Soil quality and ecosystem services: a land use perspective *by*

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Introduction

The use of land is dependent on the quality of the soil. In the Netherlands the concept of 'suitability for use' has become a leading principle in renewed soil policy, with respect to both soil remediation (BEVER 1999) and sustainable use and protection of soils (Ministry of VROM 2003). Soil remediation targets for instance may be formulated in view of the intended land use of the contaminated site, to accomplish a cost-effective clean-up target for the short term. While soil quality criteria for different types of land use obviously must be (and can be) based on acceptable levels of human exposure to contaminants, it is less clear what ecological attributes of soils should be assessed to protect the ecosystem and sustain land use (Van Wensem et al. 2000).

From a general viewpoint of soil protection and sustainable land use there is great need to establish biological references for soil quality. For long, the Dutch Technical Committee on Soil Protection has advocated an ecosystem oriented approach for use of soils, and recently elaborated on the possibilities of various kinds of land use for the management of ecological services of soils (TCB 2003), tentatively identifying relevant ecosystem services. Next, the Netherlands Ministry of Housing, Spatial Planning and the Environment (Ministry of VROM) has instigated the development of biological references for sustainable land use. A framework was constructed based on extensive survey of soil biota and soil processes in agricultural grasslands and arable land or nature conservation areas (Rutgers et al. 2005b). In this framework ecosystem services were further specified with ecological requirements in terms of soil biota and soil processes that are considered to be related to a history of particular land use. Whilst the methodology of derivation is still debated, the description of actual references per type of land use is expected in the near future.

Both soil protection and soil remediation therefore will benefit from describing desirable soil quality in ecological terms. In view of the two lines, this paper presents a rationale for the identification of ecosystem aspects that can be considered critical parts of soils, needing protection to achieve a soil quality suitable for use. Thus, the approach is part of the risk scenario description methods that are developed in NoMiracle Research Pillar 1. Whilst other studies directly focus on hazard aspects of chemicals (see Sørensen et al., Thomsen et al., Fauser et al., Jensen et al. in this issue), our study[1] is complementarily aimed at vulnerability of soil ecological receptors.

In a healthy soil ecosystem a natural balance or succession of relative balances is maintained between the physical, chemical and biological soil components. Soil health has been defined as the capacity of a living soil to function within its physical and environmental boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran 1998). It is the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, promote the quality of air and water environments and maintain plant and human health (Nielsen and Winding 2002). Thus, every soil ecosystem provides goods and services for society, so called ecosystem services. Ecosystem services have been described as the properties or the processes in an ecosystem, which are of use to mankind (TCB 2003). They comprise the delivery, provision, production, protection or maintenance of a set of goods and services that people perceive to be important, resulting from the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfil human life (Chee 2004). The health of a soil ecosystem can therefore be determined from its physical, chemical and biological properties as, for example, activity levels, stability, resilience and organisation. These properties however, cannot yet be expressed in well-defined measurable indicators for the ecosystem as a whole. Because of the complexity of the soil ecosystem indicators as such might not be available at all. Therefore, new ways of looking at the soil ecosystem health (and sustainability) have to be found; to this extend, ecosystem services can be used as proxies for ecosystem health and sustainability (TCB 2003; Breure 2004).

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[1] This contribution is based on NoMiracle deliverables D1.1.4 and D1.2.4 and will also be reported in more detail elsewhere (Faber et al. in prep.). In addition to the present summary, the report will further elaborate and include a list of indicators for ecological requirements for soils, and tests for measuring these indicators. Also, the report will present literature data on toxicological effect limits for NoMiracle test substances, with interpretation in terms of critical ecological aspects for agricultural land use and nature.

The main goals of this study are firstly to give a general description of ecosystem services and representative indicators for a selection of specific types of land use. Secondly, to develop a rationale for a systematic approach to identify highest-risk scenarios in land use in view of environmental stressors, based on a vulnerability assessment of indicators for ecosystem services. The resulting methodology may also facilitate risk assessment to develop soil quality targets. In addition, the systematic approach will also help to identify gaps in knowledge, so that uncertainty and ignorance in the risk assessment may be better understood.

Land use and soil ecosystem functioning

For many land use stakeholder groups in society it is clear what ecosystem services are needed for a certain forms of land use (*e.g.* farmers know what to demand from their soils to grow crops). Less knowledge is present, however, about underlying ecological requirements that relate to these ecosystem services. Rather more often this knowledge is present (if at all) at a scientific level. For scientists it is a challenge to communicate that ecological requirements are needed to provide the ecosystem service for sustainable land use. The connection between the scientific knowledge and the demands of society may ease effective answers to the question *what to protect?* from a soil management motive as well as from a soil protection viewpoint.

Several forms of ecological services have been distinguished in general, which may be of relevance to some extent for all types of land use (TCB 2003; Mulder et al. 2004). While still other, more precise or comprehensive divisions may be conceived, for practical and illustrative reasons the following shortlist (TCB 2003) is used:

Soil fertility, the capacity to provide nutrients and produce biomass (including soil structure, organic matter, all essential nutrients for plant and animal);

Adaptability and resilience, the; soil ecosystem capacity to withstand or recover from stress, also the flexibility for land use.

Buffer and reactor function, the ability to store and buffer water, gases, substances, energy, cation exchange capacity, ability to decompose or synthesise substances (natural attenuation, humification);

Biodiversity, a container wording for genetic biodiversity (diversity in genes), functional biodiversity (diversity in ecological processes) and structural biodiversity (species richness and eveness);

Disease suppression and pest resistance, the natural capacity to prevent diseases and control pests;

Physical structure, foundation support, historical archive, and landscape identity.

Ecosystem services

The type of land use determines what ecosystem services are required. Different stakeholders may specifically appreciate the relevance of these services. Some services are important for local users, while other services are of interest to stakeholders at higher scales. Likewise, the management of soils aimed to sustain particular ecosystem services may not be equally important to local users and stakeholders involved at higher scales alike, and different management approaches and measures may be required as well (Fig. 1).

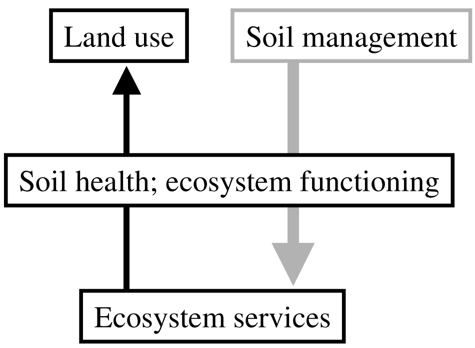

Figure 1. Schematic representation of the relevance of soil ecosystem health and functioning in terms of the provision of ecosystem services for sustainable land use, and the focus of soil management towards the sustainable development and exploitation of these services. To optimise soil use land management needs to be focussed on the relevant ecosystem services, especially so within the framework of sustainable land use, or in the case of setting remediation targets for polluted soils suitable for use.

Ecosystem services can be recognised to be of great importance at the local scale, thus local managers may be expected to show consideration in their management. At higher scales ecosystem services may be relevant for a wider and more common interest, but may not necessarily be managed at the local scale. A rating of the importance of ecosystem services for particular types of land use should therefore consider various scales. This rating is elaborated elsewhere (NoMiracle deliverable D114; Faber et al. in prep).

Soils in general may provide a number of ecosystem services, and depending on the intentional land use some of these may be considered more relevant than others. A systematic approach is used to identify highest-risk scenarios in land use on the basis of available information. This approach involves consecutive steps of describing the risk problem of soil suitability for use into complementary sub-problems, down into criteria data sets that can be weighed and ranked to set priorities for risk assessment and identification of uncertainty from gaps in knowledge (Sørensen, this issue; Thomsen et al. in prep). Thus, ecosystem services are subdivided into ecological requirements and subsequent indicators. Indicators susceptible to chemical stressors are of relevance for the identification of specific criteria, made up by toxicological sensitivity data, and are used as input data in a criteria model to select worst-case scenarios in subsequent risk assessment. The Problem Decomposition Model for the maintenance and enhancement of soil health may for every type of land use be illustrated as in Figure 2, following the stepwise approach of a problem tree (*cf.* Thomsen et al. in prep).

Every ecosystem service may be represented by a suite of ecosystem aspects that vary in relevance depending on type of land use. These aspects can either be physical, chemical or biological of nature (Zalidis et al. 2004; Anderson 2003; Bouma 2002; Schloter et al. 2003). Aspects that are crucial for a particular type of land use to sustain the ecosystem service in question may be considered as *ecological requirements*.

Ecological requirements
As mentioned before, it is not possible to directly determine quality and condition of soil on the basis of land use or ecosystem services. The services themselves are not quantifiable; moreover, they are often relevant for all types of land use at different scales of management, offering little discriminative power for management scenario studies. A further splitting of services into separate aspects seems useful, if regulatory functions and structures of the soil ecosystem are defined that can be acknowledged as minimum requirements to support the designated land use. An inventory was made of ecological requirements linked to ecosystem services (Table 1). All ecosystem services are dependent on a range of requirements, many of which seem to be concurrent for different services.

The relation between ecosystem services and ecological requirements is complex and subdivision for ecological requirements is not independent. However, for every service respective requirements can be translated into *indicators*, quantifiable measures of some biological, chemical or physical characteristics of the soil ecosystem. These indicators will most often be specific proxies for the particular ecosystem services.

Soil ecosystem indicators
Focussing on the risk of impact from chemicals and other stressors, soil health vulnerability criteria that may potentially be influenced by such stressors need to be identified. Indicators were denominated as potential means to assess the state of ecological requirements; they may include indicators for soil biota, soil processes, or conditions of ecological nature. Numerous indicators may be conceived; preference was given to those that have been used in toxicity testing in the field or in the laboratory. The sets of indicators representing sub-problems related to ecosystem services for land use were assessed for susceptibility for chemical pressure (yes/no), and, if affirmative, were selected to be included in a scenario composition model (*cf.* Thomsen et al. in prep). Toxicity data were compiled from literature to make up data sets (i.e. approximations of toxicological sensitivity criteria) that may be used for ranking risk scenarios in a Scenario Selection Model (Thomsen et al. in prep). The indicators may also be assessed in terms of susceptibility for other stressors, but this was not part of our study.

Criteria data sets

Toxicity data were compiled for cadmium, as a well studied chemical stressor, and for compounds in the NoMiracle set of test substances: chlorpyrifos, diazinon, lindane and nickel. An exemplifying overview of data availability is presented for chlorpyrifos (Table 2). In general, it is clear that there are data gaps for all chemicals throughout the range of indicators, or even for entire ecological requirements: absence of toxicity data for particular indicator and chemical combinations is frequently observed. Some of the chemicals are well studied (cadmium, chlorpyrifos), but still show a lack of adequate data for a number of relevant indicators. Data absence is the rule, rather than the exception. A full overview of available toxicity data will be addressed elsewhere (Faber et al., in prep.).

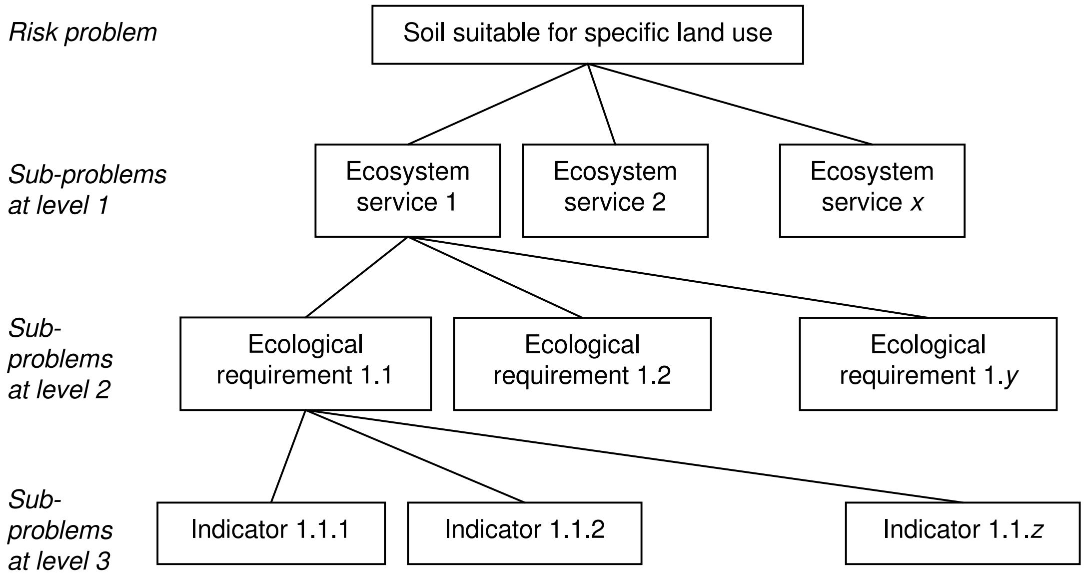

Figure 2. Problem tree configuration for soil ecosystem health, depicting land use requirements in terms of soil ecosystem services with subdivisions through ecological requirements down into indicators for essential soil ecosystem structures and processes.

Concluding remarks

Despite innumerable studies that have been performed on soil ecosystem functioning, it is still difficult to capture the general condition of the ecosystem by some standard descriptors. Our approach was not aimed to provide an ultimate list of suitable indicators for this purpose, rather we suggest a *rationale* for the selection of parameters and development of criteria to harmonize the principles behind general soil quality targeting and site-specific ecological risk assessment. Focussing on soil suitability for use, we have adopted the risk scenario modeling approach developed in NoMiracle, and compiled a systematic set of soil ecosystem health indicators with toxicity data criteria that are now ready for risk scenario ranking. Thus, our data can be applied under the main aims of this Integrated Project: to develop new methods for assessing the cumulative risks from combined exposures to several stressors including mixtures of chemical and physical/biological agents, and to achieve more effective integration of the risk analysis of environmental and human health effects.

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Table 1. Regulatory functions and other aspects as ecological requirements composing ecosystem services

Ecological requirement	Ecosystem Service					
	Soil fertility	**Adaptability and resilience**	**Buffer and reaction function**	**Biodiversity**	**Disease suppression and pest resistance**	**Physical structure**
Functional biodiversity	X	X	X	X	X	
Structural biodiversity, species richness	X	X	X	X	X	
Ecosystem productivity	X	X		X	X	
Organic matter fragmentation, mineralisation	X		X	X		
Soil properties	X		X	X		X
Nutrient cycling	X		X	X		
Autonomic development (nature)	X	X		X		
Soil organic matter build up and maintenance	X		X		X	X
Carbon sequestration	X		X	X		
Greenhouse gases	X		X	X		
Groundwater supply and quality	X		X	X		X
Genetic variation and storage of genes		X	X	X	X	
Natural attenuation		X	X	X		
Adaptability, flexibility for use		X				
Air quality amelioration			X			
Water transport and storage			X	X		X
Landscape diversity				X		X
Soil archive (archaeological, geological)						X

Table 2. Numerical overview of risk scenario criteria for chlorpyrifos in terms of subdivisions of ecosystem services down into indicators, and the number of toxicity data available in the literature.

Ecosystem service	Ecological requirements	Indicators		Chlorpyrifos criteria data	
		Total	Susceptible	Observed toxicity	No observed toxicity
Soil Fertility	8	70	60	14	9
Adaptability and resilience	4	16	16	0	0
Buffer and reaction function	11	6	6	0	0
Disease suppression	1	6	6	0	0
Biodiversity	2	6	6	1	1
Physical support	5	8	8	0	0

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