.

A set of 51 benchmark soils were then selected, for which simulations were performed according to selected climatological and management scenarios, representative of the diverse areas and of different level of inputs, in terms of both management (low and high input agriculture) and climate (from ustic to udic moisture regimes). For this set of soils, field descriptions, routine analyses and hydrological measures were produced during the project. A total of 217 simulation have been eventually performed, as summarised in table 5. Benchmark soils have been chosen in accord to their diffusion in the different parts of the Pianura Padano-Veneta and for their hydraulic characteristics. The soil type variability is then very high ranging from the sandy-skeletal Entisols of the Friuli plains to the fine Vertisols of the Emilia Romagna low-lands. The agricultural scenarios were also selected as the most representative of the study areas, with a maize mono-culture common for all the areas and a typical crop rotation, i.e. ryegrass- wheat, for the zootechnical areas of the northern part of the Pianura Padano-Veneta and alfalfa-wheat for "Parmigiano Reggiano" producing areas of Emilia Romagna. All these crops are irrigated, even if with different kinds of irrigation systems and intensities. A third, not irrigated, crop scenario was chosen for Emilia Romagna and Friuli, i.e. a three year rotation with sugar beet, soybean and wheat. For each study area two different meteorological stations were chosen (except on the case of Veneto, for which only one station was selected), representing the extremes of the rain distribution of the areas.

Table 5. Simulations performed for 51 benchmark soils.

	Benchmark soils	Crops Station	Meteo	Average P runs	Simulation
Piemonte	13	maize-maize	Lanzo (TO)	1390	52
		ryegrass-wheat	Fossano (CN)	856	
Lombardia	14	maize-maize	Milano 2 (MI)	1072	56
		ryegrass-wheat	Ostiglia (MN)	615	
Veneto	3	maize-maize	Castelfranco V.to (TV)	863	6
		ryegrass-wheat			
Friuli V.G.	7	maize-maize	Talmassons (UD)	1218	28
		beet-soybean-wheat	Vivaro (?)	1463	
Emilia Romagna	14	maize-maize	Gariga (PC)	778	75
		alfalfa-wheat	S. Pietro Capof. (MO)	559	
		beet-soybean-wheat			

In the second case, a 1:50,000 cartographic representation of the water balance is planned. Due to the point working scale of MACRO model, the results of the simulations can be aggregated at regional scale following different criteria.

In a "traditional" approach the input data for the PTF estimation of hydrological parameters are derived from the soil typological units, as defined in the local soil database. In order to take into account the variability of the soil typological units, beside the average values of the pedological parameters, also their variability range must be considered. This can be achieved taking into account all the available information contained in the database, related to the same typological unit within the considered soil map sheet. As a result of multiple simulations, for each map polygon an average value and a range of variability in model outputs can be defined.

For areas where a higher density of information is available, the spatial variability of soil properties can be explicitly taken into account to describe soil hydrological behaviour at regional scale. This was the case of he sheet 181 of the 1:50,000 Regione Emila Romagna soil map, for which an experimental procedure was followed. In this soil map sheet, where 29 different soil typological units (STU) and 51 map polygons are present, a few hundreds of soil observations are present. These basic soil data, such as textural fractions, organic carbon content and bulk density, were regionalised using a geostatistical methodology capable of taking into account the exhaustive secondary information available for each soil series from local soil catalogue.

The value of a soil property Z to be estimated at a given point in space **u** in the $\mathbf{i}^{th}$ STU is then given by:

$$Z(\mathbf{u})_i = m(\mathbf{u})_i + R(\mathbf{u}) + \varepsilon \qquad (3),$$

where $m(\mathbf{u})_i$ is a deterministic function describing the structural component of Z at **u**, which in this case is given by the STU mean value of the soil property considered, $R(\mathbf{u})$ is a stochastic, locally varying but spatially dependent term which represents the residual from $m(\mathbf{u})_i$, and ε is a residual, spatially independent Gaussian noise term having zero mean and variance σ^2.

Secondary information available at all unsampled locations was used to characterise the spatial trend of primary attribute, replacing the global mean with known varying local means, through the following steps:

(1) available data were grouped in terms of STU and for each variable the conditional mean was computed;

(2) the STU conditional mean was subtracted from each observation to compute the residuals of each variable;

(3) exploratory spatial analyses and experimental variography of the residuals was carried out; computing the residual semivariograms:

$$\gamma_{RES}(\mathrm{h}) = \frac{1}{2N(\mathrm{h})}\sum_{\alpha=1}^{N(\mathrm{h})}\left\{\left[z(\mathrm{u}_\alpha) - m^*_{SK}(\mathrm{u}_\alpha)\right] - \left[z(\mathrm{u}_\alpha + \mathrm{h}) - m^*_{SK}(\mathrm{u}_\alpha + \mathrm{h})\right]\right\}^2 \quad (4)$$

where $\gamma_{RES}(\mathbf{h})$ is the residuals semivariance, $N(\mathbf{h})$ the number of pairs of data locations a vector **h** apart, $z(\mathbf{u}_\alpha)$ and $z(\mathbf{u}_\alpha+\mathbf{h})$ are the observed values of the random variable Z at location $\mathbf{u}_\alpha$ and $\mathbf{u}_\alpha+\mathbf{h}$ and $m^*_{SK}(\mathbf{u}_\alpha)$ and $m^*_{SK}(\mathbf{u}_\alpha+\mathbf{h})$ the means of the corresponding soil series at location $\mathbf{u}_\alpha$ and $\mathbf{u}_\alpha+\mathbf{h}$ respectively;

(4) using the semivariograms models of the residuals, residuals were kriged at unsampled locations on a 1000x1000 regular grid and the corresponding STU mean was added to estimated values. The kriging estimator adopted (*simple kriging with varying local means* or SKlm; Goovaerts, 1997) has the form:

$$Z^*_{SKlm}(\mathrm{u}) - m^*_{SK}(\mathrm{u}) = \sum_{\alpha=1}^{n(\mathrm{u})}\lambda^{SK}_\alpha(\mathrm{u})\left[Z(\mathrm{u}_\alpha) - m^*_{SK}(\mathrm{u}_\alpha)\right] \quad (5)$$

where $m^*_{SK}(\mathbf{u})$ is the known varying mean and the kriging weights λ_α^{SK} were obtained by solving a simple kriging system of type:

$$\sum_{\beta=1}^{n(\mathrm{u})}\lambda^{SK}_\beta(\mathrm{u})\gamma_{RES}(\mathrm{u}_\alpha - \mathrm{u}_\beta) = \gamma_{RES}(\mathrm{u}_\alpha - \mathrm{u}) \qquad \alpha = 1,\ldots,n(\mathrm{u}) \quad (6)$$

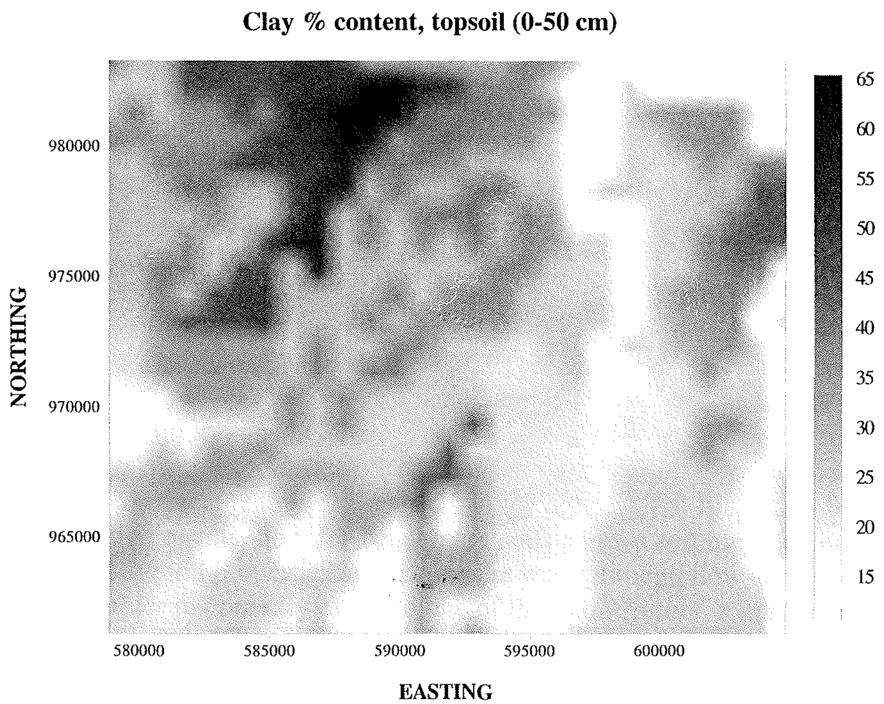
where $\gamma_{RES}(\mathbf{h})$ is the semivariogram function of the residual random function $RES(\mathbf{u}) = Z(\mathbf{u}) - m(\mathbf{u})$.

To check the congruency of SKlm results with the available observations and to evaluate the degree of the smoothing effect associated with kriging, the SKlm estimated soil properties were compared with the observed ranges for the whole study area and for each soil typological unit present in the area, and results were more then acceptable, and always inside the observed ranges of the STU (Ungaro and Calzolari, 1998).

In figure 5 the SKlm map of clay content for topsoil (0-50 cm) is shown.

Figure 5.

Regione Emilia Romagna 1:50.000 soil map, sheet 181: Sklm estimated clay % content, topsoil (0-50 cm).

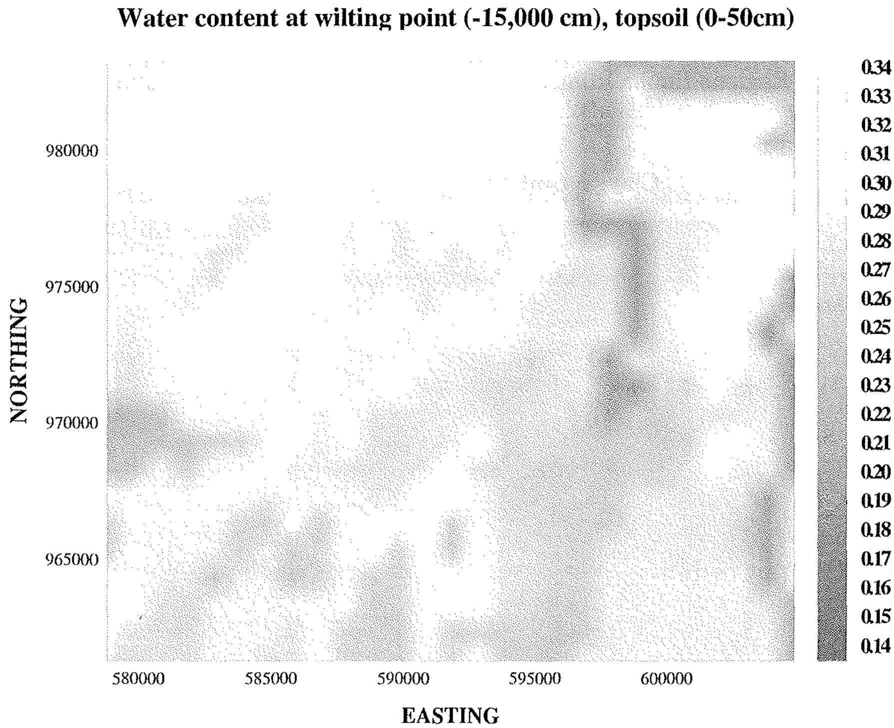


The SKlm estimates of basic soil data at nodes of the 1000x1000 grid were used as inputs for a set of previously validated pedotransfer functions (Jarvis *et al.*, 1997) for estimating the hydrological parameters required as inputs by the MACRO model. Figure 6 shows the SKlm map of the estimated soil water content at wilting point for the topsoil.

For this set of simulations (602 runs) the meteorological station of S. Pancrazio, of the Regional Meteorological Service – ARPA Regione Emilia Romagna (44°48' N, 10°16' E, 59 m a.s.l., mean annual temperature 12.72 °C, mean annual precipitation 770 mm), was used for climate input data.

Figure 6.

Regione Emilia Romagna 1:50.000 soil map, sheet 181: Volumetric water content at -15.000 cm, topsoil.



Three different management scenarios were then selected for the simulations: a) a three year crop rotation with sugar beet, soybean and wheat, without irrigation; b) a two year rotation with tomato and wheat, with irrigated tomato; c) a four years rotation with three years of alfalfa and one year of wheat, with irrigated alfalfa. In all the cases three years are conside-red for the simulations (1995-1997).

Integration with soil data base

As one of the main objectives of the SINA project was the establishment of an inter-regional soil database structure, harmonising the data acquisition, processing and interpretation at a regional level and coherent with the requirement of the Georeferenced Soil Database for Europe (Finke *et al.*, 1997), both the validated set of PTFs and the model structure have to be integrated within the soil data base.

Some tools have been then introduced in data base structure for calculating, from the basic soil properties stored in the data base the hydrological properties with the PTFs algorithms, or to retrieve, when available, direct measurements. The basic soil properties, and the hydrological properties, both PTF derived and measured, are eventually used for preparing, by means of the data base procedures, the MACRO soil parameter file needed to run the simulation.

Conclusions

The interregional experience of the SINA project has lead in the first years of its course to some important results. The high number of data made available by the local agencies responsible for soil survey permitted to validate the PTFs necessary to infer the hydrological properties for benchmark soils in the whole study area and to select the best performing ones. The water balance simulation with MACRO model gave satisfactory results in different sites for which control data were available. The periodical meetings among the groups involved in the research allowed to discuss the results and to control their reliability, thanks to the experience and to the knowledge of the local reality of each soil survey agency. The first water balance simulation results, both for benchmark soils and for soil maps, show that the role of the soil properties in affecting the water through flow can be quantified, in order to correctly evaluate one of the main factors in nitrate potential leaching risk. The co-ordination between the different sub-projects allowed the integration of PTFs and models as standard operative tools. In the last few months of the research the linkage with SoilN model will be completed, in accord to the research schedule.

References

BOUMA, J. (1989). Using soil survey data for quantitative land evaluation. In B.A. Stewart (ed.) *Advances in Soil Science* 9. Springer and Verlag, Berlin, pp. 177-213.

BROOKS R.H., COREY A.T. (1964). Hydraulic properties of porous media. *Hydrology* paper no. 3. Colorado State University, Fort Collins.

Commission of the European Communities (1991). Soil and groundwater research project II: nitrate in soils. Final report on contracts EV4V-0098-NL and EV4V-00107-C. Directorate-General for Science, Research and Development, Environmental Research Programme. 544 pp.

CRPV (1998). Gestione fertilizzazione e contenuto idrico di suoli diffusi nella pianura emiliano-romagnola: realizzazione di analisi verifiche e valutazioni di campo e/o laboratorio per la validazione e la puntualizzazione delle indicazioni tecniche da inserire nei disciplinari di produzione integrata e nei bollettini provinciali di produzione integrata. Rapp. Interno.

ECKERSTEN H., JANSSON P.E., JOHNSSON H. (1996). SOILN model, user's manual, third edition. Communication 96:1, Swedish University of Agricultural Sciences, Dept. of Soil Sciences, Uppsala, pp. 93.

FINKE R., DUDAL L., HARTWICH R., IBÀÑEZ J., JAMAGNE M., KING D., MONTANARELLA L., YASSOGLOU N. (1997). Georeferenced Soil Database for Europe. Manual of Procedures, Draft 1.0. European Commission, Directorate general JRC, Joint reserch centre, Space Applications Institute, European Soil Bureau, Ispra (Va), Italy.

GOOVAERTS P. (1999). Geostatistics in soil science: state-of-the-art and perspectives. *Geoderma* 89, 1-45.

HEUVELINK G.M.B., PEBESMA E.J. (1999). Spatial aggregation and soil process modelling. *Geoderma*, 89, 47- 65.

I.ter (1996). Verifica dell'applicabilità ad aree sperimentali della pianura emiliano-romagnola del modello di simulazione del bilancio idrico dei suoli Criteria. Rapp. Interno.

Istituto Sperimentale Agronomico – MiPA Sezione ricerche agronomiche applicate all'ambiente settentrionale (1999). Controllo di adeguatezza del modello MACRO-SoilN alla simulazione della dinamica dell'acqua e dell'N nel suolo, in ambiente padano. Rapporti intermedi 1-2 SINA, ottobre 1998-aprile 1999.

JANSSEN P.H.M., HEUBERG P.S.C. (1995). Calibration of process-oriented models. *Ecological Modelling*, 83, 55-66.

JARVIS N.J (1994). The MACRO model (version 3.1). Technical description and sample simulations. Reports and dissertations n. 19, Swedish University of Agricultural Sciences, Dept. of Soil Sciences, Uppsala, pp. 51.

JARVIS N.J., HOLLIS J.M., NICHOLLS P.H., MAYR T., EVANS S.P. (1997). MACRO-DB: a decision tool for assessing pesticide fate and mobility in soils. *Environmental Modelling and Software*, 12: 251-265.

JARVIS N.J., HOLLIS J.M., NICHOLLS P.H., MAYR T., EVANS S.P. (1997). MACRO-DB: a decision tool for assessing pesticide fate and mobility in soils. *Environmental Modelling and Software* 12, 251-265.

LARSSON M.H., JARVIS N.J., JOHNSSON H. (1996). A dual-porosity model for nitrogen turnover and nitrate leaching from arable soil. *Annales Geophysicae*, Supplement to Volume 14, Part II, C323.

LOVELAND P.J., ROUNSEVELL M., LEGROS J-P., DE LA ROSA D., ARMSTRONG A., GLINSKI J., RAJKAI K., SIMOTA C. (Eds.) (1995). ACCESS Agro-Climatic Change and European Soil Suitability: a spatially distributed soil, agro-climatic and soil hydrological model to predict the effect of climatic change on land use within the European Community. Volume I: a description of the ACCESS project, 361 pp.

RAWLS W.J., BRAKENSIEK D.L. (1985). Prediction of soil water properties for hydrological modelling. In: E.Jones and T.J. Ward (eds.): Proceedings of the ASCE Symposium Watershed Management in the Eighties, 30 Apr. -2 May, Denver, CO, 293-299.

RAWLS W.J., BRAKENSIEK D.L., SAXTON K.E. (1982). Estimation of soil water properties. *Trans. ASAE* 108, 1316-1320.

SAXTON K.E., RAWLS W.J., ROMBERGER J.S., PAPENDICK R.I. (1986). Estimating generalised soil-water characteristics from texture. *Soil Science Society of America Journal*, 50, 1031-1036.

SCHEINOST A.C., SINOWSKI W., AUERSWALD K. (1997). Regionalization of soil water retention curves in a highly variable soilscape, I. Developing a new pedotransfer function. *Geoderma* 78, 129-143.

STANNERS D., BOURDEAU P. (eds.) (1995). Europe's Environment. The Dobríš Assessment. European Environmental Agency, Copenhagen, 676 pp.

TIETJE O., TAPKENHINRICHS M. (1993). Evaluation of pedotransfer functions. *Soil Science Society of America Journal*, 57: 1088-1095.

UNGARO F. (1997). Modelli per la descrizione del flusso di soluti nel suolo: approcci, struttura e finalità. Rapporto SINA 1.1, maggio 1997.

UNGARO F., CALZOLARI C. (1998). Soil water content estimation: performance of available pedotrasfer functions for predicting the water retention properties in areas at high environmental risk of the Pianura Padano-Veneta (Northern Italy). Presented at 7th- International Congress for Computer Technology in Agriculture: "Computer technology in agricultural management and risk prevention", Florence, Italy, Nov. 15, 1998

VAN GENUCHTEN M.Th. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil *Science Society of America Journal*, 44: 892-898.

VEREECKEN H., MAES J., FEYEN J., DARIUS P. (1989). Estimating the soil moisture retention characteristic from texture, bulk density and carbon content. *Soil Science* 148, 389-403.

SOIL PHYSICS AND SOIL VULNERABILITY IN A TYPICAL WATERSHED OF THE HILLY AREA OF CENTRAL ITALY

Marcello Pagliai, Paolo Bazzoffi, Sergio Pellegrini,
Nadia Vignozzi, Rossella Papini

Istituto Sperimentale per lo Studio e la Difesa del Suolo, MiPAF
Piazza M. D'Azeglio 30 – 50121 Firenze, Italy

Introduction

The need to reduce the environmental impact of agricultural activities and to control soil structure degradation is one of the main aims of land management, especially in the hilly environment. It has led farmers to consider the possibility of adopting "more simplified" cultivation practices as an alternative to conventional tillage. The abandoning of traditional farming rotations and adoption of intensive monocultures, without application of farmyard manure to the soil, has decreased the organic matter content in soils with evident deterioration of soil structure. In fact, the main consequence of long-term intensive cultivation is the degradation of soil structure which can reduce the effect of chemical fertilizers. As soil erosion increases, solid soil particles and nutrients can be transported with the consequent risk of surface water pollution. Moreover, the resulting soil porosity conditions are often unfavourable to crop growth.

To evaluate the impact of management practices on the soil environment it is necessary to quantify the modifications to the soil structure. Soil structure is one of the most important properties affecting crop production because it determines the depth that roots can explore, the amount of water that can be stored in the soil and the movement of air, water and soil fauna. Soil quality is strictly related to soil structure and much of the environmental damage in intensive arable lands such as erosion, desertification and compaction, originate from soil structure degradation. To quantify soil structural changes following agricultural activities, besides traditional measurements such as aggregate stability and hydraulic conductivity, pore space measurements are being increasingly used. In fact, porosity is the best indicator of soil structure conditions and pore space measurements are increasingly being used to quantify soil structure because it is the size, shape and continuity of pores that affect many of the important processes in soils. A detailed insight into the complexity of the pore system in soil can be obtained by using mercury intrusion porosimetry to quantify pores less than 50 µm (equivalent pore diameter) inside the soil aggregates, and image analysis on thin sections prepared from undisturbed soil samples to quantify pores larger than 50 µm, i.e. macropores, which determine the type of soil structure. Technological and theoretical advances, regarding both sample preparation and image analysis, have improved the methods for direct quantification of soil pores. Such methods allow the quantification of the effects of tillage practices on soil porosity and structure and, in turn, on the optimum tillage needs for sustainable agriculture.

Results of field experiments frequently recommend the adoption of reduced tillage practices to prevent soil structural degradation, soil losses by erosion and to reduce consequent environmental impacts. Soil structure degradation following intensive agricultural activities, soil compaction, lost of structural stability and the formation of surface crusts give rise to the lost of continuity of elongated transmission pores which cause a strong reduction of water movements resulting on increasing runoff and soil erosion. Until now they are not adequately quantified and over all not sufficiently considered both in models for soil erosion prediction and in models for optimising land management and environmental protection.

This study summarize the results obtained in long-term experiments carried out in a typical watershead of the hilly environment of Central Italy to determine the effects of different types of management systems on soil structural characteristics through the quantification of differences in porosity and erosion. The soils, developed on Pliocenic marine clays, are particularly vulnerable to soil erosion and soil structure degradation following intensive agricultural activities.

Experimental approach

This study was carried out on the hilly clayey watershed "Cavalcanti" near Volterra, in the Era Valley (Pisa). This watershed has a surface of 85 hectares and drains in the homonymous ephemeral torrent.

Following Pinna (1977) the climate of the station is classified as Csa (mesothermic, humid, Mediterranean). The average temperature is 12.7 °C, ranging between extreme values of -10°C and +40°C. The average yearly rainfall is 678 mm; rainfall is concentrated in spring and autumn. ETP, following Thornthwaite, is 569 mm.

Soils have a clay-silt texture (sand 20%, silt 38% clay 42%), and are classified by Soil Taxonomy as Vertic Xerorthents and Vertic Xerochrepts. They derived from pliocenic clayey marine deposits and can be placed in the family of clayey-fine, mixed, calcaric, mesic soils (Delogu and Lulli, 1982).

Dominant clay minerals are, in order of decreasing importance, Illite-montmorillonite, Chlorite, Chlorite-Vermiculite (Bazzoffi *et al.*, 1995). Moisture content (on mass basis) at -1.5 MPa,-0.033 MPa, -0.01 MPa and 0.0 MPa are respectively 1, 9, 23 and 41%. Other soil characteristics are: pH 8.2, liquid limit 51.5%, plastic limit 23.2%, O.M. 1.5%, total $CaCO_3$ 12.8% (Mbagwu and Bazzoffi, 1987).

Shrink-swelling phenomena dominate the hydrological behaviour of soils. In winter they present a very slow infiltration capacity, with maximum runoff coefficient of 0.85. In summer, on the contrary, cracks determine high infiltration capacity, and runoff coefficient approaches to 0.

The soil structure qualities were evaluated through the characterization of pore system by image analysis on thin sections from undisturbed soil samples, collected in the surface layer (0-10 cm) and at selected times and depths along the profile in the areas under different management systems. Samples are dried by acetone replacement of water (Murphy, 1986), impregnated with a polyester resin and made into 6(7 cm, vertically oriented thin sections (Murphy, 1986). Such sections are analysed by means of image analysis techniques (Pagliai *et al.*, 1984), using a PC-IMAGE software produced by Foster Findlay Associates (London). Total porosity and pore distribution are measured according to their shape and size. The instrument is set up to measure pores larger than 50 µm. Thin sections are also examined using a Zeiss "R POL" microscope at 25x magnification to observe soil structure.

Soil erosion was quantified both at the watershed scale by monitoring runoff and sediments with a flume, eletronic level detector ISCO and automatic sampler and at the field scale by data collection on two randomized blocks of 4 plots 75 m long, up-down the slope, and 15 m wide. Each plot is equipped with an electronic Fagna-type hydrological unit, for runoff measurement and sampling (Bazzoffi, 1994). This new device allows very precise measurements and the analysis of runoff dynamics. In the experimental centre an electronic meteo-station every hour collects data of rain, radiation, humidity, temperature and wind velocity and direction. Another electronic tipping bucket raingauge collects data of rainfall with a resolution of 0.2 mm. All the electronics devices in the watershed are synchronised. Chemical analysis of waters and sediments were carried out in each runoff sample in order to quantify nutrients losses (Papini *et al.*, 1997, Papini *et al.*, 1999).

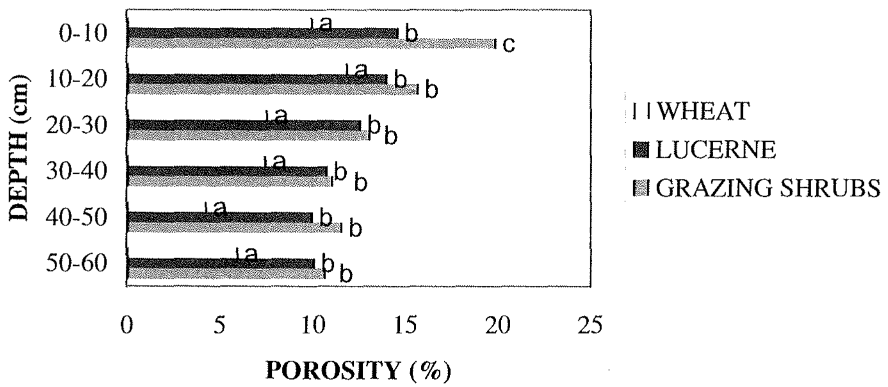
Soil porosity and structure

Results of field experiments frequently recommend the adoption of reduced tillage practices to prevent soil structural degradation, soil losses by erosion and to reduce consequent environmental impacts.

Long-term field experiments at different scales (large plots and monitored watershed) in soils, representative of a typical watershed of a hilly environment of Central Italy, have shown that alternative cultural systems, like reduced tillage, introduction of crop rotation with lucerne, grazing shrubs, etc., improve the soil pore system increasing the storage pores and the amount of the elongated transmission pores with respect to the continuous conventional systems (winter-sown cereals with deep ploughing) (Fig. 1).

Figure 1

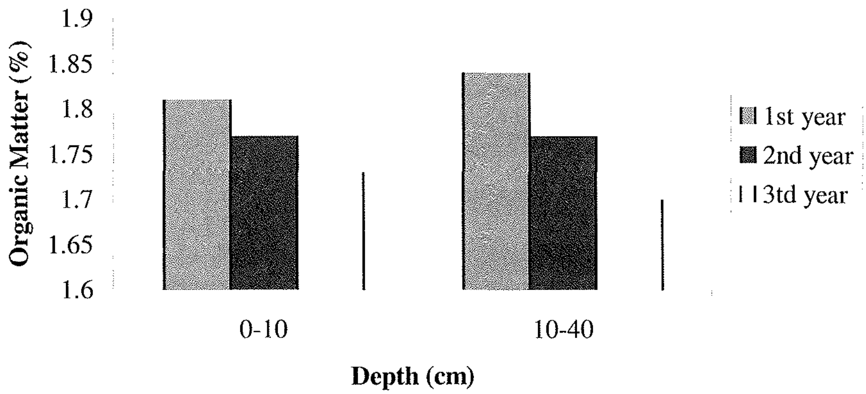
Effects of different cropping systems on macroporosity distribution along soil profile expressed as a percentage of total area occupied by pores >50 μm per thin section. Macroporosity values differ significantly when followed by different letters at P ≤0.05 employing the Duncan's Multiple Range Test.



The resulting soil structure of alternative systems is more open and more homogeneous, thus allowing better water movement, as confirmed by the decrease of runoff measured in soils under alternative systems. The continuous conventional tillage, moreover, causes a decrease of soil organic matter content (Fig. 2) that is associated to a decrease of aggregate stability, leading, as a consequence, to the formation of surface crusts, with an increase of runoff and erosion risks, and compacted structure.

Figure 2

Decrease of soil organic matter content in three years of continuous conventional tillage.

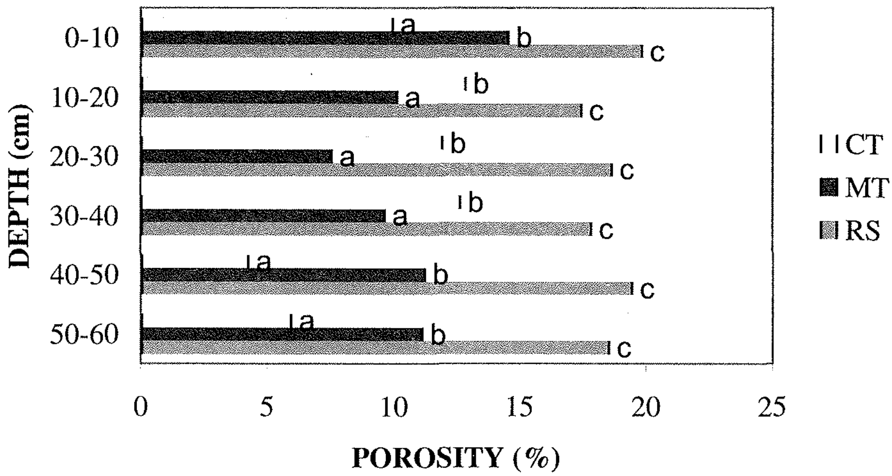


However, it was demonstrated that also in these types of soils alternative tillage systems like minimum tillage and ripper subsoiling improve the soil pore systems. Results showed that in the ripper subsoiling soil the porosity was generally higher and homogeneously distributed in the Ap horizon while in ploughed and in minimally tilled soils the porosity showed more variability (Fig. 3). In the 0-10 cm layer of the conventionally tilled soil the porosity showed the lowest significant value compared to soils under minimum tillage and ripper subsoiling. According to the micromorphometric method, a soil is considered dense (compact) when the total macroporosity is less than 10%, moderately porous when the porosity ranges from 10 to 25%, porous when it ranges from 25 to 40% and extremely porous over 40% (Pagliai, 1988).

Therefore, the low porosity values observed in this layer with conventional ploughing indicated a compact soil and the morphological examination revealed the presence of a thick platy surface crust developed as a consequence both of the low soil aggregate stability and of the high kinetic energy of the summer rainstorms. Such a crust was much less developed in minimally tilled soil and practically absent in ripper subsoiling. This means that the surface soil aggregates of ploughed soil were less rain stable compared with those from minimum tillage and, over all, ripper subsoiling.

Figure 3

Effects of different tillage systems on macroporosity distribution along soil expressed as a percentage of total area occupied by pores >50 µm per thin section (CT, conventional deep ploughing; MT, minimum tillage; RS, ripper subsoiling). Macroporosity values differ significantly when followed by different letters at P ≤0.05 employing the Duncan s Multiple Range Test.



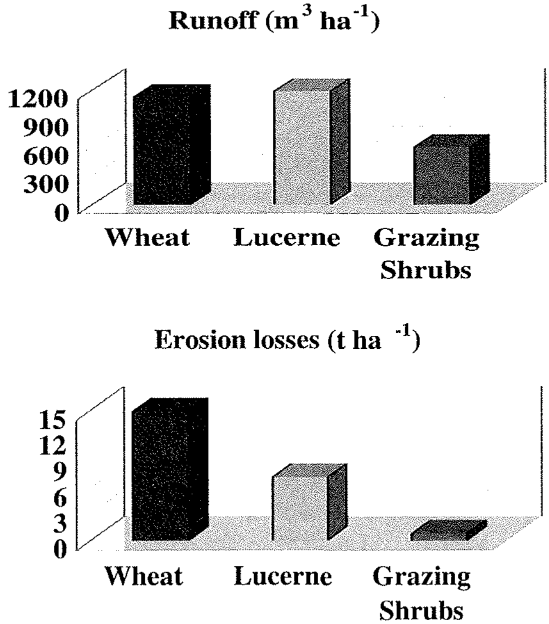
In the 10-20 cm layer, the macroporosity values in the minimally tilled soil significantly decreased, in comparison to ploughed and ripper soils, to a value lower than 10% indicating a compact soil structure such as a ploughpan or ploughsole. Such a ploughpan was much more developed in the 40-50 cm layer of the ploughed soil just at the lower depth of cultivation. On the contrary, in soil under ripper subsoiling as was the case of soil porosity, a subangular blocky structure was homogeneously present down the profile. The ripper subsoiling, in this type of soil, seems to be the most efficacious tillage system to prevent soil structure degradation and to reduce the negative effects of the compaction due to wheel traffic.

Soil erosion

Soil erosion remains one of the most important factors of soil degradation in these types of watershed and it is strongly related with soil use and, over all, with soil tillage. The decrease of aggregate stability is the main cause of accelerated erosion in conventionally tilled soils cultivated with winter-sown cereals. The soil erosion is significantly reduced in soils under lucerne and grazing shrubs; this reduction regards mainly the solid losses (Fig. 4).

Figure 4

Runoff and erosion in soils under different cropping systems.

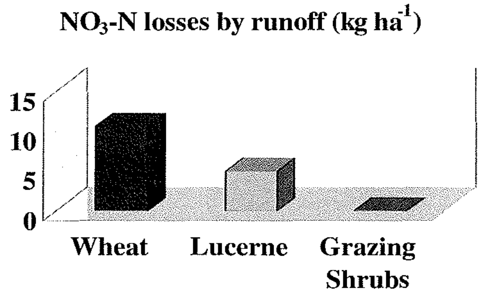


But considering the nutrient losses with runoff water, in particular nitrate and soluble phosphorus that are responsible of pollution of surface waters, differences among the considered cropping systems are higher. Indeed the average nitrate losses for year are 10 kg ha^{-1} in soil under wheat, 4 kg ha^{-1} in lucerne and less than 1 kg ha^{-1} in soil under grazing shrubs (Fig. 5). Losses of soluble phophouruos by runoff, that are low also in soil planted to wheat, became negligible in lucerne and grazing shrub soils (Fig. 6). On the contrary, the losses of phophorus by soil erosion are considerable in soil under wheat; such losses can be reduced in soil under lucerne and are negligible in grazing shrub soils.

Taking into account the ratio between wheat and lucerne in the different years of lucerne vegetation (Fig. 7), it can be observed that the year of planting is the most critical time of this crops, that is able to reduce substantially soil and nitrate losses only in the second and third year. The vulnerability respect to soil erosion that lucerne shows the year of planting is correlated with the deep ploughing usually carried out before the seed-bed preparation and lets the soil very sensible to the rainfall until lucerne is able to cover the soil surface and, therefore, able to reduce the kinetic energy of raindrop impact.

Figure 5

Nitrogen losses by runoff and erosion in soils under different cropping systems.



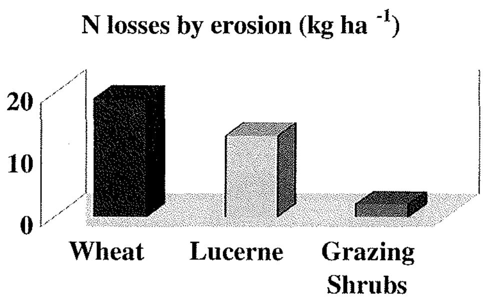
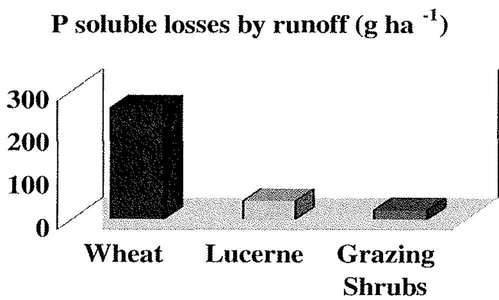


Figure 6

Phosphorus losses by runoff and erosion in soils under different cropping systems.



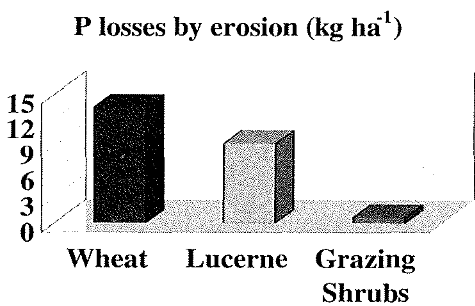


Figure 7

Ratio between wheat and lucerne in different years of vegetation.

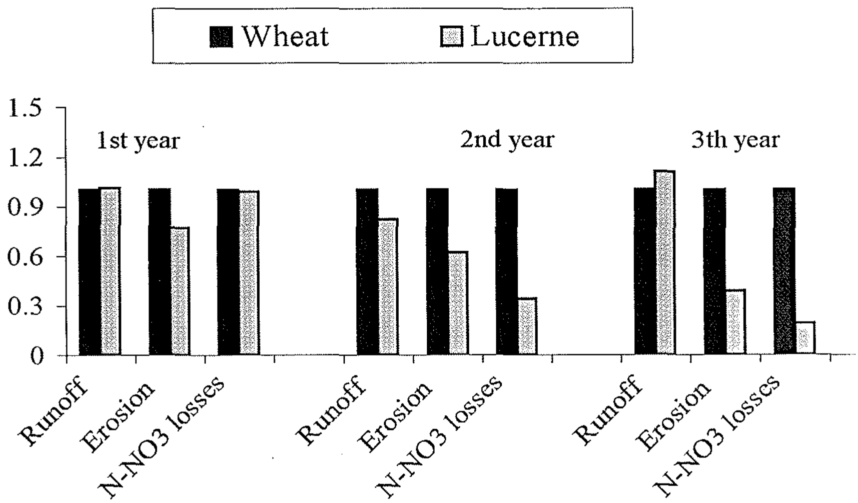
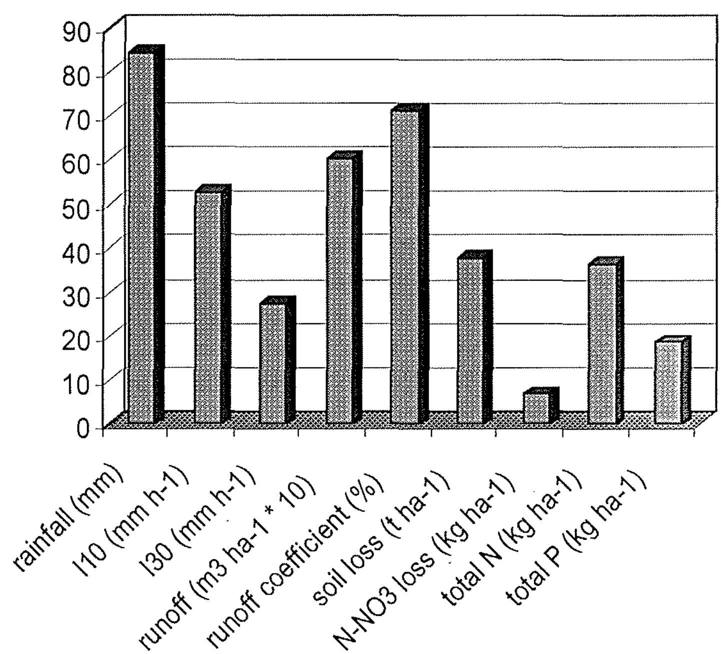


Figure 8

Runoff, soil and nutrient losses in a very intense rainfall event on soil in the time of seed-bed preparation.



The vulnerability respect to the erosion in ploughed bare soil, is well demonstrated from the Fig. 8 in which are reported the runoff, the soil and the nutrient losses in a very intense rainfall event on soil in the time of seed-bed preparation.

However, for the soil erosion in the hilly vulnerable areas it is fundamental to establish the threshold within it the soil loss must be maintained, otherwise the soil damage became irreversible.

The increase of surface runoff can also be ascribed to the formation of surface crust, or better a sealing crust, that strongly reduces the water infiltration especially in winter when the crack systems, typical of these clay soils, are closed. Besides the surface runoff, it is also very important the subsurface runoff due to the presence of a compact layer (ploughpan or ploughsole), that strongly interrupt the continuity of elongated transmission pores, at the lower limit of cultivation in conventionally tilled soils.

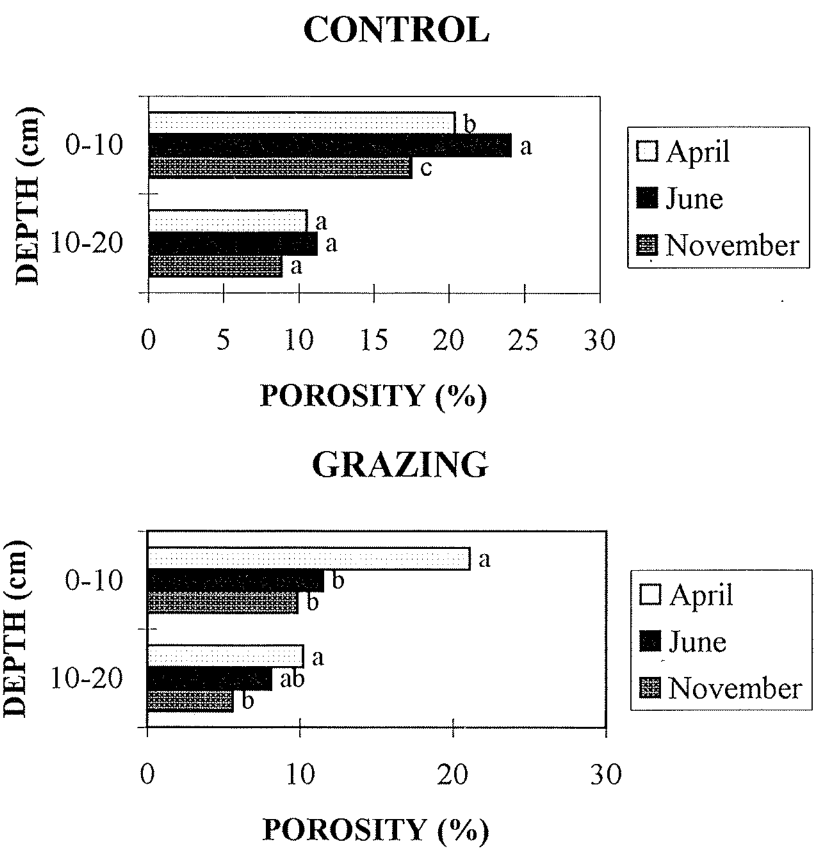
Soil compaction

Soil compaction is another of the most important factors responsible for environmental degradation. It causes strong modifications to soil structure and reduces soil porosity. Soil compaction is mainly caused by vehicle wheel traffic, tillage implements and also by animal grazing and have a much greater compactive effect than natural forces such as raindrop impact, soil swelling and shrinking, and root enlargement. This is because trends in agricultural engineering over the last few decades have resulted in machines of a greater size and weight.

Therefore, soil compaction has become one of the most significant aspects of soil degradation and problems of finding tyres, inflation pressures, etc., able to reduce soil compaction are far from being solved. It is therefore fundamental to evaluate the impact of wheel traffic and animal grazing on soil structure and porosity measurements can help to quantify the degradation effects of compaction. Results showed that compaction due to both wheel traffic and overgrazing, not only reduces total soil porosity (Fig. 9) but also modifies the pore system. In fact, the proportion of elongated pores, useful for water movement and root growth is strongly reduced in compacted soil. The modifications to the pore system also changes the type of soil structure: the platy structure is a common feature in compacted soils. Results also showed that the reduction of porosity and of elongated pores following compaction, is strictly related to the increase of penetration resistance and to the decrease of water infiltration and root growth. Soil regeneration after compaction depends on the type of soil and on the degree of damage to the soil and in these soils such a regeneration is very low and may take several years. For this, it is very important to take into consideration the damage that can be caused by the overgrazing. The animal load should be strictly related to the soil water content.

Figure 9

Effect of animal grazing on soil macroporosity. Macroporosity values differ significantly when followed by different letters at $P \leq 0.05$ employing the Duncan's Multiple Range Test.



Conclusions

In conclusions the main aspects of soil degradation in the investigated watershed are represented not only by erosion but also by the modification of pore system in term of reduction of elongated transmission pores, by the lost of structural stability, soil crusting and compaction. To prevent such degradation aspects it is necessary to adopt soil management practices more suitable for the environmental protection.

Acknowledgements

The authors wish to thank Giorgio Brandi, Giorgio D'Egidio, Miranda Morandi and Andrea Rocchini for technical assistance. Thanks are also due to Dr. Olga Grasselli for her assistance in the activity of the experimental fields. Part of the work reported in this paper was supported by the Finalized Project PANDA, Subproject 1, Series 2, Paper No 51.

References

BAZZOFFI P. (1994). The enhanced Fagna-type hydrological unit for measurement and sampling of runoff waters. Int. Workshop on Soil Erosion in Semi-Arid Mediterranean Areas. ESSC-CSEI,Taormina 28-30th Oct. 1993. CNR (ed.). pp. 195-204.

BAZZOFFI P., MBAGWU J.S.C., CHUKWU W.J.E. (1995). Statistical models for predicting aggregate stability from intrinsic soil components. *Int. Agrophysics*, 9: 1-9.

DELOGU F., LULLI L. (1982). Nota pedologica su cinque piccoli bacini sperimentali della Valdera (Pisa). *Annali Istituto Sperimentale per lo Studio e la Difesa del Suolo*, Firenze, pp. 141-145.

MBAGWU J.S.C., BAZZOFFI P. (1987). Estimating the consistency limits moisture retention and availability of some italian soils from physical properties. *Annali Istituto Sperimentale per lo Studio e la Difesa del Suolo*, Firenze, pp. 111-120.

MURPHY C.P. (1986). *Thin section preparation of soils and sediments*. A B Academic Publishers, Herts. pp. 149.

PAGLIAI M. (1988). Soil porosity aspects. *International Agrophysics*, 4, 215-232.

PAGLIAI M., LA MARCA M., LUCAMANTE G., GENOVESE L. (1984). Effects of zero and conventional tillage on the length and irregularity of elongated pores in a clay loam soil under viticulture. *Soil Tillage Res.*, 4: 433-444.

PAPINI R., BAZZOFFI P., PELLEGRINI S., BRANDI G., MONTAGNA G. (1997). Perdite di nutrienti per ruscellamento da suoli argillosi marginali a diversa utilizzazione nella Val d'Era. *Agricoltura Ricerca*, 170: 21-32.

PAPINI R., PANICHI A., BAZZOFFI P., PELLEGRINI S., BRANDI G. (1999). Influence of soil use on nitrate losses by erosion and leaching in a hilly clayey mediterranean area. 6th International Meeting on Soils with Mediterranean Type of Climate. Extended Abstract Ed. J. Bech, 4-9 July 1999 Barcellona (Spain), 1026-1028.

PINNA M. (1977). *Climatologia*. UTET, Torino.

SISS - IUSS

European Soil Bureau
European Commission
JRC - S.A.I.

International Congress

SOIL VULNERABILITY AND SENSITIVITY

Poster Session

Simulating water flow in areas at environmental risk with the MACRO model. Model evaluation with data from lysimetric studies

R. Marchetti (*), G. Ponzoni (**), P. Spallacci (*), E. Ceotto (*), F. Ungaro (***), C. Calzolari (***)

(*) Istituto Sperimentale Agronomico – Sezione Ricerche agronomiche applicate all'ambiente settentrionale, Modena

(**) Consulente, Regione Emilia Romagna, Ufficio Pedologico

(***) Istituto Genesi ed Ecologia del Suolo, CNR, Firenze

Introduction

A large area of cultivated land, in the Lower Po Valley, is characterized by vertic soils with macropores (Regione Emilia-Romagna, 1994). This feature is very important when evaluating the influence of agricultural practices - such as crop fertilization with pig slurry - on nitrate leaching, since these practices interact with soil properties which affect groundwater vulnerability. The model MACRO, which was developed to simulate water flow and solute transport in soils with macropores, seems to be particularly well suited to this use, especially since it was recently coupled with the model SOILN, which simulates nitrogen dynamics in agricultural soils (Larsson and Jarvis, 1999).

The aim of this study was to test the MACRO model at simulating water percolation in soils that are representative of the most common types of soil found in the Lower Po Valley.

Materials and methods

Experiment. The data set we used for testing the model comes from a poliennial experiment that was carried out in lysimeters (1 x 1 x 1 m), at the Agronomical Research Institute (ISA), in Modena, between 1976 and 1979 (Spallacci and Boschi, 1980). The crop sequence was the following: forage sorghum (*Sorghum bicolor* (L.) Moench), Italian ryegrass (*Lolium multiflorum* Lam.); grain maize (*Zea mays* L.), winter wheat (*Triticum aestivum* L.) , forage maize and grain sorghum. Selected crop management details are reported in Table 1. Four soil types were compared, in factorial combination with 4 rates of pig slurry and 3 replications. Soils were: silty-clay, SiC, sandy-loam, SL, loam, L (USDA classification); and a coarse sand (S).

Table 1.

Sowing date, harvest date and irrigation amount for each crop, between 1976 and 1979. The irrigation value includes also the water amount supplied with pig slurry fertilization.

Crop	Seeding date	Harvest date	Irrigation amount (mm)
Forage sorghum	6 May 1976	6 Sept. 1976	191
Italian ryegrass	13 Sept. 1976	15 Apr. 1977	18
Grain maize	28 Apr. 1977	27 Sept. 1977	192
Winter wheat	25 Oct. 1977	7 July 1978	21
Forage maize	12 Jul. 1978	13 Oct. 1978	179
Grain sorghum	4 May 1979	10 Sept. 1979	69

Simulation. Features of the model's version which we used in this study are well detailed by Larsson and Jarvis (1999). The model simulates vertical water movement, dividing flow between between micro- and macropores; lateral water exchange between the two flow domains; different bottom boundary conditions; and soil temperature dynamics. It does not simulate climate-driven crop growth. Crop evapotranspiration estimate is based on Leaf Area Index (LAI) evolution, which in turn is a function of the day number in the year (Jarvis, 1994). Consequently, calibration of crop parameters, such as maximum LAI and maximum root depth, has to be carried out year by year, on the basis of available information about crop performances under those specific weather conditions.

Measured values of relevant soil properties are reported in Table 2. Lysimeter soil thickness (0.9 m) was divided into 5 layers (0-0.03, 0.03-0.2, 0.2-0.4, 0.4-0.6 and 0.6-0.9 m). Values of the soil properties were adjusted, layer by layer, in order to simulate different soil compaction at increasing lysimeter depths. Other unmeasured parameters that serve as model inputs for simulating soil hydrological processes were estimated from the measured ones by means of pedotransfer functions, PDTF (Jarvis *et al.*, 1997). PDTF for estimating the parameters of water retention curves had been validated for benchmark soils in the Po Valley by Ungaro and Calzolari (1998). The value of the parameter "effective diffusion pathlength", *d* (Tab. 3), which influences water exchanges between micro- and macropores, depends on soil structure and was fixed according to Jarvis *et al.* (1997).

Table 2.

Measured values of selected soil properties.

Soil	Clay %	Silt %	Organic C g kg^{-1}	Total N g kg^{-1}	γ Mg m^{-3}	K_s mm h^{-1}	θ_w m^3 m^{-3}	θ_{fc} m^3 m^{-3}
Silty-clay	41.6	47.5	9.7	1.44	1.25	190	0.28	0.43
Sandy-loam	15.8	20.5	7.0	1.11	1.26	161	0.17	0.27
Loam	10.9	32.5	9.3	1.25	1.32	207	0.16	0.29
Sand	1.2	1.2	0.3	0.10	1.45	2010	0.02	0.03

γ, bulk density; K_s, saturated hydraulic conductivity; θ_w, extractable water content (wilting point); θ_{fc}, water content at -33 kPa (at -10kPa, for the sand).

Table 3.

Estimated parameter values.

Soil	Layer	θ_s m^3 m^{-3}	K_b mm h^{-1}	d mm
Silty-clay	0 - 0.03	0.50	0.10	25
	0.03 -0.2	0.50	0.10	25
	0.2 - 0.4	0.47	0.10	80
	0.4 - 0.6	0.47	0.10	80
	0.6 - 0.9	0.47	0.10	100
Sandy-loam	0 - 0.03	0.47	0.29	25
	0.03 -0.2	0.47	0.29	25
	0.2 - 0.4	0.42	0.27	80
	0.4 - 0.6	0.42	0.27	80
	0.6 - 0.9	0.42	0.27	100
Loam	0 - 0.03	0.45	0.29	35
	0.03 -0.2	0.45	0.29	35
	0.2 - 0.4	0.41	0.27	25
	0.4 - 0.6	0.41	0.27	25
	0.6 - 0.9	0.41	0.29	10
Sand	0 - 0.03	0.42	0.06	35
	0.03 -0.2	0.42	0.06	35
	0.2 - 0.4	0.42	0.06	25
	0.4 - 0.6	0.42	0.06	25
	0.6 - 0.9	0.42	0.06	25

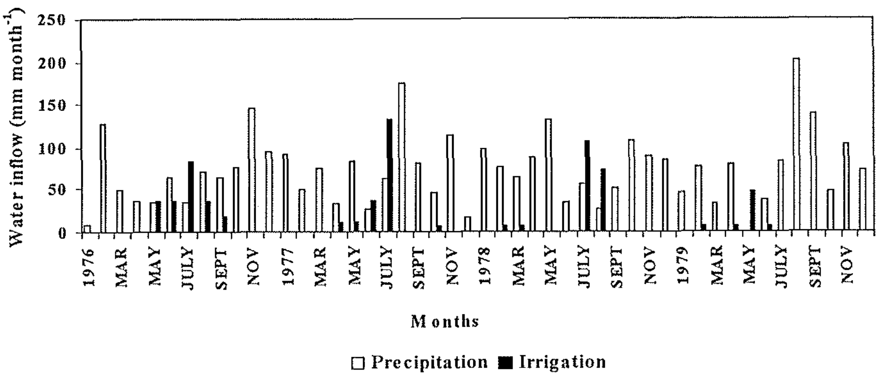
θ_s, saturated water content; K_b, boundary hydraulic conductivity; d, effective diffusion pathlength.

Climatic data was collected at the meteorological station located near the lysimeter devices, in Modena. Monthly-accumulated precipitation and irrigation-water amounts are reported in Figure 1.

For the purpose of comparing measured and predicted soil water percolation values, since there were not significant differences in water percolation among N-rate treatments, plots that had received different N rates were here considered as replications (n=12, for each soil).

Figure 1.

Precipitation and irrigation amounts accumulated monthly during the 1976-1979 experiment.



Results

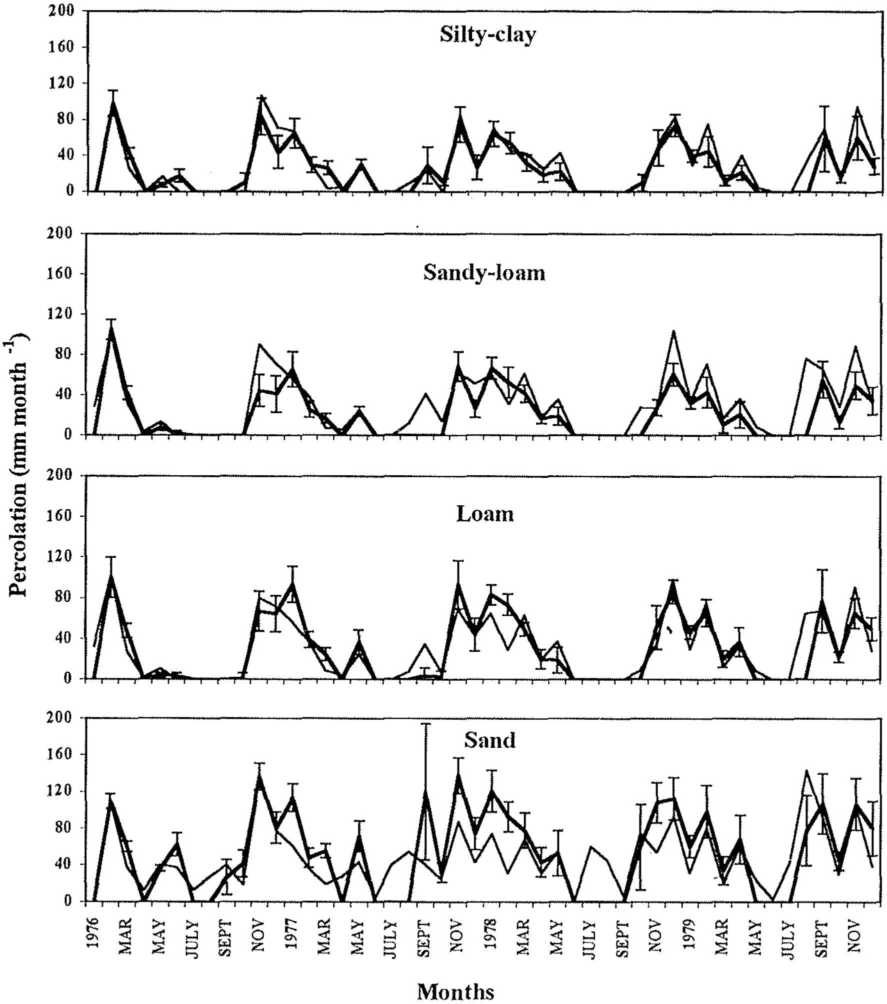
Percolation time course. Simulated time courses of water percolation fitted the measured ones fairly well (Fig. 2). The coefficient r of correlation between measured and predicted monthly percolation (n=48) equalled 0.92 for the SiC soil; 0.81 for SL; 0.85 for L; and 0.71 for the sand.

Accumulated percolation values. In general, simulated percolation periods, occurring approximately from July-August to May-June of the following year, began earlier and lasted longer than the measured ones (Fig. 3).

When comparing the accumulated percolation values measured throughout the 4-year period with those estimated by the model (Tab. 4), percolation was overestimated for the SiC, SL and L soils, while it was underestimated for the sand. On the other hand, the standard deviation of the measured accumulated percolation values was higher than the difference between predicted and measured values, in 3 out of 4 cases.

Figure 2.

Soil water percolation in different soils during 1976-1979 as measured (bold line) and predicted (thin line) by the MACRO model. Bars are standard deviation of the measurements.



Macropore flow. Water lost through macropores accounted for 83% of the accumulated percolation value in the SiC soil; 25% and 35 % in SL and L respectively; and 72%, for the sand (Tab. 4). Percolation values differed only slightly with or without macropore flow simulation, for all 4 soils (Tab.5).

Figure 3.

Time course of sequential periods of percolation (accumulated values) for different soils in 1976-1979 as measured (bold line) and predicted (thin line) by the MACRO model.

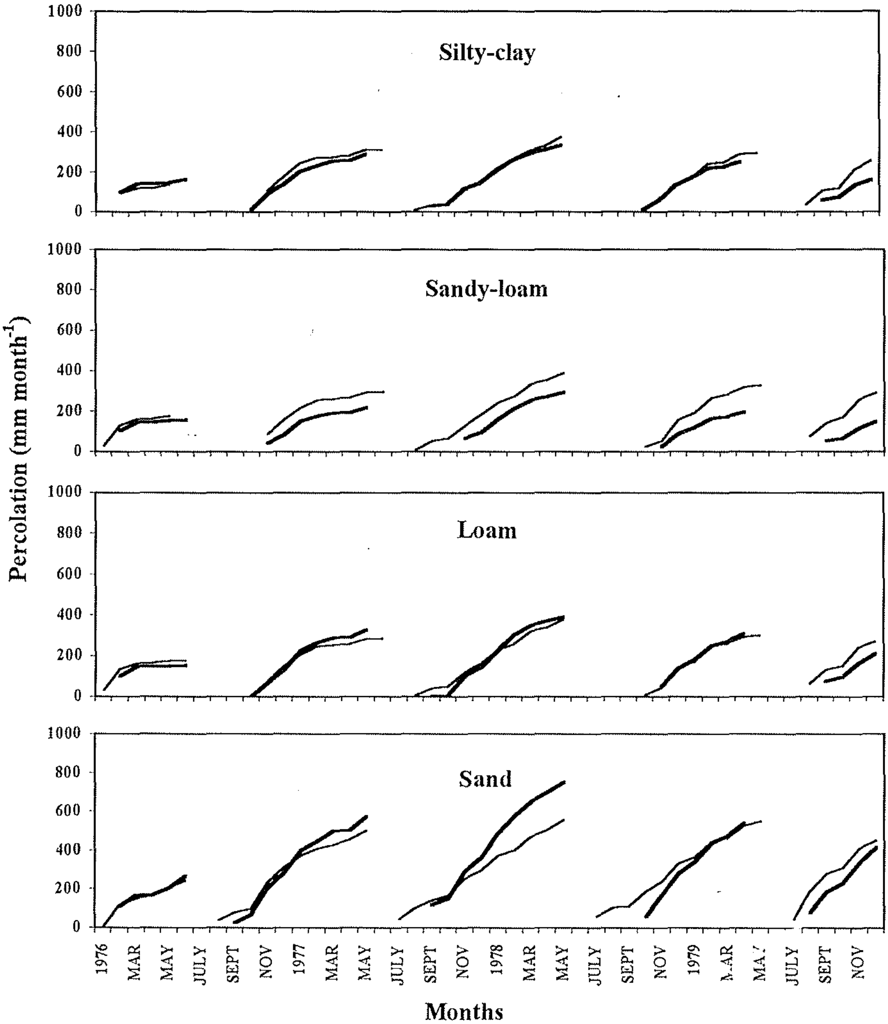


Table 4.

Comparing predicted and measured percolation values (mm) accumulated over the 4-year period (n=12, for each soil).

Soil	Measured percolation (O)	Predicted percolation From micropores	From macropores	Total (P)	(P-O)	((P/O)-1) x 100	SD[1] of O	CV[1] of O
Silty-clay	1206	229	1147	1376	170	14	253	21
Sandy-loam	1021	1120	370	1490	469	46	174	17
Loam	1398	916	503	1419	21	1	238	17
Sand	2555	648	1661	2309	-246	-10	460	18

(1) SD, standard deviation; CV, coefficient of variability

Table 5.

Simulated accumulated percolation values with macropore flow (effective diffusion pathlength, *d*: see table 3) and without macropore flow (*d*=1).

Soil	Accumulated percolation (mm)	
	With macropore flow	Without macropore flow
Silty-clay	1410	1400
Sandy-loam	1520	1530
Loam	1460	1460
Sand	2370	2380

Discussion

Differences between measurements and model predictions could partly be attributed to an inadequate estimation of saturated hydraulic conductivity by PDTF. Namely, it was not possible to distinguish between sandy-loam and loam soil on the basis of their estimated hydrological characteristics, even though measured percolation values suggest that the hydrological behaviour of these soils is actually different. Moreover PDTF estimated K_b values for the sand which seem too low to be realistic.

The limited effect that simulation of macropore flow showed on percolation values may be explained by the low difference existing among soils, as related to the "effective diffusion pathlength" parameter. On the other hand Jarvis reported that the effect of this parameter on water flow and solute distribution between micro- and macropores becomes important only for high values of the parameter itself (Jarvis, 1998).

Conclusions

Given the high values of the coefficient r of correlation and the low differences between estimates and measurements of percolation observed in 3 out of the 4 soils, our results encourage the use of the MACRO model for the simulation of water flow in soils of the Lower Po Valley.

The use of pedotransfer functions can be very helpful for model applications when measured data is not available; however, further testing of their adequacy for the estimate of saturated conductivity, which is so important in regulating water flow in soil, seems necessary.

Acknowledgements

This study was partially supported by Regione Emilia-Romagna, Soil Bureau (SINA Project).

References

JARVIS N. (1994). The MACRO model (Version 3.1). "Technical description and sample simulations". Reports and Dissertations 19, Dept. Soil Sci., SLU, Uppsala, Sweden.

JARVIS N.J., HOLLIS J.M., NICHOLLS P.H., MAYR T., EVANS S.P. (1997). MACRO-DB. A decision-support tool for assessing pesticide fate and mobility in soils. *Environmental Modelling & Software*, 12: 251-265.

JARVIS N.J. (1998). Modelling the impact of preferential flow on solute transport. In: Selim, H.M., Ma, L.A. (Eds.): *Physical non-equilibrium processes in soils: modelling and applications*. Ann Arbor Press, MI, USA.

LARSSON M.H., JARVIS N.J. (1999). "A dual-porosity model to quantify macropore flow effects on nitrate leaching". *J. Environ. Qual.*, 28: 1298-1307.

Regione Emilia-Romagna (1994). *Carta dei suoli dell'Emilia Romagna*, RER, Bologna.

SPALLACCI P., BOSCHI V. (1980). "Spreading of pig and cattle slurries on arable land: lysimeter and field experiments". In: J.K.R. Gasser (Ed.): *Effluents from livestock*, Applied Science Publ. Ltd, Barking (Essex), pp. 241-275.

UNGARO F., CALZOLARI C. (1998). "Soil water content estimation: performance of available pedotransfer functions for predicting water retention properties in areas at high environmental risk of the Pianura Padano-Veneta (Northern Italy)". 7th ICCTA, Firenze, 15-18 Novembre.

DESERTIFICATION AND AGRICULTURAL ACTIVITY IN THE INNER PARTS OF THE PLAIN OF CATANIA (SICILY - ITALY)

Salvatore Raimondi

Department of Agronomy, Herbaceous Cultivation and Pedology. University of Palermo

Abstract

The Author depicts the activity of cereal cultivation in one area of eastern Sicily always characterized by this kind of agriculture. The author, after an environmental description, underlines how crop management through minimum tillage (the most used agricultural technique in this area) is not suitable for this semi-arid environment characterized by deep soil cracking. This agricultural technique, together with the E.U. agricultural policy, which supporting, through financial help, continuous cereal crops without rest cycle deeply changed the environment. Cropping in rotation with fallow, has been replaced by huge monocultural cereal crops, where wheat plants are small, and close their biological cycle at the end of March when often the ears are, empty and immature.

The soil organic content together with fertility is decreasing. This ongoing desertification process, can be stopped by controlling crop rotation and by a more sustainable agronomic management which takes in consideration the environmental features of these areas, as should be indicated in thematic maps elaborated according to land evaluation criteria pointed by the Land Capability and Land Suitability Systems.

Introduction

Desertification is a rather quick process in which land loses or tends to lose the ability to support living beings. The reasons can be climatic (long period of drought) or linked to human activity that causes erosion, salinization and alkalinization, pollution and cementation (Aru *et al.*, 1993; Aru, 1995; Fierotti, 1997; Sequi e Vianello, 1998). In some cases, forms of tillage that do not consider the land pedologic and environmental characteristics favor the aforementioned conditions, thus causing organic matter depletion, erosion and even the lowering of the soil capacity to hold water for plants. This was noticed in an inner area of the Plain of Catania, during the mid-nineties, in occasion of a pedologic survey. Since then, the land has been object of many investigations that have the objective of controlling the conditions of the soil and the vegetation during the different seasons.

The aim of this paper is to describe the desertification in act in one of the inner zones of the Plain of Catania and to indicate the interventions apt to change the current trend.

Materials and Methods

Description of the area

The area in question falls in the territory of Ramacca, Castel di Iùdica, Raddusa (CT) and Aidone (EN). Between 100 and 500 m a.s.l., the land forms mild to steep slopes with large plain areas. The involved villages stretch between Palma, Mandola and Margherito and fall within the drainage basins of the rivers Gornalunga and Ferro. The substratum is made by recent and terraced, fluvial alluviums standing on clays from Serravalliano, by the substratum of the gypsiferous - sulphurous series (Higher Miocene) and by clays and arenaceous marl from Numidic Flysch (Lower Miocene; Geologic Service of Italy, 1976; Grasso *et al.*, 1993). It is used as rainfed cropping area where durum wheat stands out, and as irrigated land where full field vegetables (artichokes, tomatoes, egg plants, peppers and watermelons) are cultivated. In some areas there are citrus plantations (oranges). They make up the innermost strip of the large area of citrus orchards within the Plain of Catania.

The climate, in accordance with thermopluviometric data during 1980-1995, obtained in the stations of Raddusa (300 m a.s.l.) and Castel di Iùdica (210 m a.s.l.), proves to be semiarid, third mesothermic (Thornthwaite climatic classification; Thornthwaite and Mather, 1957). The probability elaboration of 60% (Raimondi, 1996; Raimondi *et al.*, 1997a) reveals that:

- Average temperature of air is 17.3 °C;

- Average annual rainfall is 364 mm;

- Index of global humidity is -51.6 (Thornthwaite climatic classification);

- Thermic efficiency is 886 mm.

The pedoclimate (elaborated through thermopluviometric data of the air, Soil Survey Staff, 1997) consists in an intermediate xeric-torrid water regime, and a continental thermic thermometric regime [15≤ T (°C) soil average <19; Raimondi *et al.*, in press]. The parameters show the following values:

- Average annual temperature of soil is 18.3 °C;

- Average annual summer soil temperature at the depth of 50 cm is 24.6 °C;

- Average annual winter soil temperature of soil at the depth of 50 cm is 10.8 °C;

- Dry days in the control moisture section >180 (Billaux, 1978).

All the cartographic elaborations, made in this area, showed severe aridity (Raimondi, 1991; Raimondi, 1993; Raimondi *et al.*, 1997b; Raimondi *et al.*, in press).

Pedologic investigation

Some Vertisols were detected during the soil survey period (Soil Survey Staff, 1997). The specific characteristic of this soil is not to close up these cracks during winter and to form at their insertions "craters", that can reach the depth of 35-40 cm (Raimondi, 1995; Raimondi, 1996). Their occurrence is linked to pedologic, thermopluviometric and pedoclimatic conditions where the soil stays dry for more than 6 months per year (Raimondi, in press). In this area the Raddusa soil series (Raimondi, 1996) was proposed and defined as: typic haplotorrerts, very fine, smectitic, thermic continental on terraced alluviums. It constitutes in Sicily the first series of soil of the Torrerts suborder (Vertisols that have open cracks during winter). Vertic and gypsic xerochrepts together with typic xerorthents have been detected in this area after several years of surveys.

In these years different profiles have been opened, samples have been drawn in all the horizons and subhorizons, and many drillings have been taken. During the field investigations, in addition to surveying the usual characteristics, cracks have been controlled, soil temperature and moisture have been checked. Table 1 shows survey data for two different periods of the year.

Table 1

Moisture and temperature data surveyed in the countryside land.

Depth (cm)	Temperature (°C)		Moisture (%)	
	08/02/1994	18/07/1994	08/02/1994	18/07/1994
Air	9,0	37,6	-	-
5	9,2	34,3	22,0	4,5
15	10,5	30,8	28,3	6,4
50	12,5	25,4	23,2	10,3
75	13,2	24,1	16,0	14,9
100	13,8	21,2	12,5	12,1

During these surveying years the objective has been to establish a relation between these semiarid areas and other adjacent wetter areas (Erei and Iblei Mountains and Etna), and to study the agronomic management of this soil, because wheat yield results are actually uncertain.

Results and discussions

Under rainfed conditions, the soils of this area are the best suited for autumn-spring cereal production and in particular for durum wheat. The town of Raddusa is called "Wheat City". The adopted cropping technique is diversified. In areas in which irrigation water is available, the cereal-horticultural trend prevails; wheat follows several vegetable species such as watermelon, melon, tomato and artichoke. With the rainfed regime, wheat is generally cultivated after complete fallow, or after wheat, or vetch [*Vicia sativa*] (seed or fodder), often associated with *Vicia faba minor* variety. The latter is present in farms in which animal breeding (sheep or cattle) takes place, while complete fallow is dominant in the remaining farms. On sloping hillsides, wheat and complete fallow increase susceptibility to erosion and a progressive evolution towards the formation of real gullies is often observed. The phenomenon's intensity is conditioned to the adopted cultivation technique and in particular to the type and modality of the tillage. The preliminary tillage on wheat is ploughing to a depth of 30-40 cm. Since about five years (due to a drop in wheat sale prices), many farmers have preferred the scarification through discissors, such as "tiller" or "Chisel" (to reduce production's costs). The ploughing is carried out only in those year in which the land is left to fallow. Such operations take place in the summer before sowing. These procedures have, as it is known, a negative effect on the organic matter's balance, and the lowering of the relative analytic value (already observed) determines a drop in soil fertility. The complementary tillage generally consists in harrowing 2-3 times with fixed teeth harrows. In recent years, some large farms on plain areas or mild slopes soils have adopted the sod-seeding with sowing machines like "Amazzone". Seeding occurs in the November-December period, and immediately after many farmers practice rolling. The seeding density ranges between 160 and 220 kg/ha. Fertilization is carried out with biammonic phosphate, or with 200 - 250 kg/ha of 16-35 and 15-30 binary fertilizers. Some farmers, to avoid the top dressing fertilization, spread urea at sowing. In most cases urea is often spread a month after plant emergency. Altogether, with pre-sowing and top dressing, 80-100 kg of nitrogen are applied in equal parts, or 2/3 during pre-sowing and 1/3 during top dressing.

The organic matter balance shows an increasing deficit due to the high rate of mineralization (*eremacausi*), and to overcome this inconvenience, the practice of ploughing in the stubble and possibly even straw is now spreading. At this stage, nitrogenous mineral fertilizers, particularly urea, are added to the soil with the crop residues. The dose is generally 1 kg of nitrogen per 100 kg of straw. Nowadays, most farmers burn the straw after having allowed the grazing. Weed control is performed chemically during pre-sowing (pre-emergency) or post-emergency (between the stem extension and the head in boot stages). In farms in which fallow is practiced, weeding is not carried out since weed control is realized through frequent tilling. Farmers that cultivate field vegetables, according to weather conditions, carry out a supplementary type of irrigation through sprinkling systems during the stem extension or the heading, and 700-1000 m^3/ha of water are supplied during this operation which is now part of the common management. Harvesting, carried out with combine harvesters, falls sometime in the second half of May. The grain yield varies from 3-5 t/ha with peaks of 6 tons.

In the last years a lot of farmers have abandoned the fallow practice due to the big disadvantage of producing yield every two year, and accelerating the depletion of the organic matter content in an already negative humic balance. However the fallow has the advantages of storing water, enriching the soil with nitrogen and phosphorus (the biotic activity is intensified), improving the structural conditions and maintaining the soil free of weeds. As Bonciarelli says (1989), fallow is a practice that is disappearing, meanwhile agricultural systems evolve towards more intensive forms, since the limited advantages that can be obtained can be achieved more economically even through the limited use of the technical equipment nowadays available. The field's observations, on the studied area, show that in these semiarid and hot-arid environments, in which during winter the moistening front can rise up to a depth of 50-60 cm, rainfed fallow is indispensable. The water reaching the soil during winter is scarce, and it does not allow wheat to close productive cycles with regular production.

The new trend of sod-seeding, where weeding is performed with herbicidal treatment, using total action chemical products and without effects, or minimum tillage (the soil is tilled to a depth of 5-15 cm), doesn't result in good yields (all the desired effects are instead obtained in other Sicilian environments). This occurs because the soil during the autumn-winter period remains cracked at surface and below the tilled layer. Rain water, which does not have enough time to penetrate the low permeability soil mass and the peds, reaches the cracks and percolates deeply in the soil, emphasizing the pedologic aridity. In some years, a short dry period after seeding is enough for the soil to reform cracks. Temperature during winter is usually high, and the vegetative stasis is short or absent. In these conditions water loss is remarkable both in depth and through evapotranspiration. Those farmers, aware of the aforementioned condition, try to close cracks with a groom harrow passage. Despite these interventions, the observed productive results are scarce, because water for plant photosynthetic activity is not sufficient and the crops enter a water stress condition. Depending on the stage of the biologic cycle, a blocking phenomenon (*stretta*) may occur.

Conclusiôn

In the areas of Ramacca, Castel di Iùdica, Raddusa and Aidone, with a hot-arid climate, productive yield results are limited by the water quantity that the soil is able to accumulate for photosynthetic activity during rainy periods. Rarely, continuous wheat cropping registers sufficient yields to justify its cultivation. Even when reducing some of the voices in the passive balance concerning tillage operation, the economic balance is negative and in some years, at the end of March, wheat starts to dry out. In this case, the cereal often is not harvested and the crop is left to sheep and cow grazing. Wheat after fallow results in excellent productions on the soils of Raddusa (more than 6 t/ha) and fair productions on vertic and gypsic xerochrepts. Where the gypsic horizon is emerging or where the salic horizon is present on the surface, the productive level drops considerably. In this last case plants do not emerge and the soil remains bare. On steeper hillsides where the soil is strongly eroded (near to gully formation) wheat crops hardly result in acceptable productions, and determines soil degradation. Only the EU funding for durum wheat production economically justifies the present agricultural reality, which has a remarkable impact on the land. In fact, farmers tend to till both steep sloping lots always used for pasture and grounds with real gullies. This happens because it is sufficient to have land grown with wheat, during the inspection, to fulfill the standards for approval of the Community grant. This type of agricultural management has a remarkable impact on the landscape. It changes its shape and the yellow color of the fields (March-April) underlines the heavy drought and the degradation that do not support the typical Sicilian plant life. Then, the development of soil evaluation maps, according to Land Capability and Land Suitability criteria, would allow a better land management. The collected and elaborated data in this research showed seeds crops should not be cultivated if the soil has a slope >15%. These areas should be assigned to other more compatible utilizations (controlled pasture, wood, olive groves), guided and financially supported by an appropriate agricultural policy. Community intervention, for durum wheat, should be reserved only to the surfaces in which this use is justified (from the productive aspect) and is compatible with the environment. Furthermore it should be realized through a proper technical assistance and control.

Bibliography

BILLAUX P. (1978). Estimation du "regime hidrique" des sols au moyen des données climatiques. La méthode graphique: son utilisation dans le cadre de la Taxonomie Americaine des sols. ORSTOM, ser. Pedol., Vol. XVI, n 3, France, pp. 317-338.

ARU A., BALDACCINI P. , MALQUORI A. , MELIS R. T., VACCA S. (1983). Il consumo delle terre a causa della espansione urbanistica nel territorio intorno a Cagliari. Istituto di Geologia, Paleontologia e Geografia fisica. Cagliari, 15 pp.

ARU A. (1995). Il ruolo della Pedologia nella pianificazione e progettazione con particolare riferimento alla Sardegna. Atti del convegno "Il ruolo della Pedologia nella pianificazione e gestione del territorio", Cagliari, 6-10 giugno, pp. 17-28.

BONCIARELLI F. (1989). *Fondamenti di Agronomia generale*. Edizioni Edagricole, Bologna, 372 pp.

FIEROTTI G. (1997). *I Suoli della Sicilia*. Flaccovio editore. Palermo, pp. 359.

FIEROTTI G., DAZZI C., RAIMONDI S. (1988). Commento alla Carta dei Suoli della Sicilia. Assessorato Territorio e Ambiente. Palermo, 19 pp.

FIEROTTI G., DAZZI C., RAIMONDI S. (1990). La valutazione delle terre ai fini agricoli: principi, metodi ed applicazioni. Quaderni di Agronomia n. 12. Arti Grafiche Siciliane, Palermo, pp. 7-99.

GRASSI M., LA MANNA F. (1993). Carta geologica del fronte della falda di Gela tra il fiume Gornalunga e il fiume Margi (Sicilia S.E.). Geologia Romana. Roma, pp. 55-72.

RAIMONDI S. (1991). L'impiego dei dati termopluviometrici in pedologia: il pedoclima dei suoli siciliani durante il trentennio 1921-1950. Atti del convegno "Agrometeorologia e Telerilevamento". Agronica, Palermo, pp. 76-92.

RAIMONDI S. (1993). Il clima ed il pedoclima dei suoli siciliani durante il trentaduennio 1951-1982. Quaderni di

Agronomia n. 13. Bonfardino, Palermo, pp. 24-51.

RAIMONDI S. (1995). I Torrerts siciliani: caratteristiche morfologiche e distribuzione geografica. Atti del XII convegno nazionale della Società di Chimica Agraria. PATRON editore, Bologna, pp.127-136.

RAIMONDI S. (1996). La serie di suoli Raddusa (Typic Haplotorrerts). In: "*Il pedoclima e applicazioni tassonomiche*". Multistampa, Palermo, pp. 43-47.

RAIMONDI S., POMA I., FRENDA A. S. (1997a). Il pedoclima come fattore di sensibilità ambientale: esempio di metodologia applicata all'agro di Sparacia – Cammarata (AG). *Rivista di Agronomia*, anno XXXI n. 3 suppl.. Edagricole, Bologna, pp. 726-733.

RAIMONDI S., LUPO M., SARNO M. (1997b). Il clima ed il pedoclima dei monti Erei meridionali. *Sicilia Foreste* anno IV N. 15/16. Palermo, pp. 39-45.

RAIMONDI S., LUPO M., TUSA D. (in corso di stampa). Il clima ed il pedoclima dei suoli vulcanici dell'Etna. Lavoro presentato a Napoli al convegno annuale della S.I.S.S. nel 1998.

RAIMONDI S. (in corso di stampa). Il pedoclima in Sicilia. Relazione presentata al convegno "Gli studi climatologici strumenti per la gestione del territorio" organizzato dall'Assessorato Agricoltura e Foreste – Servizio allo sviluppo. Palermo, 16 Dicembre 1998.

SEQUI P., VIANELLO G. (1998). *Sensibilità e vulnerabilità del suolo*. Franco Angeli. Milano, pp.404.

Servizio Geologico d'Italia (1976). *Carta geologica d'Italia*. Salomone, Roma.

Soil Survey Staff (1997). *Soil Taxonomy*. Seventh Edition. United States Department of Agriculture. Washington, pp. 544.

THORNTHWAITE C.W., MATHER j.r. (1957). Instructions and tables for computing potential evapotranspiration and the water balance. *Climatology*, X, 3. Centerton N.Y. USA.

SENSITIVITY TO ACIDIFICATION OF ACID FOREST SOILS IN FLANDERS (BELGIUM)

E. Van Ranst, G. Callaert, B. Gellinck

Laboratory of Soil Science, University of Gent
Krijgslaan 281(S8), B-9000 Gent, Belgium

Introduction

In recent decades, concern has grown about the potential impact of acid deposition on land and water. Ulrich *et al.* (1979) were among the first to pay attention to acidification of forest soils caused by acid deposition and its potentially harmful effects on forest ecosystems. Evidence exists that the vitality of forest ecosystems in Europe is seriously endangered by changes in soil chemistry in the rootzone (Roelofs *et al.*, 1985; Roberts *et al.*, 1989).

Although acidification of soils is a natural process in areas with precipitation excess, it is the present rate of soil acidification that is alarming. Current enhanced acidification of European forest soils due to elevated acid atmospheric deposition has been proven by input-output budgets (Van Breemen *et al.*, 1988; Van Dobben *et al.*, 1992), and by resampling forest soils at intervals of several decades in Sweden (Falkengren-Grerup, 1986; Falkengren-Grerup *et al.*, 1987; Hallbäcken and Tamm, 1986), Scotland (Billet *et al.*, 1988, 1990), Germany (Ulrich *et al.*, 1980; Butzke, 1981; 1988), Austria (Glatzel and Kazda, 1985), Belgium (Ronse *et al.*, 1988) and the Netherlands (Van der Salm, 1985). These studies showed that soil pH and base saturation have decreased strongly within the rootzone of most forest soils in the past 30 years.

Many existing characterizations of long-term changes in soil exchange components are speculative (Likens *et al.*, 1996), and the rate and extent of soil acidification attributable to acid deposition remains equivocal. The ability to quantify the effect of acid deposition on soil has been hindered by two important factors. First, soil properties in unmanaged ecosystems are altered over long time periods, decades to centuries. Second, acid precipitation [defined as the deposition of H ions as well as those ions or aerosols (SO_4^{2-}, NO_3^-, NH_4^+, SO_2, or NO_x) having the potential to produce acid in the soil (Abrahamsen, 1984)] is only one of a complex of sources of acidity input in forest ecosystems (Binkley and Richter, 1987). Because of the difficulty to isolate the role of anthropogenic vs. natural sources of acidity in affecting processes of soil acidification, it seems to be more appropriate to assess soil buffering against acidification, as this imparts resilience to forest ecosystems.

Soils have various mechanisms to buffer acid inputs, such as the exchange of base cations against protons and the adsorption of SO_4 on Al and Fe hydroxides against hydroxyl ions (Johnson, 1984). Both buffering processes are fast and, especially cation exchange, will prevent the occurrence of temporarily, extremely low pH values and associated high concentrations of Al. However, compared to current deposition rates, the capacity of these buffer mechanisms is limited on a long-time scale (decades or centuries). Another important mechanism, which involves proton consumption, is mineral weathering. Contrary to the capacity for cation exchange and SO_4 adsorption, the acid neutralizing capacity of silicate minerals is nearly infinite, but the rate of mineral dissolution is low. At low base saturation (and pH), dissolution of Al from secondary Al compounds (organic Al complexes and secondary Al minerals) can play an important role (De Vries and Breeuwsma, 1987).

In this paper, a new approach has been used to assess the acid buffer capacity and the risk of saturation with H^+ and Al^{3+} of the litter layer and the upper 10 cm of mineral soil in six forest plots in Flanders, ranging from sand to silt.

Principles of buffering in soils

All soil constituents can be considered as compounds formed by reaction between acids and bases. Acids, added to the soil, may break them up in an acid and a base component. The bases fix the acidity. This is the fundamental principle of buffering. But these reactions produce acids, which then determine the new acid-base status of the soil. This acid-base status depends primarily on the acidic strength of the released acids. To clearly expose this concept, the components composing the soil constituents can be divided into three groups, according to the acidic strength (pKa) of the acid member of the different conjugate pairs (Table I).

Soil constituents are composed of combinations between one of the acids and one of the bases; some are composed of bases only. Different possible combinations can be considered:

(1) Soil constituents of acids 1 + bases 1, e.g. SiONa, on reaction with acid give reaction products which cannot critically influence soil acidity.

$$SiONa + H^+ + NO_3^- \rightarrow SiOH + Na^+ + NO_3^-$$

(2) Soil constituents of acids 1 + bases 2, bases 2 only, or acids 2 + bases 1 replace the strong acid by weaker acids, but the total acidity remains unchanged.

(3) Soil constituents of acids 2 + bases 2 and acids 3 + bases 2 replace the strong acid by weaker acids, but the total amount of acidity increases.

$$\underbrace{(R\text{-}COO)_3Al + 3H^+}_{3H^+} + 3NO_3^- \rightarrow \underbrace{3R\text{-}COOH + Al^{3+}}_{6H^+} + 3NO_3^-$$

(4) Soil constituents of acids 1 + bases 3, or bases 3 only do not react with acid when the pH > 3.

(5) Soil constituents of acids 3 + bases 1 do not change the acidity by reacting with acid in soils when the pH > 3.

$$(SiO)_3Fe + 3H^+ + 3NO_3^- \rightarrow 3(SiOH) + Fe^{3+} + 3NO_3^-$$

$$Fe^{3+}.6H_2O \rightarrow Fe(OH)_3 + 3H^+ + 3H_2O$$

Buffering is complete only with constituents of pKa > 5.5. When Al^{3+}, $Al(OH)_3$, Fe^{3+} and $RCOO^-$ are present, the strong acid is replaced by weaker acids, but the total acidity may increase.

Table I

Subdivision of components of the soil constituents.

Group	Acids	Bases
Group 1: pKa > 5.5	Na^+, K^+, Mg^{2+}, Ca^{2+}, (Fe^{2+}, Mn^{2+} in reducing conditions)	SiO^-, HCO_3^-, CO_3^{2-}, PO_4^{3-}, HPO_4^{2-}
Group 2: pKa 5.5 ↔ 3.5	Al^{3+}	$R\text{-}COO^-$, $Al(OH)_3$
Group 3: pKa < 3.5	Fe^{3+}, Mn^{4+}, Ti^{4+} in oxidizing conditions	Cl^-, NO_3^-, SO_4^{2-}, $H_2PO_4^-$, $Fe(OH)_3$, MnO_2, TiO_2

Material and methods

Some characteristics of the study sites and soils

Six forest plots located in Flanders (North Belgium) and belonging to the Intensive Monitoring Programme of Forest Ecosystems of the Flemish Community, were selected for this research. Some characteristics of these plots are given in Table II. The litter layer was sampled, except in plot 5; the upper 10 cm of mineral soil in all 6 plots and ranges from sand to silt. All samples were sieved over 2 mm mesh width, to remove stones and roots, and air dried before storage. Some basic characteristics of the litter and mineral soil samples are given in Table III. All samples are acid, with pH-H2O between 3.5 and 4.0. The mineralogical composition of all samples is dominated by quartz, with minor amounts of Na-feldspars. The feldspar content increases as the soil texture becomes finer. In the sandy soils (plots 1 and 2) no other minerals were identified by X-ray diffraction (XRD). Traces of muscovite were found on the mineral fraction of the litter layer in plot 3, but this mineral seems to be absent in the underlying mineral layer. The samples of plots 4 and 5 have somewhat more muscovite compared to plot 3, as well as some traces of kaolinite and chlorite. These minerals are also present in very small amounts in the samples of plot 6, as well as traces of amphiboles only in the litter layer.

Table II

Some characteristics of the studied forest plots.

Plot nr.	Location	Main tree species	Aver. thickness litter layer (cm)	Textural class topsoil (FAO, 1977)	Soil type (FA0, 1988)
1	Ravels	*Pinus nigra* ARNOLD	8	sand	Haplic Podzol
2	Brasschaat	*Pinus sylvestris* L.	8	loamy sand	Umbric Regosol
3	Wijnendale	*Fagus sylvatica* L.	16	sandy loam	Dystric Cambisol
4	Gontrode 1	*Quercus robur* L. *Fagus sylvatica* L.	6	loam	Gleyic Cambisol
5	Gontrode 2	*Fraxinus excelsior* L. *Acer pseudoplatanus*	0	silt loam	Gleyic Cambisol
6	Zoniën	*Fagus sylvatica* L.	4	silt	Dystric Podzoluvisol

Table III

Some physical and chemical characteristics of the litter layer and the upper 10 cm of the mineral soil in the studied plots.

Plot nr	Organic carbon ($g\ kg^{-1}$)	Total nitrogen ($mg\ kg^{-1}$)	C/N ratio	pH H_2O (ratio)	Bulk density ($kg\ m^{-3}$)
		Litter layer			
1	371.8	8729	43	3.5 (1:5)	107
2	332.0	9156	36	3.6 (1:5)	102
3	388.4	15330	25	3.5 (1:10)	142
4	390.4	13944	28	3.8 (1:10)	124
5	-	-	-	-	-
6	358.4	11368	32	3.9 (1:10)	125
		Mineral layer			
1	25.2	1050	24	3.6 (1:2.5)	1250
2	14.2	770	18	3.8 (1:2.5)	1210
3	108.8	4368	25	3.5 (1:2.5)	1106
4	62.6	3311	19	3.7 (1:2.5)	1169
5	62.8	4697	13	4.0 (1:2.5)	1144
6	43.7	2415	18	3.9 (1:2.5)	1421

Collected data

The total elemental composition was determined after (1) an attack with HF and $HClO_4$ and redissolution in HCl for determination of Fe, Mg, Mn, Ca, Na and K with AAS: and (2) fusion with Li_2CO_3 and H_3BO_3 and redissolution in HCl for determination of Al and Si with AAS in a N_2O flame. P and Ti were determined colorimetrically (Ingamells, 1966; Omang, 1969). Loss on ignition was determined between 0 and 110°C (H_2O^-), and between 110 and 1000°C (H_2O^+). Total S was determined turbidimetrically with $BaCl_2$. Pyrophosphate extractable Al (Al_{pyr}) was measured with AAS. Exchangeable cations (Ca, Mg, Na, K and Al) extracted with $BaCl_2$ 0.1 M were measured with ICP. Iron bound to organic matter has not been determined, because it is difficult to distinguish it from $Fe(OH)_3$. Tests to determine Cl^- and NO_3^- showed too small amounts to obtain reliable results, and therefore, they have not been taken into account.

Calculation of the acid buffer capacity

The acid buffer capacity could be approximated adequately, taking into account the following limitations:

(1) The anions of SO_4^{-2} and NO_3^- salts do not act as a buffer. Consequently, a positive charge equal to the negative charge of these anions, cannot be taken into account for the buffer capacity. In the total elemental analysis, SO_3 and NO_2 are responsible for part of the weight loss at 1000°C and as such these elements are not determined separately. However, the amounts of these salts in the solid phase are usually low and can be ignored. The carbonate fractions do act as a buffer, and positive charges equalling their charges, contribute to the buffer capacity.

The amount of P is known as P_2O_5. However, as in most soils the pH is between 2 and 7, P is present as $H_2PO_4^-$ and not as PO_4^{-3}, and thus the charge is -1 and not -3.

(2) With regard to Al, one has to take the fraction outside the silicate lattice into account. This Al is not present with a +3 value, but is more or less strongly hydroxylised or bound to the organic material. The extent of hydroxylation depends on the pH of the environment. Because the pH is usually lower than 5, we conventionally accept that Al_{pyr} is partly hydroxylised and partly bound to the organic material, as follows : R-COO-Al-OH. In contact with acids, the following reaction takes place : R-COO-Al-OH + $2H^+ \rightarrow$ R-COOH + Al^{+3} + H_2O. Each Al_{pyr} thus fixes $2H^+$.

(3) The amounts of Fe_2O_3, MnO en TiO_2 are not taken into account as cations that can neutralise acid input.

For the calculation of the buffer capacity, it was possible to use the original, elemental total contents, because for the chemical analysis and the determination of the bulk density air dried samples were used.

The final acid buffer capacity was assessed as follows:

(1) XRD showed that the amount of clay minerals with surface can be neglected, and the exchangeable cations express the buffering charge of organic matter (OM);

(2) SO_4^{2-} salts are soluble during CEC analysis and their charge must be subtracted from the CEC;

(3) Al extracted in $Na_4P_2O_7$ is considered to have charge 2. The total Al is subdivided in Al_{sil} (Al in silicates = Al_{total} - Al_{pyr}) with charge 3 and Al_{pyr} with charge 2.

Three forms of buffering were obtained:

(1) buffering represented by the basic cations (BC) in silicates = total charge of basic cations - charge on OM including SO_4^{-2} (= CEC) - charge on $H_2PO_4^-$;

(2) charge on organic matter (OM) = CEC - charge of SO_4^{-2};

(3) charge on Al = $Al_{sil} + Al_{pyr}$.

The buffer capacities per ha were calculated according to the thickness and the bulk density of the litter layer, and the bulk density of the upper 10 cm of mineral soil (Table III).

Results and discussion

In Flanders, the precipitation exceeds the evapotranspiration. This results in a net water movement downwards, which in turn enables drainage of mobile components resulting from decomposition reactions. The removal of the decomposition products allows these reactions to continue. In a natural environment, decomposition is mainly the result of the supply or the production of acid components like H_2CO_3, HNO_3, H_2SO_4 and organic acids. HNO_3 and H_2SO_4 form when N and S are released from organic material. H_2CO_3 is a weak acid and as such does not play a major role in the decomposition reactions. The influence of NO_3^- and SO_4^{-2} on decomposition is hard to assess because these components are part of the normal cycle of nutrient uptake and release of the vegetation. The activity of the organic acids is related to the rate of decomposition of the organic material. The slower the decomposition, the longer the organic acids remain present, and the stronger the influence of these acids on the decomposition of the mineral components will be.

According to Ulrich and Matzner (1983), Van Breemen *et al.* (1984) and De Vries and Breeuwsma (1985), the production of acids in a natural environment is 0.1 to 0.9 $kmol_c ha^{-1} y^{-1}$. These figures are based either on the drainage of organic anions or on the estimated time required for podzolisation (± 10000 years). Because of the large differences between the minimum and maximum values reported, a reliable estimate for the scale of the reactions between the basic soil components and the natural acidity is hard to make. In any case, this acidity increases the acidity resulting from human activity. In the present conditions, acid components resulting from human activity are transported through the atmosphere. The deposition of gaseous acid compounds (SO_2, NO_x and NH_3) is higher in forest than in the open field, because trees act as efficient filters (De Vries and Breeuwsma, 1985). Apart from the direct influence on the compounds the deposited acidity has a toxic effect on the soil fauna. This reduces the decomposition rate of the organic material. The result is a prolonged reaction time of the organic acids on the mineral components and hence an enhanced decomposition of these components.

Table IV shows that, compared to the other basic cations, Ca is clearly predominating in the litter layers, except in plot 2, where the high Na content indicates the presence of a salt. Ca concentrations in the leaf tissues steadily increase during the growing season, till the start of the leaf drop. Ca is important for the cell structure (cell wall). Therefore, in contrast with other elements that are part of the cell plasma, Ca tends to accumulate in older tissue.

Table IV

Charge related to basic cations in silicates (BC), CEC including SO_4^{2-}, $H_2PO_4^-$, SO_4^{2-}, Al_{sil} and Al_{pyr} in mmolc kg^{-1}

Plot nr.	Ca^{2+}	Mg^{2+}	Na^+	K^+	Σ BC	CEC	H_2PO^-	SO_4^{2-}	Al_{sil}	Al_{pyr}
Litter layer										
1	71	25	42	51	189	109	16	60	524	149
2	71	30	216	60	377	119	16	96	782	129
3	121	40	42	51	254	151	16	33	418	59
4	186	70	52	77	385	280	24	31	753	118
5	-	-	-	-	-	-	-	-	-	-
6	150	65	87	96	398	333	20	21	1576	78
Mineral layer										
1	21	15	68	109	213	4	4	2	553	157
2	21	15	74	115	225	9	1	2	512	35
3	36	60	119	162	377	10	13	8	1329	118
4	75	250	171	283	779	28	12	6	3112	478
5	104	175	213	272	764	12	14	10	3412	376
6	111	130	261	349	851	16	23	4	3388	196

This might be the explanation for the distinct presence of Ca in the litter layers. The other nutrients, like N, P and K, are retranslocated starting from September, and as such their concentrations in the leaves decrease. The dominant basic cations in the mineral horizons are K and Na. This indicates the presence of Na feldspars and mica, as confirmed by XRD. All this suggests that the high Ca content of the litter layer can be attributed to Ca recycling through the leaves, and possibly the stronger retention of this cation by the organic material. For Mg, the differences between the mineral layers of the more sandy soils and finer soils are more distinct then these between the litter layers of the same soils. This puts forward the assumption that Mg is also more strongly retained by the litter layer then the monovalent cations.

According to Tables IV and V, no relation exists between texture and buffer capacity in the litter layers, but this relation is striking in the mineral layers. The considerable differences amongst the total charges of the 5 litter layers (Table V) are the result of the differences in mineralogical composition, thickness and bulk density.

Table V

Buffer capacity related to sum of basic cations (BC), organic matter (OM) and Al in $kmol_c ha^{-1}$

Plot nr	BC	OM	Al
		Litter layer	
1	5.478	4.194	57.609
2	19.747	1.877	74.338
3	19.767	26.810	108.374
4	6.324	18.526	64.802
5	-	-	-
6	2.250	15.600	82.700
		Mineral layer	
1	256.250	3.625	887.500
2	260.271	8.470	601.870
3	391.524	2.272	1600.382
4	866.697	24.900	4196.710
5	844.730	12.126	4333.472
6	1544.420	16.199	5092.864

Literature data for Belgium give an acid precipitation of 6 to 7 $kmol_c ha^{-1} yr^{-1}$. An indication of this precipitation is the high content of SO_4^{2-} in the litter layers, as compared with the mineral layers (Table IV). In the litter layers the buffer capacity by basic cations (BC) is only a fraction of the Al charge; even on the OM the charge exceeds the BC buffering to a very large extent (Table V). Without recycling by the vegetation of BC, the risk for a complete acidification of the litter layer would be real. But even with recycling, continuing addition of atmospheric acidity may lead to complete acidification by organic acids and Al in the near future. In the mineral horizons, the discrepancy between BC buffer capacity and Al buffer capacity is very striking. Further breakdown of silicates by external acidity and by the increased acidity of the litter may cause a complete saturation with Al, resulting in high toxicity levels by this element and other solubilized heavy metals. How the forest ecosystem will react to this condition is not clear at present, but one has to expect that this will strongly influence forest growth.

Conclusion

The proposed methodology to assess acid buffer capacity of acid forest soils, allowed to calculate different forms of buffering, related to (1) basic cations, (2) organic matter, and (3) Al, respectively, considering the elemental total composition, thickness, and bulk density of the litter and mineral topsoils. The results obtained for six Flemish forest ecosystems show the real danger for a complete acidification of the litter layers by organic acids and Al in the near future under a continuing atmospheric acid input. This acidification process will reduce the decomposition rate of organic matter, resulting in a prolonged reaction time of organic acids on the mineral components , and hence an enhanced breakdown of the silicates in the mineral topsoils. Finally, this will lead to a complete saturation with Al, and high toxicity levels of this element and other solubilized heavy metals, influencing forest vitality. The calculation procedure applied in this research can be used universally to assess acid buffer capacity of acid forest soils.

Acknowledgements

The authors express their gratitude to the Institute for Forestry and Game Management and the Fund for Scientific Research - Flanders, for the financial support of this research program (FWO n° G.0008.97).

References

ABRAHAMSEN G. (1984). Effects of acidic deposition of forest soil and vegetation. *Phil. Trans. R. Soc. Land.*, B 305: 369-382.

BILLET M.F., FITZPATRICK E.A., CRESSER M.S. (1988). Long-term changes in the acidity of forest soils in North-East Scotland. *Soil Use and Man.*, 4: 102-107.

BILLET M.F., PARKER-JERVIS F., FITZPATRICK E.A., CRESSER M.S. (1990). Forest soil chemical changes between 1949/50 and 1987. *J. Soil Sci.*, 41: 133-145.

BINKLEY D., RICHTER D.D. (1987). Nutrient cycles and H^+ budgets in forest ecosystems. *Adv. Ecol. Res.*, 16: 1-51.

BUTZKE H. (1981). Versauern unsere Wälder? Erste Ergebnisse der Überprüfung 20 Jahre alter pH-Wert-Messungen in Waldböden Nordrhein-Westfalens. *Forst und Holzwirt*, 36(21): 542-548.

BUTZKE H. (1988). Zur zeitlichen und kleinräumingen Variabilität des pH-Wertes im Waldböden Nordrhein-Westfalens. *Forst und Holzwirt*, 43(4): 81-85.

DE VRIES W., BREEUWSMA A. (1985). De invloed van natuurlijke zuurbronnen, afvoer van biomassa en zure regen op de verzuring van Nederlandse bosgronden. *Ned. Bosb. Tijdschrift*, 57: 111-118.

DE VRIES W., BREEUWSMA A. (1987). The relation between soil acidification and element cycling. *Water Air and Soil Poll.*, 35: 293-310.

FALKENGREN-GRERUP U. (1986). Soil acidification and vegetation changes in deciduous forest in Southern Sweden. *Oecologia*, 70: 339-347.

FALKENGREN-GRERUP U., LINNERMARK N., TYLER G. (1987). Changes in acidity and cation pools of south Swedish soils between 1949 and 1985. *Chemosphere*, 16: 2239-2248.

GLATZEL G., KAZDA M. (1985). Wachstum und Mineralstoffernährung von Buche (*Fagus sylvatica*) und Spitzahorn (*Acer platanoides*) auf versauerten und schwermetallbelastetem Bodenmaterial aus den Einsicherungsbereich. *Z. Pflanzenernähr. Bodenkd.*, 148: 429-438.

HALBÄCKEN L., TAMM C.O. (1986). Changes in soil acidity from 1927 to 1982-1984 in a forest area of south-west Sweden. *Scand. J. For Res.*, 1: 219-232.

INGAMELLS C.D. (1966). Absorptiometric methods in rapid silicate analysis. *Anal. Chim.*, 38: 1228-1234.

JOHNSON D.W. (1984). Sulfur cycling in forests. *Biogeochem.*, 1: 29-43.

LIKENS G.E., DRISCOLL C.T., BUSCO D.C. (1996). Long-term effects of acid rain: Response and recovery of a forest ecosystem. *Science*, 272: 244-246.

OMANG S.V. (1969). A rapid fusion method for decomposition and comprehensive analysis of silicates by atomic absorption spectrophotometry. *Anal. Chem. Acta.*, 46: 225-230.

ROBERTS T.M., SKEFFINGTON R.A., BLANK L.W. (1989). Causes of type 1 spruce decline. *Forestry*, 62(3): 179-222.

ROELOFS J.G.M., KEMPERS A.J., HOUDIJK A.L.F.M., JANSEN J. (1985). The effect of airborne ammonium sulphate on *Pinus nigra* var. *maritima* in the Netherlands. *Plant and Soil*, 84: 45-56.

RONSE A., DE TEMMERMAN L., GUNS M., DE BORGER R. (1988). Evolution of acidity, organic matter content, and CEC in uncultivated soils of North Belgium during the past 25 years. *Soil Sci.*, 146: 453-460.

ULRICH B., MAYER R., KHANNA P.K. (1979). Deposition von Luftverunreinigungen und ihre Auswirkungen in Waldökosystemen im Solling. *Schriften aus der Forstlichen Fakultät der Universität Götingen und der Niedersächsischen Forstlichen Versuchsanstalt*, Band 58: 291.

ULRICH B., MAYER R., KHANNA P.K. (1980). Chemical changes due to acid precipitation in a loess-derived soil in Central Europe. *Soil Sci.*, 130: 193-199.

ULRICH B., MATZNER E. (1983). *Abiotische Folgewirkungen der weitraümigen Ausbreitung von Luftverunreinigung, Umweltforschungsplan der Bundesminister des Inneren*, Forschungsbericht 10402615, BRD, 221 pp.

VAN BREEMEN N., MULDER J., DRISCOLL C.T. (1984). Atmosferische depositie en verzuring van bodem en water. In: *Zure regen; oorzaken, effecten en beleid. Proc. Symposium's Hertogenbosch* (Eds. Adema, E.H. and Van Ham, J.), Pudoc, Wageningen, pp. 121-128.

VAN BREEMEN N., VISSER W.F.J., PAPE Th. (1988). *Biogeochemistry of an oak-woodland ecosystem in the Netherlands, affected by acid atmospheric depositio.* PUDOC Scientific Publishers, Wageningen, the Netherlands, 197 pp.

VAN der SALM C. (1985). *Verzuring van bosbodems in de boswachterij Doorwerth in de periode 1950-1983*, Univ. Amsterdam, Rapport n° 19, 68 pp.

VAN DOBBEN H.T., MULDER J., VAN DAM H., HOUWELING H. (1992). *Impact of atmospheric deposition on the biogeochemistry of Moorland pools and surrounding terrestrial environment*, PUDOC Scientific Publishers, Wageningen, the Netherlands, 232 pp.

A NEW GEOSTATISTICAL APPROACH FOR ASSESSING SOIL QUALITY

Annamaria Castrignanò, Grazia Convertini, Nicola Martinelli

Istituto Sperimentale Agronomico
Via Celso Ulpiani, 5 - 70125 Bari (Italy)

Introduction

What is soil quality? Many farmers can easily recognise good soil quality, but defining it in quantitative scientific terms has proved more difficult. Nevertheless, awareness of the importance of soil quality for sustainability has increased in the last years and policy makers worldwide are demanding measurable indicators in order to formulate soil protection policies. Subsequent to defining soil quality is identification of specific soil parameters or indicators, intended to be the objective basis of an evaluation of soil quality. Table 1 lists a set of 17 physical, chemical and biological properties that have been proposed as the minimum required for measuring soil quality (Doran *et al.*, 1996). In addition it is necessary to specify maximum concentrations of various toxic substances including metals such as cadmium and zinc and organic pollutants.

Table 1

Proposed minimum data set of physical, chemical and biological indicators for screening the condition, quality and health of soil.

Physical:	***Chemical:***
• texture	• soil organic matter
• depth of soil, topsoil and rooting	• pH
• infiltration rate and bulk density	• electrical conductivity
• water hold capacity	• extractable N, P and K
Biological:	
• microbial biomass C and N	
• potentially mineralisable N	
• soil respiration	

There is no simple, single measure. Soil quality is multi-functional and is best considered in relation to the specific use to which the soil is put, in particular its capacity to perform crop production. To be practical for use by practitioners, extension workers, conservationists, scientists and policy makers over a wide range of ecological and socio-economic situations, the set of basic soil quality indicators should meet the following criteria:

- Describe soil physical, chemical and biological properties and processes;
- Be accessible to many users and applicable to field conditions;
- Be sensitive to variations in management and climate.

These individual soil quality indicators have then to be integrated to form a global soil quality index. This integration needs to be flexible enough to evaluate soil quality at different spatial scales, ranging from the farm to the regional scale and be applicable to any type of land use.

We have applied a geostatistical approach to integrate a potentially unlimited number of soil quality indicators (Castrignanò, 1998; Castrignanò and Giglio, 1998). The proposed method utilises multiple-variable indicator transform, which transforms measured data values into a binary value according to specific criteria. The criteria, developed independently for each indicator, are critical values or ranges which define the variation allowed for a soil of good quality. The approach can be used for assessment of both good and poor soil quality (vulnerability) and then allows to delineate areas needing some remedial procedure. Soil vulnerability is rated on the probability scale of areas having some limiting factors and the technique utilised is drawn from non-parametric geostatistics, called indicator kriging, to estimate values for unsampled locations.

Here we want to describe the validity of this method in evaluating soil quality, therefore we will present an application without rigorous treatment of geostatistics methodology. Detailed development of the approach can be found in the above-mentioned papers.

Methodology

Our work is based on a set of applied statistics techniques known as geostatistics (Goovaerts, 1997). Geostatistical methods can be used to detect, model, estimate and simulate spatial patterns of different kinds of data, such as soil parameters (Warrick *et al.*, 1986) or ecological phenomena

(Rossi *et al.*, 1992). The proposed approach is based on a simple binary transformation whereby each datum is transformed into an indicator, before variography and kriging. By convention, the data are coded 1, if they lie above or below the threshold value, in conformity with the definition of vulnerability interval, and 0 otherwise. The threshold value is arbitrary and depends on the objective of the study. In our example to define the nutrient status of a soil used for conventional arable agriculture, we selected four chemical parameters: total nitrogen (‰) (IN), $NaHCO_3$–extracted phosphorus (IP), expressed as P_2O_5 (ppm), exchangeable potassium (IK), expressed as K_2O (ppm) and pH (IPH). The critical threshold values were set to 1.5‰, 50 ppm, 100 ppm and 8, respectively for the four parameters. The result of the transform is a new data set composed of 0s and 1s from which a variogram is computed. This is then used to estimate values at other locations through kriging. The estimated values, ranging from 0 to 1, correspond to the probability that the unknown values are less than the specified thresholds for nitrogen, phosphorus and potassium, and greater than the one for pH (Journel, 1988).

Thus the probabilities calculated for unsampled locations by kriging provide a measure of vulnerability degree of the study area, i.e. they measure the probability that each parameter does not meet minimum criterium of a soil of good quality. If someone is interested in the probability of good soil quality, the calculated probability estimates have to be subtracted from 1. However, it is only the extension of single-parameter kriging to integrate information of multiple variables to make this method useful for environmental evaluation. The combined indicator (IGLOBAL) will vary within the interval [0, 1]: it will be 0 or 1 if all individual indicators are 0 or 1, respectively. Thus, soil will be coded 0 if it meets all the threshold criteria for all the soil parameters; 1 if all the individual parameters fail to match the criteria of good soil quality, revealing a condition of high vulnerability. When only some of the individual parameters fail to meet their critical thresholds, the indicators are summed according to equal weights, because, in our example, we gave the same importance to all the four selected parameters. However, this is not the general case at all and the diverse data should be integrated and weighted appropriately in a fashion which is likely to vary depending on geographic region or land use.

Results

To illustrate the method, we present an example data set containing four soil parameters (N, P_2O_5, K_2O and pH) for each of 118 positions located in a quadrangular grid pattern within a 10000 by 10000 m zone of Apulia region (south Italy). To calculate the variography of the indicator-transformed data and of the derived global indicator, we used the omnidirectional variogram function to which we fitted a spherical model for N, K_2O and pH and an exponential model for P_2O_5 and global indicator. The estimated coefficients of the models (table 2) show quite high nugget values, revealing random variability within short distances (less than 800 m). Among the indicators, P variation results more spatially structured and at longer range, whereas K variation is mostly random. Global index shows a high random variation and a quite long actual range (~ three times the range), which means that land degradation, in such forms as soil fertility decline and alkalinity, is affected by soil genesis processes but also is the physical manifestation, or syntom, of inappropriate land use and poor management.

Table 2

Regression coefficients of model indicator variograms.

VARIABLE	NUGGET EFFECT	RANGE (m)	SILL-NUGGET	MODEL
IN	0.22	6000	0.03	spherical
IP	0.16	3000	0.01	exponential
IK	0.18	4000	0.06	spherical
IPH	0.18	5500	0.09	spherical
IGLOBAL	0.065	3250	0.032	exponential

The equations representing the model variograms were then used in the ordinary kriging to estimate unknown values of 160 x 110 m cells. Each discretized point was estimated using the information from all neighbours within a 5000-m search radius. An effective way to represent landscape vulnerability is to produce contour maps of each individual indicator and of the global indicator. The figures 1 - 4 show the kriged estimates of the individual indicators for N, P_2O_5, K_2O and pH, respectively. These values indicate the probability that the soil in a particular location does not meet the threshold criteria for the four soil parameters. Summarising the four contour maps, we can say that the north-west corner of the area is estimated to have more than 70% chance to suffer P and K deficiencies and run the risk of alkalinity. On the contrary, zones with high probability (greater than 50%) of N deficiency are mostly located in south-west region. The maps also reveal several intermixed zones degrading from 90% to 10% level of probability, i.e. of decreasing susceptibility to soil nutrient decline and alkalinity risks.

Figure 1 - Kriged map of IN

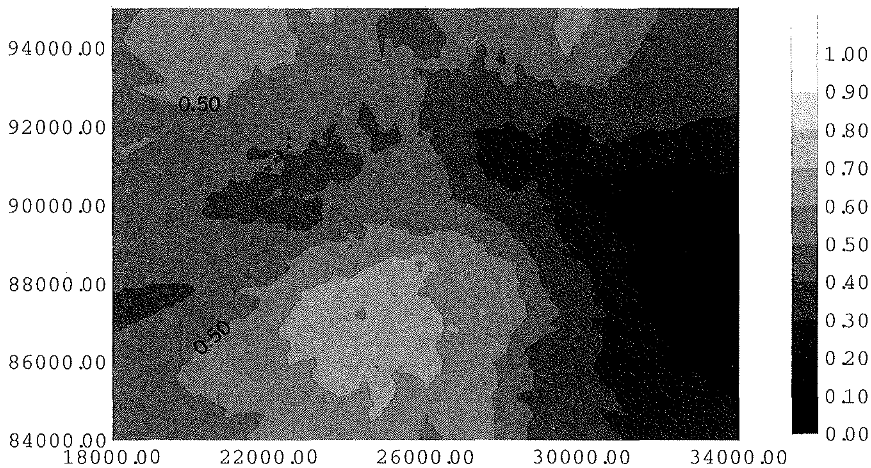
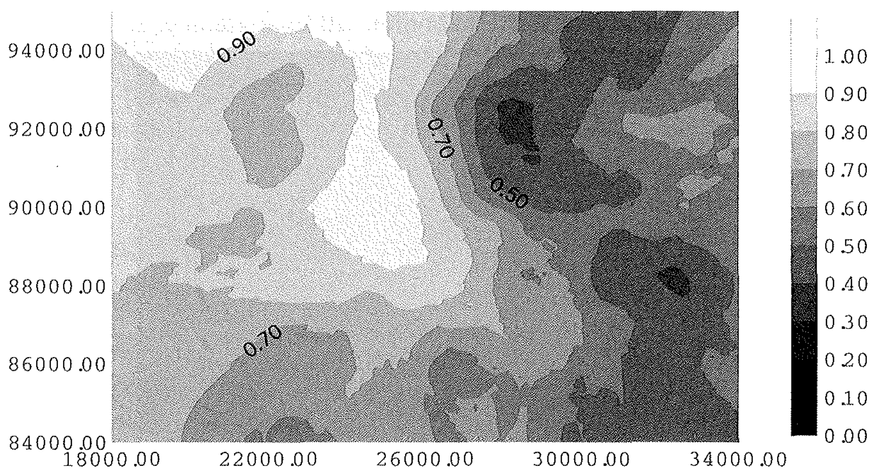


Figure 2 - Kriged map of IP



The most useful aspect of the proposed technique is that the individual soil indicators can be summarised in a single overall contour map (fig. 5). This map shows the locations in the landscape that exhibit a high probability of poor soil quality (west half of the area). To know which specific parameters are responsible for causing low soil quality, it needs to evaluate each soil indicator map separately.

Figure 3 - Kriged map of IK

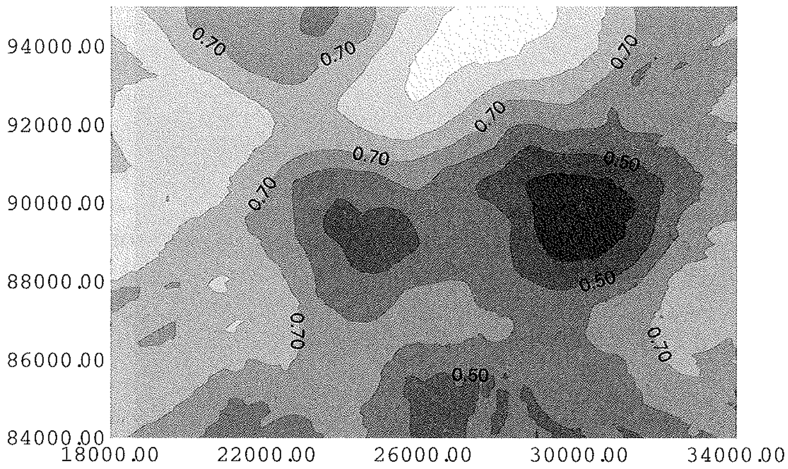


Figure 4 - Kriged map of IPH

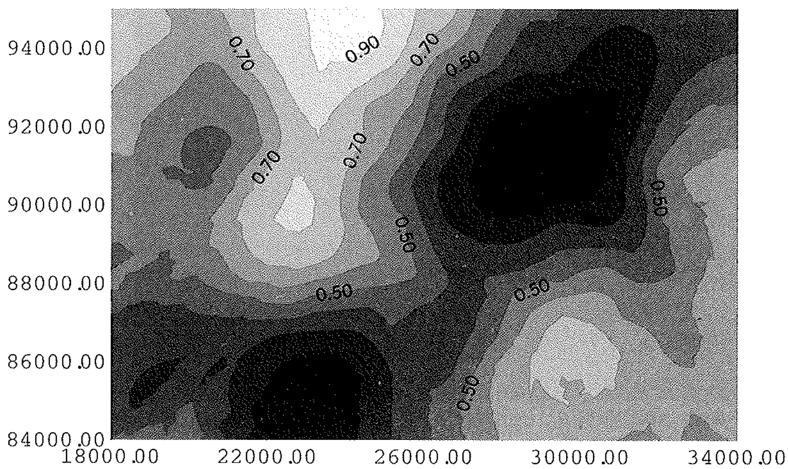
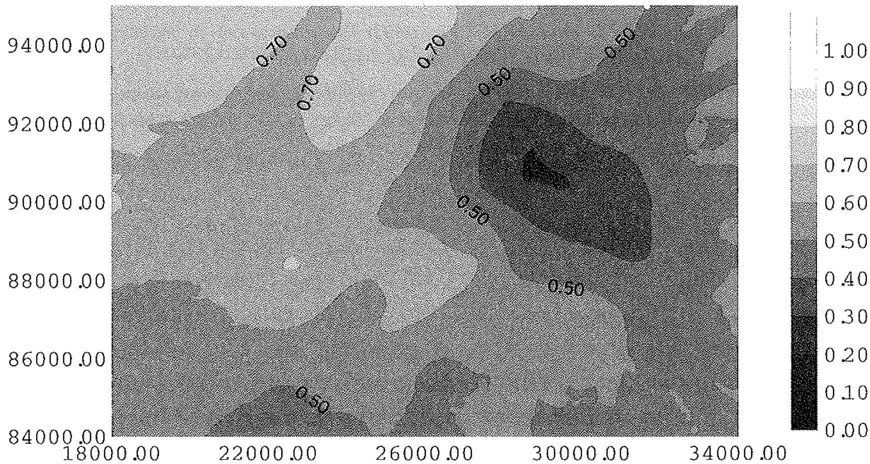


Figure 5 - Kriged map of IGLOBAL



Conclusions

The analysis of the individual maps and of the overall map suggests some conclusions that can be applicable to soil management programs. While each parameter appears to be substandard in the north-west corner, N deficiencies are located mainly in mid-south of the area. On the contrary, the east half of the area does not seem to need some urgent remedial procedure.

The proposed geostatistical approach provides an overall integrative assessment of soil quality and can be used for evaluating the sustainability of different cropping and management systems. Through the use of this method, in fact, it is possible to identify and manage areas of increasing degradation and monitor the progress of adopted treatments. However, its effectiveness depends mainly on the choice of soil indicators and their corresponding threshold values and how they are locally related to true soil quality.

Bibliography

CASTRIGNANÒ A. (1998). L'uso della Geostatistica per una stima quantitativa della qualità del suolo. *In:"Sensibilità e Vulnerabilità del Suolo"*, Franco Angeli (ed.): 153-164.

CASTRIGNANÒ A., GIGLIO L. (1998). L'uso di una procedura geostatistica multivariata per la stima della qualità del suolo. *Journal of SISS*, Year XLVII, 3: 365-380

DORAN J.W., SARRANTONIO M., LIEBIG M.A. (1996). Soil health and sustainability. *Advances in Agronomy*, 56: 1-54.

GOOVAERTS P. (1997). *Geostatistics for Natural Resources Evaluation.* Oxford Univ. Press, New York, 512 pp.

JOURNEL A.G. (1988). Non-parametric geostatistics for risk and additional sampling assessment. In L. Keith (ed.) *Principles of environmental sampling*. Am. Chem. Soc., Washington, DC: 45-72.

ROSSI R.E., MULLA D.J., JOURNEL A.G., FRANZ E.H. (1992). Geostatistical tools for modeling and interpreting ecological spatial dependence. *Ecol. Monogr.*, 62: 277-314.

WARRICK A.W., MYERS D.E., NIELSEN D.R. (1986). Geostatistical methods applied to soil science. In: A. Klute (ed.) *Methods of soil analysis*. Part I, 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI: 53-82.

HEAVY METAL CONCENTRATION IN SOILS OF THE BASING DRAINING IN THE VENICE LAGOON

Paolo Giandon, Ialina Vinci, Luciano Fantinato

ARPAV, Centro Agroambientale - Castelfranco Veneto (TV) - Italy

Abstract

Introduction in the environment of polluted air, wastes and sewage sludges has led to an increasing concern about soil protection and to an higher request of information about heavy metal content in soil.

In the frame of soil surveys carried out in the Basin draining in the Venice Lagoon, heavy metal concentration was detected on 371 samples collected from soil profiles. Final data layout, by means of a geographical information system, has led to some tentative explanations about anthropogenic accumulation of metals in soil in relation to background level.

Introduction

Starting from the 80's, law requirement for data about heavy metal concentration in soils increased more and more in consequence of a general concern about soil protection and to prevent the risk of accumulation due to the use of fertilizers, pesticides, sludges and other organic residues in agriculture.

High loads of heavy metals applied to soils may determine pollution of soil, surface and groundwater, accumulation in plants, phytotoxicity and successive transfer to the food chain.

Natural high levels may be related to heavy metal-bearing rocks or to mining areas, whereas anthropogenic accumulation is usually related to industrial activities, agriculture and application of urban sewage sludges.

To establish the background level of each heavy metal is very important to understand if any increase, caused by agricultural practices or other human activities, occurs.

For this reason in the frame of soil surveys carried out in the basin draining in the Venice lagoon and some other bordering areas, heavy metal concentration was detected on 350 topsoil and 172 subsoil samples; determinations on subsoil samples were carried out only for some representative soil profiles.

Concentrations detected can mainly be considered as the background level related to the chemical composition inherited from the parent material. Only in some cases high concentrations can be related to heavy metals added by human activities.

Heavy metals detected were those potentially present in residues and other products used in agriculture: arsenic, cadmium, cobalt, chromium, mercury, nickel, lead, copper and zinc.

Many countries have laws and regulations which define threshold concentrations of heavy metals for distribution of wastes on soil to prevent environmetal contamination; generally these limits refer to the total content of heavy metals in soil. This is an economical and precautionary approach since only a small amount of the total content can be available for plant uptake or can move and contaminate ground water.

However the total content is often of little importance in calculating the quantity of metals which can be taken up by plants and consequently enter the food chain (Petruzzelli, 1989).

For this reason also the detection of DTPA-soluble heavy metals content has been carried out; and will be the subject of successive comunications.

Materials and methods

Investigated area is located in the central part of Veneto Region, surrounded by the Venice Lagoon on the south-east side, the Livenza river on the east, the Euganei Hills on the west and the Prealps Mountains on the north.

During the last three years some soil surveys were carried out in this area, with the supervision of Agroenvironmental Centre of Regional Environmental Protection Agency, at 1:50.000 scale and a density of about 1 profile each 250 ha.

Samples for soil analysis were collected from each soil profile horizon; for 358 profiles heavy metal determination was carried out only on surface horizons. For some more representative profiles all horizons were analyzed for heavy metals.

The total content of arsenic, cadmium, colbalt, chromium, mercury, nickel, lead, copper and zinc was determined through acid extraction with aqua regia (ISO 11466) and detection by ICP (Inductive Coupled Plasma); also available cadmium, chromium, nickel, lead, copper and zinc were detected after extraction with DTPA.

All profiles data were handled in a soil database (Microsoft Access®) and represented geographically by means of the software Arc View (ESA-IRS®). The GIS has then made possible to present data grouped in classes established on the basis of law limits.

Limits for concentrations in soil stated by the european directive about sludges distribution on agricultural land and by the italian law on compost distribution, were taken into account to evaluate the risk related to the detected level of heavy metals. The classes defined for each heavy metal are reported in table 1.

Table 1

Classes used for the evaluation of the risk related to the detected level (mg/kg dm) of each heavy metal.

Element	VERY LOW	LOW	MEDIUM	HIGH
Arsenic	<2.5	2.5-5	5-10	>10
Cadmium	<0.75	0.75-1.5	1.5-3	>3
Cobalt	<15	15-30	30-60	>60
Chromium	<25	25-50	50-75	>75
Mercury	<0.5	0.5-1	1-2	>2
Nickel	<25	25-50	50-75	>75
Lead	<25	25-50	50-100	>100
Copper	<25	25-50	50-100	>100
Zinc	<75	75-150	150-300	>300

Results and discussion

Analysis results of topsoil samples are reported in tables 2, 3 and 4, classified on the basis of law limits.

Cadmium, cobalt, mercury and nickel contents (table 2) are for more than 65 % samples in the very low concentration class, and for more than 90 % in the very low and low classes; only 3 % of samples has high content of nickel.

Table 2

Frequency classes of cadmium, cobalt, nickel and mercury contents in 358 analyzed samples.

Classes	Cadmium		Cobalt		Nickel		Mercury	
	values (mg/kg dm)	frequency (%)	values (mg/kg dm)	frequency (%)	values (mg/kg dm)	frequency (%)	values (mg/kg dm)	frequency (%)
1	< 0,75	83	< 15	92	< 25	66	< 0,5	93
2	0,75-1,5	17	15-30	8	25-50	27	0,5-1	4
3	**1,5**-3	0	30-60	0	50-75	4	**1**-2	3
4	> **3**	0	> 60	0	> **75**	3	> **2**	0

Table 3

Frequency classes of chromium, lead and zinc contents in 358 analyzed samples.

Classes	Chromium		Lead		Zinc	
	values (mg/kg dm)	frequency (%)	values (mg/kg dm)	frequency (%)	values (mg/kg dm)	frequency (%)
1	< 25	40	< 25	53	< 75	28
2	25-50	52	25-50	43	75-150	68
3	**50**-75	8	50-100	3	150-300	4
4	> 75	0	> **100**	1	> **300**	0

Table 4

Frequency classes of copper and arsenic contents in analyzed samples.

Classes	Copper (358 samples)		Arsenic (306 samples)	
	values (mg/kg dm)	frequency (%)	values (mg/kg dm)	frequency (%)
1	< 25	15	< 2,5	3
2	25-50	41	2,5-5	20
3	50-100	30	5-10	25
4	> **100**	14	> **10**	60

Cadmium is the most dangerous heavy metal for it is easily taken up by plants and introduced in the food chain; phytotoxicity level is hundred times higher than the toxicity level for animals. Cadmium contents are for 83 % of samples in the very low concentration class, and for 100 % in the very low and low classes. This situation assures that no soil contamination process occurred for cadmium at the sites examined.

Also cobalt, which is usually considered not to be very important in relation to soil contamination, shows a distribution of 92 % of samples in the very low concentration class, and 100 % in the very low and low classes.

Mercury contents are for 93 % of samples in the very low concentration class, and for 97 % in the very low and low classes; very few samples (3 %) have medium concentration, probably due to industrial activities and their emission fallout.

Nickel contents are for 66 % of samples in the very low concentration class, for 27 % in the low class, 4 % in the medium class and 3 % in the high concentration class; these ones are mostly situated in the area of Euganei Hills and high levels are probably due to parent material, as pointed out by similar investigations carried out in other areas of northern and central Italy.

Chromium, lead and zinc contents (table 3) are higher on average but only in the upper layer, whereas they are similar in the lower ones. More than 90 % of samples are in the very low or low class but more frequently in the second one; only 1 % of samples has high content of lead.

Chromium has very low mobility in soil and it is very rarely taken up by plants and introduced in the food chain; it can be a constituent of some parent materials so it could be found naturally in soils. But it also can be found at high concentrations in some sludges from textile industry that could be applied in cultivated soils. Chromium contents are for 40 % in the very low concentration class, for 52 % in the low class and for 8 % in the medium class.

Lead has low mobility in soil but could be introduced in the food chain at levels dangerous for human health; it can be at high concentrations in the upper layers of soils, near urban and industrial sites where road traffic is quite high. Soils with high lead content are situated in the inland territory of Venice which is intensively populated. Lead contents are for 53 % in the very low concentration class, for 43 % in the low class, for 3 % in the medium class and for 1 % in the high class.

Zinc is a micronutrient for plants and it is easily taken up by plants; some pesticides used against vineyards deseases contains zinc and it can be also in high concentration in urban sludges. Zinc contents are for 28 % in the very low concentration class, for 68 % in the low class and for 4 % in the medium class.

Copper contents (table 4) are quite high with respect to other heavy metals; accumulation is mainly due to intensive use of copper products against vineyard disease (*Plasmopara viticola*): the highest concentration levels are found in the Euganei Hills and Piave areas (Deluisa *et al.*, 1995), where vineyards are widespread. Both copper and zinc are considered micronutrients and are easily taken up by plants; anyway, the introduction in the food chain at dangerous levels is not probable.

Copper contents are for 15 % in the very low concentration class, for 41 % in the low class, for 30 % in the medium class and for 14 % in the high class.

Arsenic is not always considered in laws dealing with limits for soil characteristics in case of distribution of sludges or other residues; many soils of Veneto Region have relatively high contents of arsenic, usually between 10 and 20 mg/kg d.m. but sometimes higher than 50. Distribution of arsenic concentration in Venetian soils is not homogeneous; eastern part of the region has the lowest ones, with values between 3 and 5 mg/kg, whereas central and southern part have higher ones.

There is only an italian law, concerning the use of compost from Municipal Solid Waste in agriculture, that states a limit of 10 mg/kg d.m. for arsenic concentration in soil; 60 % of analyzed samples has more than 10 mg/kg d.m. of arsenic, and results of lower layers are very simlar. This is probably due to the composition of the parent material, as soils with highest concentrations of arsenic are the ones developed on the Brenta river alluvial material, while the ones developed on Piave river alluvial material or on vulcanic and calcaric rocks of Euganei Hills have usually concentrations below 10 mg/kg d.m.

In next future the investigation will be extended to the rest of the soils of the Veneto Region, adding also the analysis of the available fraction, in order to acquire a significative picture of background levels and anthropogenic addition of heavy metals and to project some activities and measures to prevent soil contamination.

Figure 1 - Location of profiles analyzed for heavy metals.

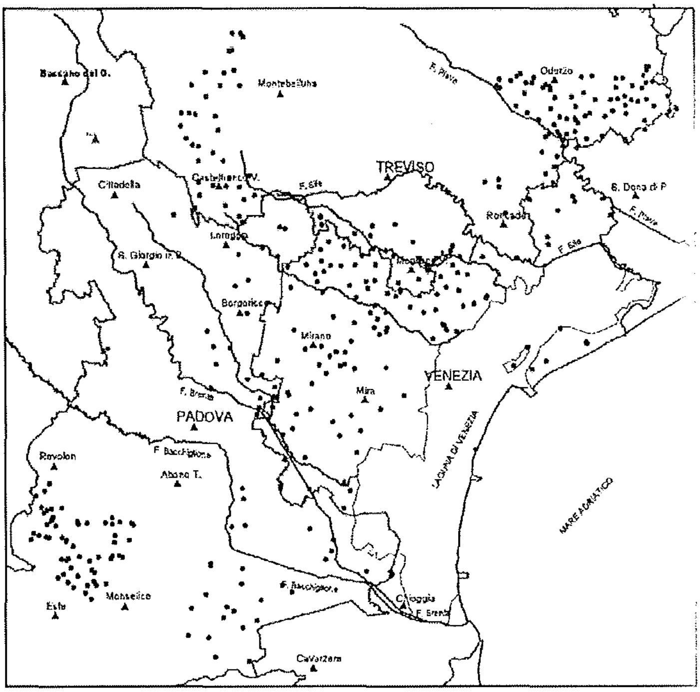
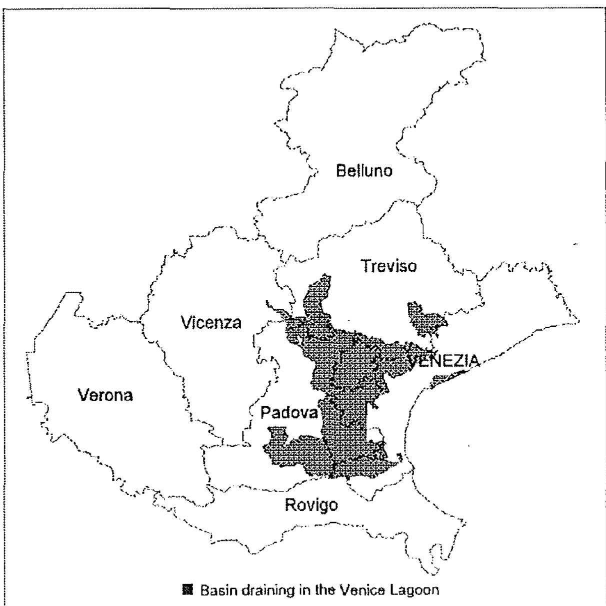


Figure 2 - Location of the study area in the Veneto Region.



References

CONSALTER A., GIANDON P., GHERARDI M., SIMONI A., VIANELLO G. (1998). "Approccio metodologico per definire la distribuzione e il differente grado di concentrazione in metalli nei suoli per cause naturali ed antropiche". Sensibilità e vulnerabilità del suolo: metodi e strumenti di indagine, Progetto Panda, Franco Angeli editore, pp. 279-303.

DELUISA A., GIANDON P., AICHNER M., BORTOLAMI P., BRUNA L., LUPETTI A., NARDELLI F., STRINGARI G. (1995). "Copper pollution in italian vineyard soils". *Communication in Soil and Plant Analysis*, 27/5-8, pp. 1537-1548.

GIANDON P., ZAMPIERI G., BETTINI D., FERROLI R. (1991). "Un'indagine agronomico-ambientale a Pernumia, San Pietro Viminario e Tribano". Provincia di Padova.

KABATA-PENDIAS A., PENDIAS H. (1985). *Trace elements in soil and plants*. CRC Press.

ISO 11466. Soil Quality - Extraction of trace metals soluble in aqua regia.

PETRUZZELLI G. (1989). Recycling wastes in agriculture: heavy metal bioavailability. *Agriculture, Ecosystem and Environment*, 27, pp. 493-503.

MAP OF THE SOIL ATTENUATION CAPACITY CONCERNING GROUNDWATER POLLUTANTS. FRIULI-VENEZIA GIULIA PLAIN

G. Michelutti, L. Bruggianesi, D. Bulfoni, S. Zanolla

ERSA - Ente Regionale per lo Sviluppo e la Promozione dell'Agricoltura
Servizio della Sperimentazione Agraria

Regione Autonoma Friuli-Venezia Giulia

Preface

Among the aims of the Law May 11,1999 n.152 art.1, who derives from the 91/676/EEC, there's the identification of vulnerable zones concerning the pollution caused by nitrates derived from agricultural sources.

Purpose of this act is the definition of measures to prevent and to reduce pollution.

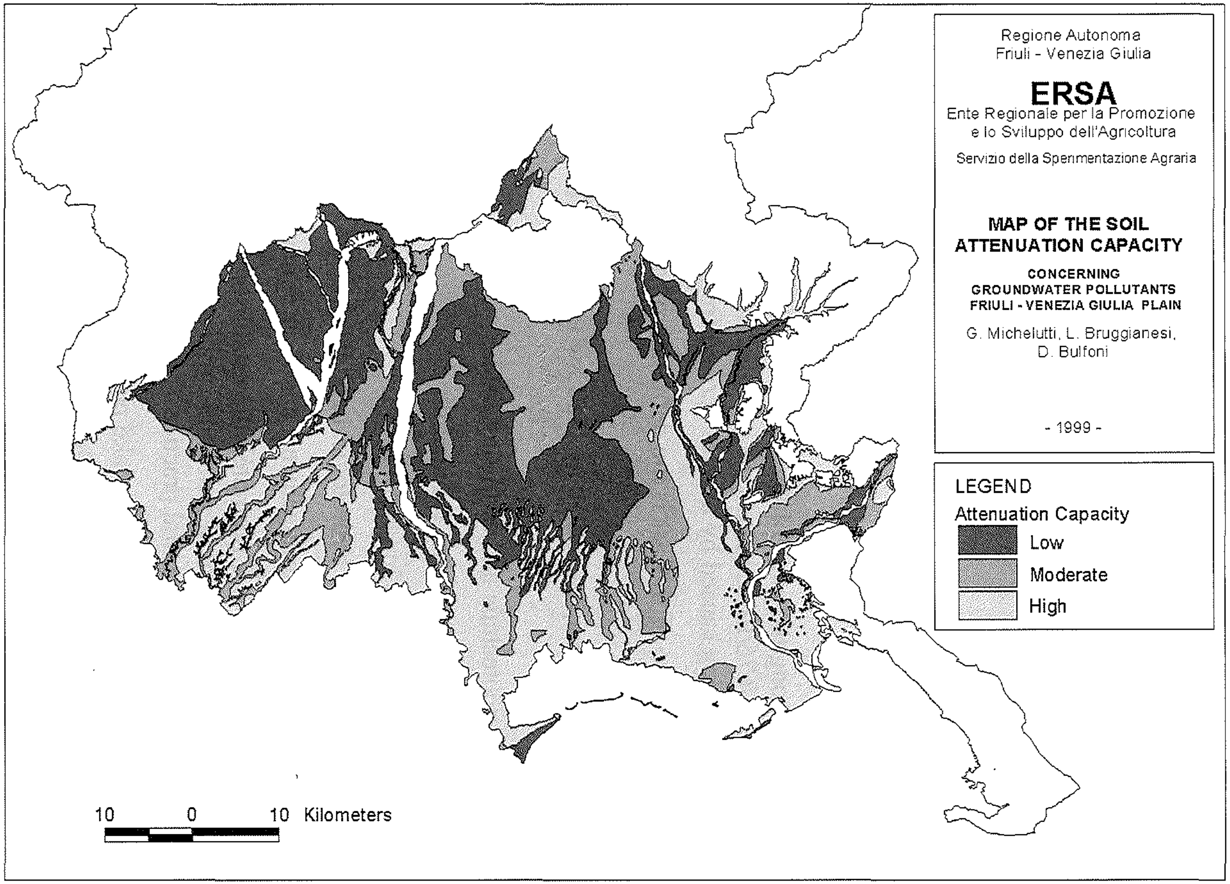
The principles settled by the Law in order to define vulnerable zones are:

- zootechnic and fertilising loads;
- aquifer intrinsic vulnerability;
- soil attenuation capacity;
- climatic and hydrological conditions;
- cultivation arrangements and their agricultural practices.

In 1998 ERSA promoted thè establishment of a regional working group for the definition of vulnerable zones, and the drafting of the regional code of good agricultural practice.

At the working group take part: ERSA, Regional Directions of Agriculture, Environment and Health, the Universities of Udine and Trieste and the Experimental Institute for Plant Nutrition (Gorizia section).

ERSA produced the soil attenuation capacity map for the regional plain at an identification scale (1: 250.000).


Regione Autonoma
Friuli - Venezia Giulia
ERSA
Ente Regionale per la Promozione
e lo Sviluppo dell'Agricoltura
Servizio della Sperimentazione Agraria
MAP OF THE SOIL
ATTENUATION CAPACITY
CONCERNING
GROUNDWATER POLLUTANTS
FRIULI - VENEZIA GIULIA PLAIN
G. Michelutti, L. Bruggianesi,
D. Bulfoni
- 1999 -
LEGEND
Attenuation Capacity
Low
Moderate
High
10 0 10 Kilometers

Geomorphological aspects

The studied area covers the whole Friuli-Venezia Giulia alluvial plain, with a surface of 305.592 ha, representing the 39% of the regional territory.

It can be divided into twelve phisiographic regions with a high degree of lithological and geomorphological homogeneity.

We recognise:

1. gravelly late pleistocene Cellina and Meduna plain;

2. gravelly late pleistocene Torre, Tagliamento and meltwater channel plain;

3. gravelly late pleistocene Isonzo and Natisone plain;

4. silty late pleistocene Cellina plain;

5. silty and clayey late pleistocene plain built by Tagliamento River on its right bank and late pleistocene plain of the Piave River;

6. late pleistocene mixed plain built by meltwater channels of Tagliamento morain complex on the Tagliamento left bank;

7. coarse post-glacial Cellina and Meduna sediments;

8. coarse post-glacial other rivers sediments;

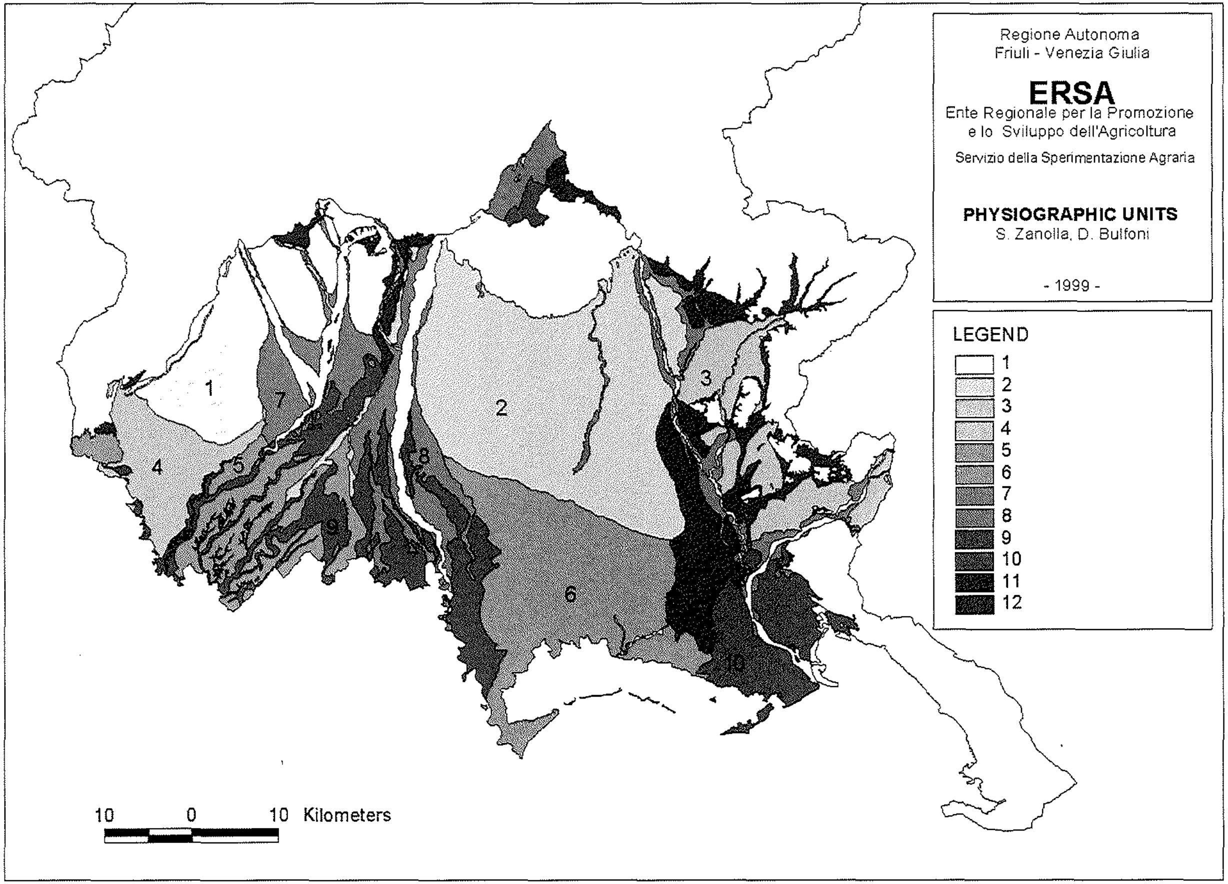
9. mainly thin post-glacial sediments from Tagliamento right bank river channels;

10. mainly thin post-glacial Tagliamento and Isonzo sediments;

11. mainly thin post-glacial sediments from Cosa, Torre and other tributaries;

12. colluvial materials accumulation areas.

The division was first based on the age and the characteristics of the sediments, connected to their lithology and grain size. The alluvial plain built in the late pleistocene was first divided into an upper gravelly part and in a lower portion characterized by thinner sedimentation. Afterwards, it was further divided according to the sediment composition coming from the rock outcroppings in the mountain part of the basin. The Cellina and Meduna Rivers are characterized by a prevalently carbonatic basin, essentially made of dolomites and limestones. The Torre, Piave, and Tagliamento Rivers, as well as the other meltwater channels of its morainic complex, have a mixed


Regione Autonoma
Friuli - Venezia Giulia
ERSA
Ente Regionale per la Promozione e lo Sviluppo dell'Agricoltura
Servizio della Sperimentazione Agraria
PHYSIOGRAPHIC UNITS
S. Zanolla, D. Bulfoni
- 1999 -
LEGEND
1
2
3
4
5
6
7
8
9
10
11
12
10 0 10 Kilometers

basin, composed by terrigenous, carbonatic and igneous rocks. The basins of the Isonzo and Natisone Rivers are mainly calcareous.

Concerning the part of the late pleistocene Tagliamento plain below the spring boundary, it was split in two parts, since they present different morphological aspects. On the right, it is characterised by several abandoned river channels generally below plain level, both braided or meandering, which are occupied by secondary rivers with thin active sedimentation. The left side presents wide gravelly tongues rich in peat and organic substance. The upper-pleistocenic gravel flood plain built mainly by the Cellina River in the western part of the studied area gently decreases into the lower silty and clayey plain. Examples of other rivers pleistocene thin sediments are not preserved.

Recent coarse sediments are divided only into two groups: those in the Cellina-Meduna area, coarser and extremely carbonatic, and the other main rivers holocene gravels. Thinner sediments were divided on grain size distribution criteria: the secondary rivers which occupy abandoned Tagliamento channels on its right bank have a prevalently silty sedimentation, while clays from the Cosa River and the Torre River system were differentiated from Isonzo and Tagliamento coarser sediments.

Another class comprehends the areas at the hills' foot where soil sediments easily accumulate.

Methods

In order to estimate the soil attenuation capacity concerning pollutants it has been used a point count system model (like DRASTIC or SINTACS).

- Soil qualities considered are:
- cation exchange capacity (CEC);
- available water capacity (AWC);
- permeability;
- substratum particle-size classes.

The **CEC** expresses the soil capacity to absorb metal cations reducing their leaching. The soil absorbing power is strictly linked to the organic substance and clay content and type.

The CEC measured on the horizons has been pondered on the soil first metre considering their thickness and rock fragment content.

The **AWC** measures the available water for plant growth.

The AWC has been estimated on the horizons using a pedofunction that takes into consideration sand, clay and organic carbon content, corrected for rock fragment content and bulk density. The so obtained values have been pondered on the soil first metre. The algorithm used has been elaborated from a dataset of water retention analyses obtained using the Richard's chambers method on regional soils samples (ERSA, not publ.).

The **permeability**, estimated on the least permeable layer at least 30 cm thick, has been classed using particle size class, texture and structure of the considered horizons. The control section used is 0-150 cm. A table that interprets permeability (Rasio, 1997) has been used for this evaluation, a first validation of this table on Friuli-Venezia Giulia soils has been carried out (ERSA, not publ.) with the double ring infiltrometer method (FAO,1986).

The **substratum particle-size class** with a control section of 100-150 cm (USDA, 1994), has been used to distinguish soils with a coarse particle size which present limitations for root penetration and have a water retention capacity and a CEC lower than that of finer particle size classes.

Soil **reaction** plays an important role in nutrients availability, but in Friuli plain it is generally higher than 6 pH points, so it has not been considered in this valuation since it was not discriminant.

A rating is given to every selected parameter subdivided into value ranges and stated types as a function of its importance within the final global assessment: high = 1; moderate = 2; low = 3.

Ratings of each parameter are then multiplied by a weight string that is able to describe each pedologic and impact situation to magnify the action and the importance of the parameters: 30% to CEC, 27.5% to AWC, 22.5% to substratum particle-size class, 20% to permeability.

The cartographic base is the Soil Map of Friuli's Plain (Comel *et al.*, 1982). Some polygons were modified for this application.

A reference soil, based on the pedological survey carried out by ERSA in the last ten years has been attributed to each polygon of the map. An attenuation capacity was estimated for every reference soil, and the founded value was ascribed to the polygon.

Soil attenuation capacity rating system for Friuli–Venezia Giulia plain.

ATTENUATION CAPACITY CLASSES	CEC cmol/kg	AWC mm	SUBSTRATUM PARTICLE-SIZE CLASSES	PERMEABILITY mm/h
HIGH	≥ 10	≥ 150	Fine, Very Fine, Fine Silty, Fine Loamy, Coarse Silty, Loamy, Clayey Skeletal, and the strongly contrasting particle-size classes over Sandy, Sandy Skeletal e Fragmental where the first term is Fine, Very Fine or Fine Silty	< 0.36
MODERATE	5 – 10	75–150	Coarse Loamy, Loamy skeletal, and the remaining over Sandy, Sandy Skeletal or Fragmental classes.	0.36–36
LOW	< 5	< 75	Sandy, Sandy Skeletal, Fragmental, and the strongly contrasting particle-size classes where the first term is Sandy, Sandy Skeletal and Fragmental.	> 36

Results

The regional plain presents wide areas with a low soil attenuation capacity.

Soils with low and moderate attenuation capacity cover respectively 110.007 ha (36% of the plain) and 79.408 ha (26%) of the examined territory.

In the following table the soil attenuation capacity is qualified referring to the physiographic regions:

1	low	5	high	9	moderate
2	moderate and low	6	from high to low	10	high
3	moderate and low	7	low	11	high
4	high	8	low	12	high

The regions with the lowest soil attenuation capacity correspond to gravelly late pleistocene Cellina and Meduna plain, to coarse post-glacial

Cellina and Meduna sediments and to coarse post-glacial other rivers sediments, caracterized by shallow soils with a high rock fragment content.

Unsettled from moderate to low soil attenuation capacity has been found in the gravelly late pleistocene Torre, Tagliamento and meltwater channel plain and in the gravelly late pleistocene Isonzo and Natisone plain. These are areas with a coarse substratum and with a moderate or poor soil thickness.

The late pleistocene mixed plain built by meltwater channels of Tagliamento morain complex on the Tagliamento left bank presents an unsettled attenuation capacity, especially in the northern part where it is characterized by an alternation of pedological patterns for the presence of coarse material tongues that insinuate in fine fluvioglacial sediments.

The mainly thin post-glacial sediments from Tagliamento right bank river channels present a moderate soil attenuation capacity.

High soil attenuation capacity is found in the silty late pleistocene Cellina plain, in the silty and clayey late pleistocene plain built by Tagliamento on its right bank, in the mainly thin post-glacial Tagliamento, Isonzo, Cosa, Torre and other tributaries sediments and in the colluvial materials accumulation areas.

References

COMEL A., NASSIMBENI P., NAZZI P. (1982). *Carta pedologica della pianura friulana e del connesso anfiteatro morenico del Tagliamento*. C.R.S.A. Udine.

FAO (1986). Soil survey investigations for irrigation. *Soils bulletin*, 42: 187-188. Roma.

PAMPALUNA M., BRENNA S. (1996). *Manuale per la compilazione delle schede delle unità cartografiche*. ERSAL. Milano

RASIO R. (1997). *Norme generali per il rilevamento e la compilazione della Carta Pedologica della Lombardia alla scala 1:50.000. Progetto carta pedologica*. ERSAL. Servizio del Suolo. Milano.

Regione Emilia Romagna (1995). *Normativa Tecnica Generale. Carta dei suoli regionale scala 1: 50.000.* Ufficio Pedologico. Bologna.

USDA (1994). *Keys to Soil Taxonomy*. Soil Conservation Service. Blacksburg, Virginia.

Soil analysis made by Servizio Chimico-Agrario e della Certificazione dell'ERSA.

ENVIRONMENTAL RISK DUE TO SOIL PHOSPHORUS ACCUMULATION IN FARMS WITH INTENSIVE ANIMAL HUSBANDRY

Luciano Cavani, Claudio Ciavatta, Nino Rossi

Istituto di Chimica Agraria, UCI-STAA, Università degli Studi di Bologna
Via San Giacomo 7, 40126 Bologna, Italy

Introduction

Diffuse phosphorus (P) loss from arable land in general is very low and usually in the range of a few hundreds of grams of P $ha^{-1}yr^{-1}$. Only in specific situations can losses be as high as several kg of P $ha^{-1}yr^{-1}$. While such losses have very little importance in agronomic terms, they are nevertheless very important with regard to eutrophication of surface water. In the field, during the drainage process, water transports nutrients and particulate matter from the topsoil to drains and/or ditches through macropores or via runoff. The process not only poses problems of surface eutrophication through increased P loss but also problems with sediment-bound contaminants such as pesticides and heavy metals.

According to many scientists (Wollenweider and Kerekes, 1982; Breeuwsma and Silva, 1994; Rossi *et al.*, 1997; Indiati and Rossi, 1998; Rossi and Cavani, 1998) eutrophication of shallow water is controlled mainly by diffuse losses of P from arable land. In general the waters of shallow lakes and rivers become eutrophic above a threshold P concentration of 0.10-0.15 mg P L^{-1} (Kronvang *et al.*, 1993). Since the P concentration in drainage water coming from cultivated fields is not always below that threshold, P losses from soils can represent a major source of diffuse P loss to the aquatic environment. For this reason it is important to investigate the cases in which these losses take place in order to devise some measures to control them.

Over the last 30-40 years animal husbandry activity in Italy has changed from family-run farms to industrial-intensive farming with several hundreds, even thousands of head of livestock. This paper deals with P accumulation that occurs in soils receiving repeated applications of the high quantities of manure/slurries resulting from intensive livestock farming.

Materials and methods

Thirty soil samples were collected from the cultivated layer (45 cm) of representative sites in the Emilia-Romagna Region where repeated applications of high quantities of manure/slurries from cows or pigs are common. Soil samples, collected at the end of the growing season 1998, were air dried, sieved at 2 mm and analysed for their physico-chemical characteristics. In these soils the most frequent crop rotations are the following: a) maize for silage (1 year), alfalfa (4 years); b) winter wheat (1 year), alfalfa (3 years). The long-term records of exact soil P input and output are not available. In general the quantity of animal slurry distributed annually per ha of the soils examined is in the order of 4-5 LU and even higher [one LU (Livestock Unit) is equivalent to an animal manure production of about 50 and 15 kg yr^{-1} of N and P respectively, the amount of manure produced annually by 1 dairy cow (500 kg), 3 sows (180 kg each), 6 pigs (80 kg each), etc.].

As a result of these repeated slurry/manure applications over the past 2-3 decades the P content of these soils is very high.

Results and discussion

Some of the main physico-chemical characteristics of the soil samples examined are reported in Table 1. According to the Soil Taxonomy Keys (Soil Survey Staff, 1994), the soils are classified as fine silted, mixed, mesic Aquic Aplustalfs. The available P (Olsen *et al.*, 1954) of the soils is, for the large majority of the samples, well above the value of the threshold for normal growth of the crops. At the same time many of the values are also higher than 100 mg P kg^{-1}.

The distribution of the soil samples according to their available P concentration values is presented in Table 2.

From an agronomic point of view, 20-30 mg P kg^{-1} can be considered a threshold for normal crop requirements. This value was exceeded by 83% of the samples examined. Indeed, 33% of the samples have a P concentration higher than 100 mg P kg^{-1}, which is of concern from an environmental point of view (Indiati and Rossi, 1999).

Indiati and Rossi (1999) using some of the soil samples of this research, studied the P supplying capacity (leaching potential) of these soils in relation to the degree of P saturation (DPS). In their study the authors showed that a value of around 100 mg P kg^{-1} of available P (Olsen-P) corresponds to the critical value of DPS equal to 25%. This value was reported by Van der Zee *et al.* (1990) as a value shown to be environmentally sound because at this value the concentration of P in groundwater remains below the critical limit set by the Dutch Regulations (0.1 mg ortho P L^{-1}). Soils above this critical level of 100 mg P kg^{-1} (as Olsen-P) should be considered very probable non-point sources of P for surface water eutrophication. For this reason such soils should be subjected to some environmental regulation (limitation) in regard to P fertilisation practices.

Table 1

Some physico-chemical properties of the soil samples examined

Soil Properties	Average ± CL [a]	Comment
Texture: (Sand,%; Silt,%; Clay,%)	23 ± 3; 46 ± 3; 31 ± 2	Loamy, silty-loamy
pH	7.3 ± 0.1	Neutral
C.E.C. [cmol(+)kg^{-1}]	22.7 ± 1.1	Medium to high
Organic Matter (%)	2.5 ± 0.2	Normal to high
Nitrogen, Kjeldahl (N, ‰)	1.6 ± 0.2	Normal
Phosphorus, Olsen (P, ppm)	84 ± 24	Very high

[a] CL = Confidence Limit at $p \leq 0.05$

Table 2

Distribution of the soil samples according to their available P concentration (Olsen method)

Range in P concentration mg P kg^{-1}	Number of samples	Percentage of samples
< 25	5	17
25 - 50	8	27
50 - 100	7	23
100 - 200	8	27
> 200	2	6

Industrial-intensive animal husbandry activity usually results in the necessity to dispose of more waste than the available land can accept and utilise as fertiliser. In these farms, where the P input in the soil is higher than the P output due to nutrient uptake by the crops, after several years of repeated slurry/manure applications the result is P accumulation in the soil. In turn high P accumulation in the soil increases the probability of P losses through drainage and soil erosion. A soil that is low in P can accept quantities of slurry/manure having a P content higher or much higher than P crop uptake for a limited numbers of years, after which it is advisable to balance the P supply with the P removed by crops. On the contrary when P build-up in the soil continues indefinitely, the ecological consequences on the quality of surface water will pose environmental problems.

Conclusions

In the present case-study over 30% of the soil samples examined exceeded the critical value of DPS = 25% and consequently the environmental risk for P eutrophication of surface water deriving from these soils is relatively high. Soils with high contents of available P (>100 mg P kg^{-1} with the Olsen method) should not continue to be fertilised in the future with amounts of manure/slurry well above the normal P crop uptake.

The practice of using the soil not as a medium for plant growth to be fertilised, but rather as a means of disposing of large amounts of unwanted slurry should not be allowed anymore. In this regard some of the Italian Regional Governmental Institutions (e.g. Emilia-Romagna Region) have already started to implement specific regulations on the suitability of soils to accept animal slurry (Boll. Uff. Emilia-Romagna, June 4, 1998 - Parte II - N. 75). In these Regulations the soil available P content is one of the key parameters that must be taken into consideration to assess this suitability.

Acknowledgement

This research was partially supported by the Italian Ministry of Agricultural, Food and Forestry Resources (PANDA) Project-Subproject 3, Series 2, No. 87.

References

BREEUWSMA A., SILVA S. (1994). Phosphorus fertilisation and environmental effects in the Netherlands and the Po region (Italy). Report No. 57, Agricultural Research Department, Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands.

INDIATI R., ROSSI N. (1998). Environmental sound soil phosphorus tests for sustainable agricultural systems. In: *Practical and Innovative Measure for the Control of Agricultural Phosphorus Losses to Water.* Department of Agriculture for Northern Ireland, 16-19 June 1998, pp. 74-75.

INDIATI R., ROSSI N. (1999). Extractability of residual phosphorus from highly manured soils. Accepted for publication in the: *Italian Journal of Agronomy*, September 1999.

KRONVANG B., ÆRTEBJERG G., GRANT R., KRISTENSEN P., HOVMAND M., KIRKEGAARD J. (1993). Nationwide monitoring of nutrients and their ecological aspects: State of the Danish aquatic environment. *Ambio* 22: 176-187.

OLSEN S.R., COLE C.V., WATANABE F.S., DEAN L.A. (1954). Estimation of available phosphorus in soils by extracting with sodium bicarbonate. USDA Circ. 939. U.S. Gov. Print. Office, Washington D.C.

ROSSI N., MONTECCHIO D., GOVI M., CIAVATTA C. (1997). Erosione superficiale e perdite di nutrienti per lisciviazione nei terreni di pianura. *Agricoltura Ricerca* 170: 63-70.

ROSSI N., CAVANI L. (1998). Phosphorus content in drainage water from cultivated soils in the Emilia-Romagna Region (Northern Italy). In: *Practical and Innovative Measure for the Control of Agricultural Phosphorus Losses to Water*. Department of Agriculture for Northern Ireland, 16-19 June 1998, pp. 148-149.

Soil Survey Staff (1994). Keys to Soil Taxonomy. 6th edition. U.S.D.A., Soil Conservation Service, Pocahontas Press, Inc., Blacksburg, VA.

VAN der ZEE S.E.A.T.M., VAN RIEMSDIJK V.H., en DE HAAN F.A.M. (1990). Het protocolfosfaatverzadidge gronden. Wageningen, Landbouwuniversiteit, Vaekgroep Bodemkunde en Plantvoeding.

WOLLENWEIDER R., KEREKES J. (1982). Eutrophication, monitoring, assessment and control. Final Report. OECD Cooperative Programme Monitoring of Inland Waters (Eutrophication Control). Environmental Directorate, Paris, France.

First observations of a soil "catena" to evaluate the vulnerability of the pasture areas in the Gollei basaltic plateau of Orosei (central-eastern Sardinia)

S. Madrau*, P. Mulè**, M. Spano*

* Dipartimento di Ingegneria del territorio

** Dipartimento di Scienze Ambientali Agrarie e Biotecnologie Agro-Alimentari
Università degli Studi di Sassari

Introduction

In many areas of Sardinia intended for pasture, the soils are subject to serious erosion due to vegetation cover degradation because of the frequent fires, overgrazing, and the prolonged persistence of the livestock in the pasture.

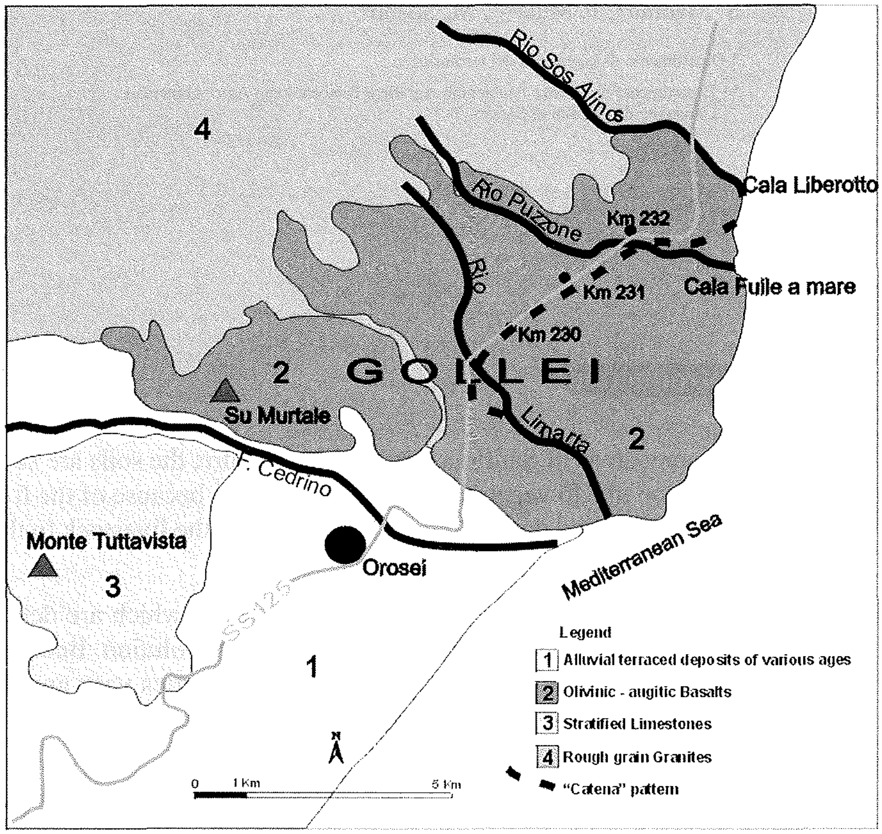
The soils are natural entities, the properties of which are determined by the pedogenetic factors interacting during their evolution. Because these factors can vary even in limited areas, the soil properties vary greatly both vertically (horizons differentiation), and/or laterally (succession of more pedons), as is often seen in pedologic maps.

The aim of this paper is to describe this variability inside a soil "catena" found on a basaltic tableland of central-eastern Sardinia and thus to provide the first indications of the vulnerability to erosion of these pasture areas.

The "catena" Studied

The "catena" studied was in the Orosei (NU) area, on a tableland of pleistocenic basalts locally called *Gollei* (Fig.1), bounded, in the south, by the floodings of the last part of the Cedrino river and, in the north, by the river-bed of Rio Sos Alinos where the mouth widens into Cala Liberotto. The highest point is Su Murtale (the remains of the core of a vulcano) at 197 m. above sea level, and the tableland descends gradually towards the east until it reaches the sea. There is also a well-developed hydrographic pattern on the tableland but this only cuts shallowly into the effusive substratum.

Figure 1 - Geological scheme



There is a difference in altitude of about 80 metres between the extremities of the "catena" and the average slope is about 2-3%. In extensive areas, i.e. those between 40 and 50 metres above sea level, the slope is less than 1%.

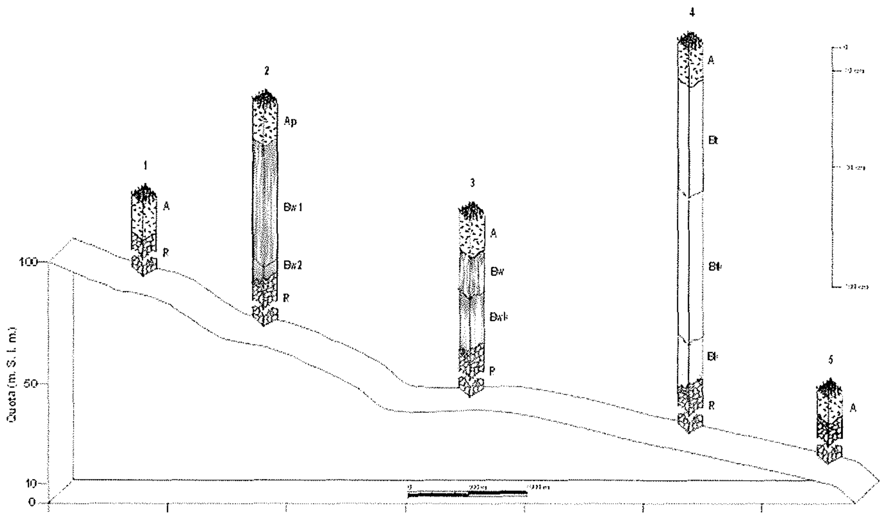
The natural vegetation is Mediterranean *maquis* usually highly degraded, which is normally found in the marginal areas because of thin soil, high rocky outcrops etc. In all the others areas it has been substituted almost everywhere by either natural or improved pasture.

The principal crops are grass and cereals with a small area of tree and bush cultivation, principally grapes. All along the coastal arc there is a zone of between 200- 250 m. which has been reforested with Pinus sp.

The soils present in the "catena"

The following five profiles are used to describe the "catena" (Fig. 2).

Figure 2 - Soils "catena"



Soils classification

(Soil Taxonomy, USDA 1998)	(W.R.B. 1998)
1 Lithic Xerorthents	Eutric Leptosols
2 Typic Haploxerepts	Typic Cambisols
3 Calcic Haploxerepts	Eutric Cambisols
4 Typic Haploxeralfs	Typic Luvisols
5 Lithic Xerorthents	Eutric Leptosols

Profile n. 1

The profile at the highest altitude was the least developed of the series. It was taken along the SS 125 at Su Chilometro Mannu at 77 m above sea level. The vegetation consisted of *maquis* at various levels of degradation, depending on the amount of pasture. There were few large stones, and between 5 - 10% of the surface was covered by rocky outcrops, with a distance between outcrops of less than 5 metres.

Between the SS 125 and the station point there was a shallow depression slightly less than 100 square metres in size, which became swampy in winter.

The profile is of type A R with a thickness ranging from 10 to 15 cm. The skeleton, with minute and rounded elements, was evaluated on the ground as common in quantity. The texture was loamy – sandy – clayey. The aggregation was polyhedric subangolar, medium, strong., adhesive and plastic. The reaction was moderately acid. The exchange complex was saturated, with 56% of the bases represented by the Calcium ion. It was classified as Lithic Xerorthents (Keys to Soil Taxonomy, 1998) and as Eutric Leptosols (W.R.B. 1998).

This profile can be considered as the classic profile type for the more marginal situations present in the basaltic tableland.

Profile n. 2

The vegetation cover was currently cereals alternated with pasture.

There were almost no large stones. There were no outcrop rocks at the station site, but some were present in small areas some 50 - 60 m south, "morphologically higher" even if by only a few dm, than the observation site.

The profile is of type Ap Bw R less than 70 - 80 cm thick, due to the presence of pockets in the basaltic rock. The Ap horizon is 15 - 18 cm and a Bw1sub-horizon 22 - 25 m thick.

The skeleton, from ground observation, was common in quantity with minute elements. The texture varies from loamy – sandy – clayey in the Ap horizon to clayey – sandy in the Bw1 horizon, becoming loamy – sandy – clayey again in the Bw2 horizon. The aggregation was polyhedric subangolar, strong, from medium to coarse, from friable to resistant with the increase in depth and always plastic and adhesive. The reaction was weakly sub – acid in the Ap and Bw2 horizon and neutral in the Bw1 horizon.

The exchange complex was always saturated. The amount of Calcium ions can be considered constant as an absolute value in the three horizons, but varied in percentage from a maximum of almost 74% in the Ap horizon to a minimum of almost 59% in the Bw1 horizon.

This soil was classified as Typic Haploxerepts (Keys to Soil Taxonomy, 1998) and Typic Cambisols (W.R.B. 1998) and can be considered as the soil type in the areas at cereals and/or improved pasture which was cut out of the undergrowth present in the Gollei. Whether this was done usually depended on the morphology and the outcrop rock present.

Profile n. 3

The vegetal covering consisted of set-aside ground, at present used as pasture. The blocky superficial stoniness was absent or negligible because of a recent mechanised intervention to remove the stones. Outcrop rocks were absent.

The profile was of type Ap Bw Bwk R 85 - 87 cm thick, 65 cm of which was attributed to the Bw horizon and 5 - 7 cm to the Bwk horizon. The skeleton, on ground evaluation, was common with minute elements in the Ap and Bw horizons, and slightly more in the Bwk. The texture in the three horizons was respectively loamy – sandy – clayey, clayey – sandy, and loamy. The aggregation was polyhedric subangolar, strong, from medium to coarse, from friable to resistant with the increase in depth, and always plastic and adhesive. The exchange complex was always saturated and the amount of the Calcium ions decreased from 66% to 60% in the passage from the Ap to the Bw horizon. Some nodules of secondary carbonates were observed in the Bwk horizon. They were soft, with a clear outline, a diameter of less than 2 cm and represented almost 60 - 70% of the mass volume of the soil.

This soil was classified as Calcic Haploxerepts, (Keys to Soil Taxonomy, 1998) and Eutric Cambisols (W.R.B. 1998), and has to be considered as the intermediate phase towards the Inceptisoils with calcic horizons.

Profile n. 4

The morphology was flat with weak depressions diffused inside the area.

There was no superficial stoniness. Only a few strongly rounded gravels containing quartz were present on the surface. There were no outcrop rocks.

The profile was of the type Ap Bt Btk Bk 170 - 180 cm thick. The skeleton was common with elements containing quartz very similar to the gravels present at the surface. The texture was loamy – sandy – clayey in the Ap horizon, clayey in the Bt and from loamy – sandy to loamy sandy in the passage from the Btk to the Bk. The amount of carbonates nodules, the diameter of which can reach 5 cm in the Bk horizon, varied from 5% in the Btk to 30% in the Bk. The reaction varies from neutral in the Ap horizon to medially alkaline in the Bt and Bk horizon, to the alkaline in the Btk horizon. The exchange complex was saturated, with the Calcium ion representing almost 74% of the total bases amount.

This profile was classified as Typic Haploxeralfs (Keys to Soil Taxonomy, 1998) and Typic Luvisols (W.R.B. 1998). The calcic horizon thickness, observable from 140 cm in depth was not significant enough to attribute this to the calcic sub - groups.

The profile was the most developed of the soil "catena" in the *Gollei* basalts studied.

Ground observation along all the coast, from Cala Liberotto in the north to the mouth of the Cedrino river in the south, and the analysis made, showed that as "catena" closure there were profiles of type A R similar, in their characteristics, to the one described at point 1 (**profile 5**).

Results and Discussion

From the profile descriptions and the table of the analytical data (Tab. 1) the characteristic elements of the "catena" studied were:

a) a succession of profiles with a developing rank which appear strictly correlated to height: Xerorthents (Leptosols) at the highest altitudes , Haploxeralfs (Luvisols) at the lowest altitudes and, in the intermediate position, the Haploxerepts (Cambisols);

b) the presence of secondary carbonates, the amount of which was a function both altimetric position of the profile and of its developing rank. The pedon genesis with a different developing rank could be explained by observing that the substratum of the most developed profile was very probably not made up of basalts but of deposits of already pedogenised finer materials, which filled the depression in question with little barring lakes made by successive flows.

Another characteristic aspect of the evolution of the "catena" was the high ratio of bases saturation, (values always higher than 90%) and a considerable amount of Calcium in the exchange complex, always higher than 50% in all the profiles.

Table 1 - Chemical-physical analisys

Profile		**1**	**2**	**2**	**2**	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**5**
Horizon		**A**	**Ap**	**Bw1**	**Bw2**	**Ap**	**Bw**	**Bwk**	**Ap**	**Bt**	**Btk**	**Bk**	**A**
Depth	*(cm)*	0 - 10/15	0 - 15/18	15/18 - 40	40 - 70/90	0 - 15	15 -80	80 - 85/87	0 - 20	20 -70	70 - 140/150	140/150 - 170/180	0-15
PHYSICAL-MECHANICAL ANALISYS													
Skeleton (>2 mm)	*(g/Kg)*	42	139	105	56	20	11	227	26	88	33	259	38
Very large sand (2÷1 mm)	*(g/Kg)*	20	30	24	23	19	10	45	13	10	16	18	25
Large sand (1÷0,5 mm)	*(g/Kg)*	121	66	80	61	31	18	49	39	26	34	32	116
Medium sand (0,5÷0,25 mm)	*(g/Kg)*	157	102	112	75	81	40	43	57	39	41	40	150
Fine sand (0,25÷0,02 mm)	*(g/Kg)*	361	430	224	424	534	427	300	507	362	350	712	368
Silt (0,02÷0,002 mm)	*(g/Kg)*	93	109	73	84	102	85	314	76	101	163	50	90
Clay (<0,002 mm)	*(g/Kg)*	248	263	487	333	233	420	249	308	462	396	148	251
CHEMICAL ANALISYS													
pH (H_20)		5,7	6,2	6,9	6,3	6,2	6,8	7,3	6,9	8,0	8,9	8,2	5,5
pH (KCl)		4,6	5,3	5,2	5,1	5,3	5,4	7,1	6,3	6,9	7,4	7,5	4,4
Total lime	*(g/Kg)*	*Absent*	*Absent*	*Absent*	*Absent*	*Absent*	*Absent*	420	*Absent*	27	127	287	*Absent*
Active lime	*(g/Kg)*	*Absent*	*Absent*	*Absent*	*Absent*	*Absent*	*Absent*	n.d	*Absent*	n.d	n.d	n.d	*Absent*
Carbon	*(g/Kg)*	19	23,0	3,0	10,0	13	3	3	5	3	1	< 1	20
Organic matter	*(g/Kg)*	33	40	5	17	22	5	5	9	5	2	< 1	34
Total nitrogen	*(g/Kg)*	1,2	1,9	0,4	0,8	1,1	0,4	0,4	0,7	0,0	0,1	0,1	1,3
C/N		16	12	8	12	12	8	8	7	6	10	---	16
EXCHANGEABLE COMPLEX													
Calcium Ion	*(meq/100 g)*	11,79	19,40	19,65	17,15	12,16	16,34	---	13,85	---	---	---	11,50
Magnesium Ion	*(meq/100 g)*	4,84	4,01	12,04	5,76	4,12	8,85	---	3,09	---	---	---	4,80
Sodium Ion	*(meq/100 g)*	0,19	0,33	0,98	0,33	0,33	1,33	---	0,30	---	---	---	0,39
Potassium Ion	*(meq/100 g)*	0,38	0,51	0,32	0,27	0,38	0,27	---	0,83	---	---	---	0,51
Exchangeable bases sum	*(meq/100 g)*	17,20	24,25	32,99	23,51	16,99	26,79	---	18,07	---	---	---	17,20
C.E.C.	*(meq/100 g)*	20,90	26,10	33,40	25,00	18,30	27,00	15,50	18,60	22,90	18,70	21,80	20,90
B.S.G.	*(%)*	82	93	99	94	93	99	---	97	---	---	---	82,00
Exchangeable acidity	*(meq/100 g)*	3,70	1,85	0,41	1,49	1,31	0,21	---	0,53	---	---	---	3,70

Conclusions

The comparing the soil characteristics of a "catena" allow us to demonstrate the erosive processes which occur along the slope; i.e. the transport of the finer particles towards lower altitudes and their accumulation there.

From the above observations of the soils studied we can reach some preliminary conclusions on how vulnerable the area may be to erosion.

First, in the sampling area of profile n°1 the undergrowth was seriously degraded, a sign of overstocking. In the others areas we noticed the increase of the aggregation rank with the increase in soil depth, due both to the accumulation of clays and cementation of carbonates, and to the probable formation of the ploughed soil. Further physical– mechanical analysis of the soil structure are in progress, but at this point enough information has already emerged to suggest that the territory could be suffering from erosion because of overstocking and the fact that the soil is always ploughed to the same depth. These two negative forms of land management make the removal of the superficial layer of the soil easier in certain well-defined morpho-climatic conditions.

Bibliography

COSTANTINI E., DAZZI C. (a cura di) (1999). *World Reference Base for Soil Resouces*. ISSDS Firenze.

DIENI I., MASSARI F. (1966). Il Neogene e il Quaternario nei dintorni di Orosei (Sardegna). *Mem. Soc. Italiana Sc. Naturali*, vol. XV, fasc. II, pag. 91-142.

DIENI I., MASSARI F. (1973). La formazione fluvio-lacustre di Nuraghe Casteddu ed i suoi rapporti con i basalti di Orosei-Dorgali (Sardegna). *Mem. Soc. Geologica Italiana*, vol. 12, pag. 377-410.

DUCHAUFOUR Ph. (1977). *Pédologie. Pédogenèse et classification*. Masson, Paris.

GERRARD A.J. (1981). *Soils and Landforms. An integration of Geomorphology and Pedology*. George Allen & Unwin editors, London.

GILE J.H., PETERSON F.F., GROSSMAN R.B. (1966). Morphological and genetic sequences of carbonate accumulation in desert soil. *Soil Science*, Vol. 105, 5, pag. 347-360.

SAVELLI C., PASINI G. (1973). Nota preliminare sulla età K/Ar di basalti della Sardegna orientale e del canyon sottomarino di Orosei (Mar Tirreno). *Rendiconti del Seminario della Fac. di Scienze dell'Univ. di Cagliari*, suppl. vol. XLIII, pag. 321-326.

SERRA A. (1943). Studi lito-mineralogici riguardanti le provincie di Sassari e Nuoro. *Boll. Soc. Geol It.*, vol. XLI, 3, pag. 289-341, Roma.

Soil Survey Staff, U. S. Dept. of Agricolture, Natural Resources Conservation Service, 1998. *Keys to Soil Taxonomy*. 8th ed. USA.

CRITERIA TO IDENTIFY VULNERABLE AREAS ACCORDING TO THE LEGISLATIVE DECREE MAY 11 1999, N° 152 CONCERNING WATER POLLUTION CONTROL

Stefano Lucci[1], Carlo Zaghi[2]

[1] National Agency for Environmental Protection, Roma
[2] Ministry of Environment, Roma

Introduction

It is urgent to assure deep water protection from either nitrates or plant protection products contamination processes, also in the light of the delay with which the latter appear.

The presence of nitrates of agricultural origin in deep waters is partly caused by the use or over-use of fertilizers. Statistics (ISTAT, 2000) on N fertilizers indicate a 1997 average national consumption of 82.28 kg ha^{-1} N units. Such use reached peak values in a few Italian region, in particular: 155.99 kg ha^{-1} in Lombardia, 137.75 kg ha^{-1} in Friuli-Venezia Giulia, 134.98 kg ha^{-1} in Veneto, 102.08 kg ha^{-1} in Piemonte, 106.09 kg ha^{-1} in Trentino-Alto Adige (with a peak of 159.72 kg ha^{-1} in the Bolzano province), 95.46 kg ha^{-1} in Emilia-Romagna and in Campania.

The contribution of N contained in manure-slurry can be relevant too. The approximately estimated amount of N contained in bovine and pig slurry, calculated with the procedures indicated by Corsinotti *et al.* (1988) and Regione Emilia Romagna (1996) on the basis of 1997 head of cattle figures (ISTAT, 2000), is 38.79 kg ha^{-1} in Emilia-Romagna, 30.28 kg ha^{-1} in Friuli-Venezia Giulia and 52.51 kg ha^{-1} in Veneto. However, it can be much higher in the other above mentioned regions.

The available statistical data concerning plant protection products (amount of active ingredients) for year 1997 (ISTAT, 2000) show an overall use of 84,799 tons divided in:

fungicides	52,638
insecticides and acaricides	11,934
herbicides	**10,536**
others	9,691

The mean national consumption of plant protection products per ha in 1995 (ISTAT, 1998) was 13.1 kg ha^{-1}. Peak values were reached in regions characterized by intensive agricultural activities: Trentino-Alto Adige (35.3 kg ha^{-1}), Liguria (23.1 kg ha^{-1}), Veneto (23.0 kg ha^{-1}), Emilia-Romagna (21.9 kg ha^{-1}), Piemonte (17.7 kg ha^{-1}), Friuli-Venezia Giulia (15.9 kg ha^{-1}), Campania (15.1 kg ha^{-1}).

Apart from Lombardia, where the said consumption is limited, in many cases the strongest consumers of plant protection products are the regions using the largest N-fertilizer amounts and producing the largest amounts of manure-slurry. Thus, these factors of environmental pressure clearly affect the above mentioned areas as well as their deep water resources.

Annex 7 to the legislative decree May 11 1999, n° 152 (table 1) establishes the criteria for the identification of the areas vulnerable to both nitrates of agricultural origin (Part A) and plant protection products (Part B).

Such identification is needed in order to preserve deep water resources from pollution caused by an over-application of N fertilizers and manure-slurry on the soil (nitrates), as well as by the use of plant protection products (in particular fungicides, insecticides, herbicides, acaricides, nematocides). Annex 7 of the above decree plans successive approximations, adjustable to the differing regional and local know-how.

Such approach proves suitable to a context of permanent planning, and is open to new information and scientific achievements. Parts A and B of the Annex have different objectives but share a few methodological chapters (chapter AII and BIII), which are essential for controlling both contamination from nitrates of agricultural origin and plant protection products. As to nitrates of agricultural origin, the above decree implements the directive 91/676/CEE; therefore, in the identified vulnerable areas it definitively establishes limitations in the use of nitrogen.

Conversely, concerning phytosanitary products, on the basis of the legislative decree March 17 1995, N°. 194 the Minister of Health can fix restrictions or prohibitions, also temporary, of authorized substances as well as treatment periods in specific areas (par. 20 art. 5), in consideration of specific requests by both Regions and Autonomous Provinces (par. 21). Both prevention and restriction measures can be applied only when vulnerable areas are identified.

Table 1 - Outline of Annex 7 to the legislative decree N°. 152/99

PART A — AREAS VULNERABLE TO NITRATES OF AGRICULTURAL NATURE

PART AI

- CRITERIA FOR THE IDENTIFICATION OF VULNERABLE AREAS
- CHECKS TO BE MADE IN VIEW OF THE VULNERABLE AREAS REVIEW
- REFERENCE METHODS

PART AII *

- METHODOLOGICAL ASPECTS

Reconnaissance preliminary investigation

Subsequent updating

PART AIII

- DESIGNATED VULNERABLE AREAS

PART AIV

- INDICATIONS AND MEASURES TO DRAW UP ACTION PROGRAMMES

PART B — VULNERABLE AREAS TO PLANT PROTECTION PRODUCTS

PART BI

- IDENTIFICATION CRITERIA

PART BII

- METHODOLOGICAL ASPECTS

Reconnaissance preliminary investigation

Subsequent updating

PART BIII *

- GENERAL ASPECTS TO PRODUCE MAPS OF AREAS WHERE DEEP WATERS ARE POTENTIALLY VULNERABLE

I Level: Aquifers intrinsic vulnerability

II Level: Specific vulnerability

* part shared by nitrates and plant protection products.

Identification of areas where deep water resources are potentially vulnerable

The identification of areas vulnerable to contaminants percolation takes into account the factors which are at the origin of the vulneration process, allowing their comparison with physico-chemical features of potential contaminants. Such factors are:

- aquifers intrinsic vulnerability to contaminants (aquifers and underground lithostratigraphy, hydrogeological, hydrodynamical features),

- soil attenuation capacity towards contaminants (soil texture, organic matter content and other features relating to its composition and chemico-biological reactivity),
- climatic and hydrological aspects,
- cultivation system and agronomic practices.

All the methodological approaches to the vulnerability evaluation require suitable and homogeneous geo-environmental information and data (Giuliano, 1995 and 1997).

As is well known, in our Country there occur:

- areas with appropriate environmental data set and partly already covered by vulnerability maps;
- areas with environmental information and data sufficient to produce a preliminary vulnerability map at the reconnaissance scale (1:250,000);
- areas with scanty and/or fragmentary information where vulnerability determination requires additional data collection or temporary similarity evaluation.

Identification at a reconnaissance scale (1:250,000)

The Annex 7 espects to proceed through subsequent approximations: preliminary reconnaissance investigations and following reviews based on updating, stemming also from the results of more detailed studies.

Preliminary reconnaissance investigation. The first approximation is indicative and has the main task of producing a preliminary map pointing out the most critical areas. The dissimilarity of the available environmental data calls for a simplified approach, which can also require the use of replaceable data and information. The mapping scale is 1:250,000. The Annex fixes in one year the deadline for presenting the results of this investigation.

The present investigation does not aim at describing aquifer vulnerability throughout the Country, at any intensive degree, but rather at identifying those zones where deep water contamination hazards clearly appear. In the first approximation it is not necessary to distinguish vulnerability classes. Such discrimination is, however, rather difficult due to the dishomogeneity of the data and of the evaluations, sometimes obtained by means of differing and not comparable methodological approaches.

Critical factors considered in the identification are:

a) presence of a free water table or, where the hydraulic connection with surface water is possible, a partially confined one; in case of fracturated bedrock, presence of aquifers at a depth lesser than 50 m, to be doubled in strongly karstic areas;

b) presence of permeable rock at surface or permeable unsaturated horizon (sand, gravel or fracturated rocks);

c) presence of low attenuation capacity soils (e.g. sandy or gravelly soils, low organic matter rate, thin soils).

The concurrence of these conditions identifies the most vulnerable areas. Exception is made for those areas where the rock type does not allow the presence of an aquifer, or where there exists a sort of protection given by either a poorly permeable but continuous horizon, or a soil with a high capacity of contaminants absorption and transformation. As regards plant protection products, the first aproximation includes areas where monitoring activities caught hazardous contaminant concentrations in deep waters (Funari *et al.*, 1995) on the basis of standard water quality requirements for human consumption.

During this phase it is possible to consider also the climatic factors relevant to vulnerability evaluation and information on cultivation system and related agronomic practices.

Updating. The investigation and the map can be updated on the basis of new information, even in parallel to more detailed studies.

Concerning plant protection products, and nitrates too, it is expected that updating should identify more than one vulnerability class (three at most) referred to the highest degrees (e.g. extremely high, very high, high). This makes it possible to establish, mainly as regards plant protection products, use restrictions or exclusions, taking into consideration the intrinsic characteristics of the substances employed. To identify plant protection products to be restricted or excluded, Annex 7 suggests the use of parameters, indexes, models and classification systems able to group substances on the basis of their percolation potential[1].

Semi-detailed scale identification (1:50,000-1:100,000)

An investigation aimed at working out a semi-detailed map (1:50,000-1:100,000), where major efforts are concentrated on the most vulnerable areas, is envisaged by Annex 7. Such investigation will be carried out after, or in parallel to the reconnaissance studies formerly described. The medium/long term deadline is not rigorously fixed.

The factors taken into consideration regards aquifer "intrinsic vulnerability", soil attenuation capacity, climate, cultivation system and agronomic practices and, in the case of plant protection products, their dynamic chemical characteristics.

Finally, the Annex suggests that local administrations can develop more detailed studies, with an operational and project implementation object. Such studies prove useful to forecast and planning activities, to prevent pollution. The investigations aim at evaluating vulnerability and risks in specific sites (well fields, farms, districts, etc.), within larger vulnerable areas. They allow us to provide more precise information about time and space restrictions and, in the case of plant protection products, to suggest technical and operational procedures for this selection and use.

General methodological aspects

Part BIII of the Annex explains the overall methodological procedures for mapping areas where deep waters are potentially vulnerable to nitrates and plant protection products. The methodological outline (table 2) can be applied to investigations with different approach scale. It shows two main investigation levels: intrinsic aquifer vulnerability and specific vulnerability.

Table 2 - Methodological outline to evaluate aquifer vulnerability by nitrates and plant protection products.

		INPUT INFORMATION	EVALUATION OUTPUT
LEVEL I	1	**Hidrogeological and soil data** Lithological structure, subsoil and aquifer hydrogeological and hydrodynamical features, soil chemico-physical and hydrodynamical characteristics.	**Aquifer intrinsic vulnerability** Matching aquifer intrinsic vulnerability and soil attenuation capacity.
		General climatic and cultivation system characteristics (e.g. irrigation)	
LEVEL II	1	**Contaminant data** Chemodynamic features and treatment dose	**Specific vulnerability** Integration of aquifer intrinsic vulnerability with soil
	2	**Dynamic simulation models** Integration of hydrogeologic and soil features with contaminant, climate, cultivation system and agronomic practices data (irrigation, soil tillage, etc.)	attenuation capacity referred to a specific pollutant

Aquifer intrinsic vulnerability (Level I)

Aquifer intrinsic vulnerability evaluation mainly takes into account lithological structure, aquifer and subsoil hydrologic and hydrodynamic features. It is referred to generic pollutants, without considering substances chemodynamic features.

Three evaluation and mapping approaches to aquifer intrinsic vulnerability are available (Civita, 1996; Civita and De Regibus, 1995; Baraldi *et al.*, 1995; Civita, 1994; Zavatti, 1990): qualitative (e.g. VAZAR – GNDCI-CNR), parametric (e.g. DRASTIC, SINTACS, ISIS) and numeric methods (or analogico-mathematical models), these latter being generally less used than the preceeding ones.

The choice among the different approaches, provided it gives comparable results, should be based on suitability (e.g. available maps and investigations) and organizational criteria (e.g. scientific structures present or working on a specific area).

Wherever soil information is available, the aquifer intrinsic evaluation can already take into account the soil capacity to control contamination processes (Baraldi *et al.*, 1996; Regione Veneto, 1996). Attenuation capacity is defined by Baraldi (1995) as "the potential to absorb, dilute, retard, transform the contaminants through a range of physical, chemical and biological processes".

Soil capacity to reduce contaminants migration processes can be assessed by qualitative and quantitative procedures (Calzolari *et al.*, 1999; Brenna *et al*, 1997; Beinat and van den Berg, 1996; Jarvis *et al.*, 1996; Regione Piemonte, 1994; Trevisan *et al.*, 1996; Hollis, 1991), usually not standardized. The estimate is referred to soil typological units or to soil types on the basis of adequate soil information (georeferenced database or maps).

Specific vulnerability (Level II)

Specific vulnerability is evaluated by integrating aquifer intrisic vulnerability with the soil attenuation capacity referred to a specific contaminant typology (nitrates) or substance (e.g. the active ingredients contained in a plant protection product) (Facchino and Giuliano, 1996 a and b; Regione Piemonte, 1997 a and b;.Trevisan *et al.*, 1995).

Being available detailed information on the environmental feaout after, or in parallel to the reconnaissance studies formerly described. The medium/long term deadline is not rigorously fixed.

The factors taken into consideration regards aquifer "intrinsic vulnerability", soil attenuation capacity, climate, cultivation system and agronomic practices and, in the case of plant protection products, their dynamic chemical characteristics.

Finally, the Annex suggests that local administrations can develop more detailed studies, with an operational and project implementation object. Such studies prove useful to forecast and planning activities, to prevent pollution. The investigations aim at evaluating vulnerability and risks in specific sites (well fields, farms, districts, etc.), within larger vulnerable areas. They allow us to provide more precise information about time and space restrictions and, in the case of plant protection products, to suggest technical and operational procedures for this selection and use.

General methodological aspects

Part BIII of the Annex explains the overall methodological procedures for mapping areas where deep waters are potentially vulnerable to nitrates and plant protection products. The methodological outline (table 2) can be applied to investigations with different approach scale. It shows two main investigation levels: intrinsic aquifer vulnerability and specific vulnerability.

Table 2 - Methodological outline to evaluate aquifer vulnerability by nitrates and plant protection products.

		INPUT INFORMATION	EVALUATION OUTPUT
LEVEL I	1	**Hidrogeological and soil data** Lithological structure, subsoil and aquifer hydrogeological and hydrodynamical features, soil chemico-physical and hydrodynamical characteristics. General climatic and cultivation system characteristics (e.g. irrigation)	**Aquifer intrinsic vulnerability** Matching aquifer intrinsic vulnerability and soil attenuation capacity.
LEVEL II	1	**Contaminant data** Chemodynamic features and treatment dose	**Specific vulnerability** Integration of aquifer intrinsic vulnerability with soil
	2	**Dynamic simulation models** Integration of hydrogeologic and soil features with contaminant, climate, cultivation system and agronomic practices data (irrigation, soil tillage, etc.)	attenuation capacity referred to a specific pollutant

tures, the agricultural system, the agronomic practices and an accurate soil assessment, it is possible to develop maps integrating the evaluations of aquifer intrinsic vulnerability with the outputs of simulation models.

While nitrates should be regarded as a single contaminant typology, plant protection products should be considered on the basis of their specific chemophysical and leachability features, showing groundwater contamination hazard.

Simulation models make it possible to integrate a multitude of data on contaminants' properties and modalities of use (i.e. treatment time, doses ha^{-1}), thus proving a more advanced instrument than synthetic indices (Trevisan, 1996; Tani *et al.*, 1996).

Regarding plant protection products, use can be made of one among the nine evaluation models (PRZM-2, PRZM, PELMO, GLEAMS, PESTLA, VARLEACH, LEACHM, MACRO and PLM) on groundwater contamination hazard identified by FOCUS (Forum for the coordination of pesticides fate models and their use – EC working group/promoted by EC) (Businelli, 1996; CCPF, 1996).

The Geographic Information Systems (GIS) certainly represent the most suitable tool to store and process geo-referenced environmental data. GISs allow large masses of information of different origin and nature to be combined, including those concerning potential contaminants, climate, agricultural systems and agronomic practices properties (Beinat and van den Berg, 1996; Civita *et al.*, 1995).

Conclusions

On the whole, Annex 7 proves innovative and opens the door to the correct use of pedological information in the vulnerability evaluation process. The concept of soil attenuation capacity is not defined in the Legislative decree 11 May 1999, N.152. In some cases it is advisable an implicit reference to aquifer vulnerability standard evaluation approaches (CNR-GNDCI and SINTACS). However, it is necessary to determine more precisely the criteria to assess soil capacity to protect deep waters from contamination, starting from the experiences developed in our country and in the light of other countries scientific achievements. In this regard, an important role is being carried out by regional soil services, which are very active in the more vulnerable areas, where most studies on contamination processes are in progress.

Bibliografia

CORSINOTTI P., BERGAMINI M.C., DE ROEST C. (1988). Valutazioni tecnico-economiche sull'impatto ambientale degli ordinamenti produttivi prevalenti delle aziende agricole (frutticole e zootecniche) nell'area padana prospiciente il bacino del Po. In: *Agricoltura ambiente* (Pinotti B. coord.) (Vol. 2). Pitagora Editrice, Bologna. pp. 153-195.

BARALDI F., CAMPANA G., CASTALDINI D., PALTRINIERI N., SPALLACCI P., ZAVATTI A. (1995). La capacità di attenuazione del suolo tra i fattori di valutazione della vulnerabilità all'inquinamento degli acquiferi. Due esempi: area morenica mantovana e alta pianura modenese (Italia Settentrionale). Quaderni di Geologia Applicata 1 (Vol. 3), Pitagora Editrice, Bologna, pp.123-140.

BARALDI F., BORALDI V., CASTALDINI D., PALTRINIERI N., SPALLACCI P., ZAVATTI A. (1996). *Pianura della provincia di Modena: Carta della vulnerabilità all'inquinamento dell'acquifero principale (scala 1:100,000)*. CNR/GNDCI - Provincia di Modena, Pubblicazione GNDCI n. 1373.

BEINAT E., van den BERG R. (eds.) (1996). *EUPHIDS, a decision support system for the admission of pesticides*. National Institute of Public health and the environment, Bilthoven, The Netherlands. Report no. 712405002, 178 pp.

BRENNA S., RIPARBELLI C., RASIO R., AZIMONTI G. (1997). Aquifer vulnerability to soil pesticide leaching at regional scale in Lombardy - North Italy. International Conference (ISSS-ITC) : Geo-Information for sustainable land management, Enschede (Olanda) 17-22 Agosto 1997.

BUSINELLI M. (1996). Attività dei gruppi di lavoro sui modelli di previsione del FOCUS. In *Valutazione dell'impatto ambientale dei prodotti fitosanitari mediante simulazione matematica*, Quaderno GRIFA n. 14, pp. 45-53.

CALZOLARI C., UNGARO F., BUSONI E., FILIPPI N., GUERMANDI M., TAROCCO P., BRENNA S., MICHELUTTI G., PIAZZI M., VINCI I. (1999). The SINA Project in the Padano-Veneto basin. International Congress Soil vulnerability and sensitivity. Florence, 18-21 October 1999. (In print)

CCPF (1996) (October). *Criteri per valutazione del destino ambientale dei prodotti fitosanitari*. 26 pp.

CIVITA M. (1994). *Le carte della vulnerabilità degli acquiferi all'inquinamento: teoria e pratica*. Pitagora Editrice, Bologna, 316 pp.

CIVITA M. (1996). La cartografia della vulnerabilità degli acquiferi nei progetti del GNDCI-CNR. In Atti della giornata di Studio: *Cartografia della vulnerabilità degli acquiferi: dagli studi conoscitivi all'applicazione normativa*. Milano, 16 Gennaio 1996. CNR, IRSA Quaderni, 99, pp.69-79.

CIVITA M., FILIPPINI G., MARCHETTI G., PALTRINIERI N., ZAVATTI A. (1995). Uso delle Carte di vulnerabilità degli acquiferi all'inquinamento nella pianificazione e gestione del territorio. Quaderni di Geologia Applicata 1 (Vol. 3). Pitagora Editrice, Bologna, pp. 141-151.

CIVITA M., DE REGIBUS C. (1995). Sperimentazione di alcune metodologie per la valutazione della vulnerabilità degli acquiferi. Quaderni di Geologia Applicata 1 (Vol. 3), Pitagora Editrice, Bologna, pp.63-72.

FACCHINO F., GIULIANO G. (1996 a). Assessing the pollution potential of pesticides for groundwater. In: *The environmental fate of xenobiotics* (Del Re A.A.M., Capri E., Evans S.P., Trevisan M. eds.), La goliardica pavese s.r.l., Pavia, pp. 355-362.

FACCHINO F., GIULIANO G. (1996 b). Una procedura per la mappatura della vulnerabilità delle acque sotterranee alla contaminazione da pesticidi. *IA Ingegneria Ambientale*, 25 (6):304-316.

FUNARI E., DONATI L., SANDRONI D., VIGHI M. (1995). Pesticide levels in groundwater: value and limitations of monitoring. In: *Pesticides risk in groundwater* (Vighi M., Funari E. eds.), Lewis Publishers, Boca Raton, Florida, USA, pp. 3-44.

GIULIANO G. (1995). Groundwater vulnerability to pesticides: an overview of approaches and methods of evaluation. In: *Pesticides risk in groundwater* (Vighi M., Funari E. eds.), Lewis Publishers, Boca Raton, Florida, USA, pp. 101-118.

GIULIANO G. (1997). (Personal Comunication -Contribution to the decree).

GUSTAFSON D.I. (1989). Groundwater ubiquity score: a simple method for assessing pesticide leachability.

Environmental Toxicology and Chemistry, 8(4): 319-357.

HOLLIS J.M. (1991). Mapping the vulnerability of aquifers and surface waters to pesticide contamination at the national/regional scale. In: *Pesticides in soils and water*, BCPC Mono. n. 47, pp.165-174.

ISTAT (1998). *Statistiche ambientali.* Italy's National Statistical Institute. Roma. 436 pp.

ISTAT (2000). *Statistiche dell'Agricoltura.* Italy's National Statistical Institute. Roma (in press).

JARVIS N., NICHOLLS P., HOLLIS M., MAYR T., EVANS S. (1996). Pesticides exposure assessment for surface waters and groundwater using the decision-support tool macro-DB. In: *The environmental fate of xenobiotics* (Del Re A.A.M., Capri E., Evans S.P., Trevisan M. eds.), La goliardica pavese s.r.l., Pavia, pp. 381-388.

Regione Emilia Romagna (1996). Circolare del direttore generale area ambiente 19 aprile 1996, n.2645. Circolare n. 2645 del 19/4/1996 (sostitutiva della circolare n. 5404 del 10/10/1995) relativa all'applicazione della L.R. 50/95 e della delibera di Consiglio regionale 2409/95. Bollettino Ufficiale Parte seconda N. 66, Anno 27, N. 114. 19 pp.

Regione Piemonte, Assessorato all'ambiente, cave e torbiere, energia, pianificazione e gestione delle risorse idriche, lavori pubblici e tutela del suolo (1994). Carta del rischio potenziale di inquinamento del suolo e delle acque - Pianura Cuneese (scala 1:50,000). In Indagini sullo smaltimento dei liquami reflui da allevamento. Indicazioni per il loro trattamento. Indicazioni tecniche per una normativa di settore. IPLA, Torino.

Regione Piemonte, Assessorato all'ambiente, cave e torbiere, energia, pianificazione e gestione delle risorse idriche, lavori pubblici e tutela del suolo (1997 a). Carta del rischio potenziale di inquinamento del suolo e delle acque per percolamento del P.A. Alachlor - Comune di Sale (scala 1:25,000). IPLA, Torino.

Regione Piemonte, Assessorato all'ambiente, cave e torbiere, energia, pianificazione e gestione delle risorse idriche, lavori pubblici e tutela del suolo (1997 b). Carta del rischio potenziale di inquinamento del suolo e delle acque per percolamento del P.A. Linuron - Comune di Sale (scala 1:25,000). IPLA, Torino.

Regione Veneto. Piano regionale di risanamento delle acque - Allegato D "Norme per lo spargimento dei liquami provenienti da allevamenti zootecnici". Struttura tecnica di supporto regionale "Metodica unificata per l'elaborazione della cartografia relativa all'attitudine dei suoli allo spargimento dei liquami zootecnici" approvata con DGRV n.615 del 21.02.1996, pp. 29-56.

TANI A., CAFFARELLI V., RAPAGNANI M.R., QUERCIA F. (1996). *I pesticidi nell'acqua: processi, metodi di simulazione e stima.* ENEA, RT/INN/96/3, 54 pp.

TREVISAN M. (1996). I modelli disponibili per predire la contaminazione delle acque superficiali profonde ai fini registrativi e di pianificazione territoriale. In Valutazione dell'impatto ambientale dei prodotti fitosanitari mediante simulazione matematica, *Quaderno GRIFA* n. 14, pp. 54-66.

TREVISAN M., NASSISI A., RUSSO E., SASSI E., DEL RE A.A.M. (1995). Mappe di vulnerabilità dell'acquifero da pesticidi per la provincia di Piacenza. Quaderni di Geologia Applicata 1 (Vol. 3). Pitagora Editrice, Bologna, pp.73-77.

TREVISAN M., CAPRI E., ERRERA G., ZAVATTI A., BORALDI V., DONATELLI M., SPALLACCI P., NASSISI A., MANICARDI A., UGOLETTI C., PALTRINIERI N. (1996). Criteria for mapping aquifer vulnerability to xenobiotics. In: *The environmental fate of xenobiotics* (Del Re A.A.M., Capri E., Evans S.P., Trevisan M. eds.), La goliardica pavese s.r.l., Pavia, pp. 697-703.

VIGHI M., DI GUARDO A. (1995). Predictive approaches for the evaluation of pesticide exposure. In: *Pesticides risk in groundwater* (Vighi M., E. Funari eds.), Lewis Publishers, Boca Raton, Florida, USA, pp. 73-100.

ZAVATTI A. (ed.) (1990). *Studi sulla vulnerabilità degli acquiferi.* Vol.1. Pitagora Editrice, Bologna, 195 pp.

Note

[1] The main chemophysical properties of plant protection products, describing leachability and groundwater contamination hazard, are:

- adsorption capacity by organic matter and other colloids
- resistance to degradation processes, persistence (half life in soil)
- water solubility
- dissociation constant, polarity
- octanol/water partition coefficient

In order to rank the plant protection products on the basis of the potential leaching, relatively simple indexes can be used. One example is the Gustafson leaching index (Gustafson, 1989):

$$\text{GUS (Groundwater Ubiquity Score)} = \log DT_{50} \times (4 - \log Koc)$$

where **DT_{50}** represents the disappearance time of 50% of applied amount of active ingredient (expressed by a day or hour number), **Koc** represents the organic carbon sorption coefficient depending on partition properties of a subtance between the organic carbon of soil and the water phase (expressed by cm^3/g). It allows the classification of chemicals, as a function of groundwater contamination potential, in the following groups:

- leacher (GUS > 2.8)
- transitional (2.8 > GUS > 1.8)
- not leacher (GUS < 1.8)

To take into account the applied amount of active ingredient per hectare, a modified GUS index can be used:

$$GUSm = GUS \times AR$$

where **AR** represents the applied amount, expressed by kg ha^{-1} (Vighi, 1995).

Influence of Grazing on Soil Degradation and Evaluation of the Risk of Desertification (Rio Astimini Basin - North West Sardinia)

Giovanna Dessì, Mario Deroma, Paolo Mulè, Paolo Baldaccini

Dipartimento di Ingegneria del Territorio
Sezione di Geopedologia e Geologia Applicata

Università degli Studi di Sassari
Via De Nicola 9 - 07100 Sassari

Introduction

The new agricultural policies of the U.E. are aimed at a more rational use of the land and, above all, at a greater respect for the environment. There is an attempt to increase the area used for cultivation and stock-breeding through financial aid to farms. The aim is to reduce degradation caused by overuse of the principal natural resources: soil and water. The objective of this paper is to identify and quantify the effects of degradation in an area used for animal husbandry. In particular the aim is to provide some useful guidelines to reduce environmental degradation to a minimum. Indeed we intend to find a methodology to reach this objective which can then be extended to cover the whole of Sardinia.

This theme was chosen because Sardinia is one of the Italian regions in which stock- rearing is of primary importance and because in recent years there has been a substantial increase in the stocking rate, above all for sheep, in this region. Most of the stock-raising is wild or semi-wild, mainly in hilly or mountainous areas and in pedomorphological areas which are particularly vulnerable to environmental degradation. The environmental problems caused by this use of such areas are becoming increasingly serious and difficult to resolve.

We therefore tried to identify certain parameters which provide major indications of the capacity of the soil to resist the structural modifications caused by trampling and its sensitivity to compaction, in relationship to its state of humidity at different times of the year. Using these parameters to assess the various types of soil is useful because it allows us not only to identify the most vulnerable areas but also to identify the periods of the year of highest risk for the different environments. If the suggestions made by this study are followed it may be possible to reduce grazing erosion and encourage a faster recovery of vegetation.

The study was a year round one as grazing takes place in Sardinia in all four seasons.

The area studied

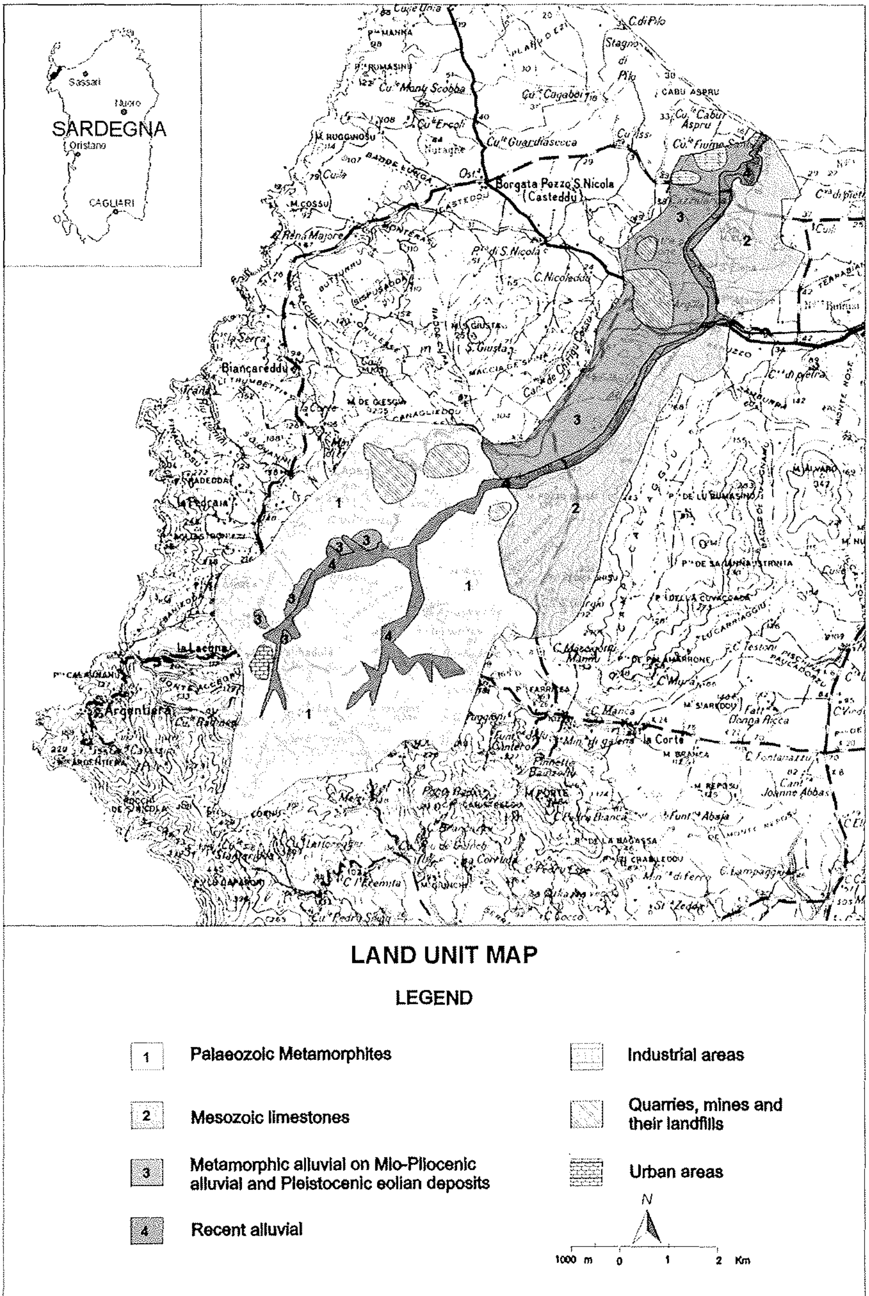
The area studied is in north-west Sardinia (figure 1). It is a hydrographic basin in the lower reaches of the rivers Rio Astimini- Fiume Santo. The area is 5760 hectares. The basin is quite complex in form and thus can be used as a model of all the different land characteristics and environments of the entire Nurra area. The principal lithographic formations are metamorphic in the south, Mesozoic limestone on the right bank of the river and alluvial mio- pliocenic deposits on the left bank.

The Palaeozoic metamorphites are made up of schistose materials which are quite changeable, so the slopes of the hilly terrain which they make up are gentle in some areas. Nonetheless, the slopes are often steep even for these areas with an average incline of 30-40%. In the Miocene limestone areas there are rounded hills which nonetheless often have steep slopes. There is often karst phenomena and there are a considerable number of rocky outcrops. The part of the basin with ancient alluvial deposits has terraces which slowly descend towards the coast.

The most useful climatic phenomena for the study were rainfall and temperature. The basin has a typical Mediterranean climate. The total amounts of rainfall was of 500-600 mm/year.

The natural vegetation of the basin is reduced to some areas of more or less degraded Mediterranean maquis. Normally the less degraded maquis is found on the slopes which are too steep for grazing or where the large percentage of rocky outcrops prevents any attempt to use the land for grazing. The areas suitable for grazing are often overstocked and this has contributed strongly to triggering off serious erosion. The animals have degraded the turf in many cases and have contributed to compacting the soil.

Figure 1 - Studied area map and Land Unit



Land Units

There were four lithographic formations which corresponded to the following four Land Units:

LAND UNITS	LITHOGRAPHIC FORMATIONS	MORPHOLOGY	SOILS
1	**Palaeozoic Metamorphites** Mainly made up of sericitic and quartziferous, with quartz elements	Although there where some steep slopes the hill wer eoften rounded	**Complex of**: Lithic Xerorthents, Lithic Ruptic Xerorthentic Xerochrepts **Association of**: Lithic Xerochrepts, Lithic Ruptic Xerorthentic Xerochrepts
2	**Mesozoic limestones** Giura-Liass compact limestones	The country consisted of rolling hills and gen tly rolling or flat plain	**Complex of**: Lithic Xerorthents, Ochreptic Rhodoxeralfs, Lithic Rhodoxeralfs **Association of**: Lithic Rhodoxeralfs, Typic Rhodoxeralfs; Lithic Xerorthents, Ochreptic Rhodoxeralfs, Lithic Rhodoxeralfs; Typic Haploxeralfs, Lithic Rhodoxeralfs, Typic Rhodoxeralfs
3	**Mio- Pliocenic Alluvial**	Typical terraces which descend slowly towards the coast	**Association of**: Typic Palexeralfs, Aquic Palexeralfs, Lithic Palexeralfs, Psammentic Haploxeralfs
4	**recent Alluvial**	Plain Morphology	Typic Xerofluvents

Materials and methods

For each physiographic unity the evaluation methodologyfor grazing suitability, for the different soils,was applied as illustrated below.

CHOICE OF THE REPRESENTATIVE PROFILES

↓ Estimate/measure and evaluation of:

Indices for the evaluation of the structural stability

- *Liquid limit/ground capacity*
- *Resistance index*
- *Clays activity index*
- *Plastic limit*
- *Contraction limit*

Slope

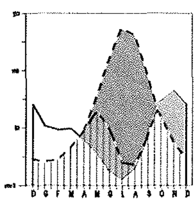
Outcrop rocks

Superficial stoniness

Depth of the low permeable horizon

Water retention capacity

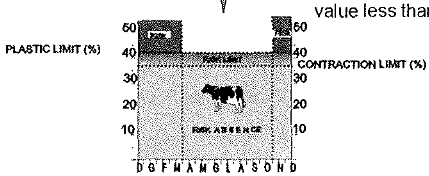
Moisture class



LEGEND

- Rainfall
- Potential evapotranspiration
- Real evapotranspiration
- Surplus
- Reserve riconstitution
- Deficit
- Reserve variation

Through the calculation of the soil hydrologic balance with the Thornthwaite-Mather method for each soil the number of months/year where the ground has a moisture value less than the limit risk was determined.



Conclusions

On the base of the data and the table above we may conclude that to avoid structural damage to, and reduce erosion of, soil which is vulnerable to structural collapse, grazing should be limited in the periods of the year when there is an excess of water.

We advise in particular:

- Grazing rotation;
- Periodic watering of the turf;
- Reduction of stocking rates.

Bibliography

ALIOTO M.N., MAGALDI D., RISTORI G. (1989). Alcune proprietà fisiche, geotecniche e mineralogiche dei suoli argillosi della Val dell'Orcia in quaderni di Scienza del Suolo, vol II Firenze.

CAVAZZA L. (1981). *Fisica del terreno agrario*, UTET, Torino.

COLOMBO P. (1975). *Elementi di geotecnica*, Zanichelli, Bologna.

FAO Soils Bullettin 58 (1991). *Guidelines: land evaluation for extensive grazing*, Roma.

FAO (1977). *Framework for land evaluation*, Roma.

HARROD T.R. (1979). Soil suitability for grassland, in Soil Survey Applications, *Soil Survey Tech. Monogr.* n° 13, Harpenden.

Technical Monograph n° 9 (1977). Water retention, porosity and density of field soils, Harpenden.

Technical Monograph n° 13 (1979). Soil Survey applications, Harpenden.

POTENTIAL RISK OF GROUNDWATER POLLUTION FROM AGRICULTURAL NON-POINT SOURCES

Laura Padovani, Ettore Capri, Marco Trevisan[1]

Istituto di Chimica Agraria ed Ambientale, Sezione Chimica Vegetale
Università Cattolica del Sacro Cuore, Piacenza

[1] Dipartimento di Scienze Agro-ambientali e della Produzione Vegetale
Università degli Studi di Perugia

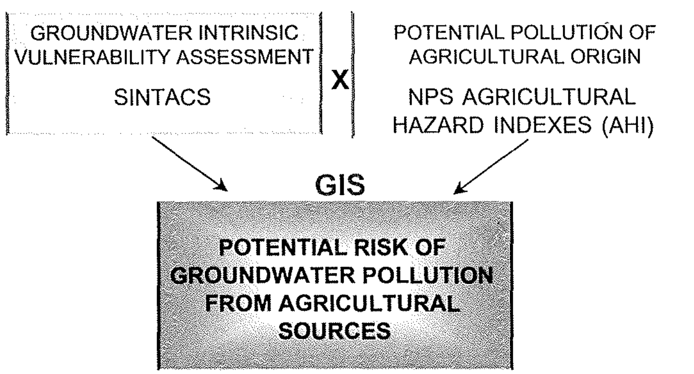
Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche, CNR; U.O. 4.15. Responsible: Prof. A.A.M. Del Re

Introduction

Groundwater pollution of aquifers has generated a growing interest in recent years both in the political and legal domain as well as in the scientific world. The finding into groundwaters of some plant protection products, nitrates, mineral oils, and halogenated hydrocarbons is evidence that this is a rather common phenomenon and derives from many human activities. Herein we present a methodology to assess potential risk of groundwater pollution due to agricultural practices.

Approach

The procedure consists in combining a valid point count system model called SINTACS (Civita and De Maio, 1997) evaluating groundwater intrinsic vulnerability, with a parametric approach based on the definition of the methodology of potential hazard indexes to include non point sources of pollution of agricultural origin (Trevisan *et al.*, 1999a).



A Geographic Information System is used to store, manipulate and analyse spatially referenced data, to create maps and to assign sensitivity rating values to mapped attributed values.

The SINTACS model is based on 7 parameters which compose the Italian acronym.

The SINTACS model: 7 parameters

S oggiacenza = depth-to-water table (piezometric level)

I nfiltrazione = effective infiltration action

N on-saturo (effetto di autodepurazione del) = unsaturated zone attenuation capacity

T ipologia della copertura = soil/overburden attenuation capacity

A cquifero = hydrogeologic characteristics of the aquifer

C onducibilità idraulica dell'acquifero = hydraulic conductivity range of the aquifer

S uperficie topografica (acclività della) = hydrologic role of the topographic slope

The index of vulnerability SINTACS corresponds to the weighted average of 7 values (1-10) corresponding to the 7 parameters multiplied by weight strings that are able to describe the effective hydrogeologic and/or impact situation.

$$IS_{NO} = \frac{IS_{GR} - IS_{MIN}}{IS_{MAX} - IS_{MIN}} \cdot 100$$

IS_{GR} = raw value

IS_{MIN} = minimum raw value (26)

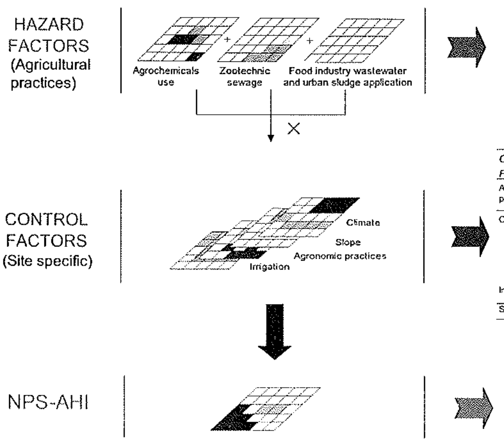
IS_{MAX} = maximum raw value (260)

Percentualised point vulnerability degrees of SINTACS index.

Point range	VULNERABILITY degree
0-24	Very low
25-35	Low
36-49	Moderate
50-69	Fair
70-79	High
80-100	Very high

The SINTACS model: the normalised vulnerability index

The overlay/index method to evaluate agricultural non-point source pollutants (NPS-AHI) is based on the combination of the HAZARD FACTORS (HF), representing all farming activities that cause or may cause impact on ground water, and CONTROL FACTORS (CF) which adapt the hazard factor to the characteristics of the site (geographical location, slope, agronomic practices and type of irrigation).



Pesticides (kg/ha)	HF	Fertilisers N + P_2O_5 (kg/ha)	HF	Trace elements kg/ha	HF
0-0.5	0	0-25	0	0-10.4	0
0.5-1.5	1	25-75	1	10.4-51.9	1
1.5-2.5	2	75-125	2	51.9-103.9	2
2.5-4.5	3	125-225	3	103.9-207.9	3
4.5-6.5	4	225-325	4	207.9-519.7	4
>6.5	5	>325	5	>519.7	5

CONTROL FACTORS	Hazard decrease		Reference conditions		Hazard increase	
Agronomic practices	No tillage; minimum tillage, orchards (grass regener.); Integrated Pest Manag.		Traditional tillage, orchards (tilled soil)		Sludge application	
Climate	Temperature (annual mean)	Precipitation (mm/yr)	Temperature (annual mean)	Precipitation (mm/yr)	Temperature (annual mean)	Precipitation (mm/yr)
	13-14 °C > 15 °C 15-17 °C	600 – 700 500 – 900 < 600	12-13 °C	600-800	6-15 °C 12 °C 14-15 °C 13 °C 15-16 °C	>1200 800 – 1000 950-1100 1050-1150 600-1000
Irrigation			No irrigation		Submersion, flowing, aspersion	
Slope	5-24 %; > 24 %		0-5 %			

Normalised scale of NPS agricultural hazard indexes

Class	Point range	Hazard
1	0 – 1.6	Absent
2	1.6 – 5.2	Unlikely
3	5.2 – 9.4	Very scarce
4	9.4 – 14.5	Scarce
5	14.5 – 21.0	Very low
6	21.0 – 28.7	Low
7	28.7 – 38.3	Moderate
8	38.3 – 50.7	Fair
9	50.7 – 68.0	High
10	68.0 – 112.5	Very high

The hazard index (HI) can be calculated multiplying the hazard factors by the control factors and, finally, the NPSAHI are obtained by dividing HI into classes on a percentile basis using a scale ranging from 1 to 10.

Cumulative potential risk values are obtained by multiplying vulnerability class values by NPS-AHI class values and normalised:

Point range	POTENTIAL RISK
0-24	Very low
25-35	Low
36-49	Moderate
50-69	Fair
70-79	High
80-100	Very high

POTENTIAL RISK OF GROUNDWATER POLLUTION FROM AGRICULTURAL SOURCES

Scope and applications

• To identify groundwater pollution risk areas for a large tract of land quickly and economically

• Information from risk maps could be effective in agricultural and territorial management (for example, to develop a sampling strategy for a groundwater monitoring programme).

The parametric approach to assess potential risk of groundwater pollution due to agricultural practices has been applied to the territory of Cremona province, Italy (Trevisan *et al.*, 1999b).

Bibliography

CIVITA M., DE MAIO M. (1997). SINTACS - Un sistema parametrico per la valutazione e la cartografia della vulnerabilità degli acquiferi all'inquinamento. *Quaderni di tecniche di protezione ambientale*, n. 60. Pitagora Ed., Bologna.

TREVISAN M., PADOVANI L., CAPRI E. (1999a). Pericolo di contaminazione delle acque sotterranee da attività agricole. Pubblicazione n. 1937, Gruppo Naz. per la Difesa delle Catastrofi, CNR.

TREVISAN M., PADOVANI L., CAPRI E. (1999b). Assessment of potential risk of groundwater pollution from agricultural non-point sources. Proceedings of the XI Symposium Pesticide Chemistry, September, 1999 - Cremona, Italy. Pp. 543-550.

EDIZIONE A CURA DEL COMITATO ISNP
Via della Navicella, 2/4 - 00184 Roma
Tel. 06-7005413, Fax 06-7005711

Registrato presso il Tribunale di Roma
il 07/04/1998 al n. 00138/98
PERIODICO TRIMESTRALE
ISSN - 0390-4865

Stampa
Delta Grafica s.r.l. - Via G. Pastore, 9
06012 Città di Castello (PG)
Finito di stampare: aprile 2000

Presidenza e Segreteria:

Istituto Sperimentale per la Nutrizione
delle Piante
Via della Navicella, 2/4 - 00184 Roma
Tel. 06-7005413, Fax 06-7005711
e-mail: psequi@isnp.it

Sito Internet: http://www.siss.isnp.it