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Abstract

Soil ecosystem profiling in the Netherlands with ten references for biological soil quality

The RIVM (Dutch abbreviation for National Institute for Public Health and the Environment) and other institutes have described ten soil ecosystem profiles, or 'biological soil quality references', based on soil quality as inferred from existing empirical evidence . This is a pilot study, since no specific protocol has been established yet. The aim is to use these new references as benchmarks in the implementation of a more sustainable use of soils.

References were derived from a combination of data on land use (e.g. dairy farms, arable fields and heathlands) and soil type (sand, peat, clay and Loess). Soils types covering about three-quarters of the surface of the Netherlands are studied in this report.

Several participants, with expertise ranging from soil ecology and microbiology to rural management, selected sites where they believed data to be representative of good soil quality. To do this, they used soil monitoring data from the Netherlands Soil Monitoring Network (in Dutch: LMB). The ten references were derived from empirical data. This report provides also the averages and frequency distributions of soil biological, chemical and physical soil characteristics. The occurence of soil organisms has also been described, as well as their biodiversity.

Key words:
Netherlands Soil Monitoring Network, Biological indicator for soil quality, ecosystem services, references, soil quality, soil biota

Rapport in het kort

Typeringen van bodemecosystemen in Nederland met tien referenties voor biologische bodemkwaliteit

Het RIVM heeft samen met diverse kennisinstituten tien veel voorkomende bodems gekarakteriseerd waar de bodemkwaliteit op orde is, zogeheten referenties voor biologische bodemkwaliteit (RBB). Hier bestonden nog geen criteria voor. Deze referenties kunnen als streefbeeld gebruikt worden om bodemgebruik duurzamer te maken.

De referenties zijn bepaald voor tien combinaties van bodemgebruik (onder andere melkveehouderij, akkerbouw en heide) en bodemtype (zand, veen, klei en löss). Dit is representatief voor driekwart van het bodemoppervlak van Nederland.

Diverse onderzoekers, onder andere op het gebied van bodemecologie, microbiologie en agrarisch bodembeheer, hebben locaties geselecteerd die volgens hun maatstaven een relatief goede bodemkwaliteit hebben. Hiervoor maakten zij gebruik van de gegevens van het Landelijk Meetnet Bodemkwaliteit (LMB) over de toestand van de bodem. Op basis van deze informatie zijn de tien referenties bepaald. Het rapport bevat ook gemiddelde waarden van de biologische, chemische en fysische eigenschappen van de bodem, evenals een maat voor de spreiding van de gegevens.
De mate waarin bodemorganismen voorkomen en hun diversiteit zijn ook beschreven.

Trefwoorden:
Referenties voor Biologische Bodemkwaliteit (RBB), Landelijk Meetnet Bodemkwaliteit (LMB), duurzaam bodemgebruik, bodemecosysteem, bodemorganismen, ecosysteemdiensten, ecologische processen

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Preface

This report provides data obtained from ten years of monitoring of the Biological Indicator for Soil Quality (BISQ) in the Netherlands Soil Monitoring Network (LMB). The database of biological, chemical and physical soil characteristics from 325 sampled locations is considered the most extensive of its kind, and represents three-quarters of the surface of the Netherlands. Based on this, several participants have therefore for the first time selected locations at which they assume the soil quality to be relatively good. Ten different but widespread combinations (‘categories’) of land use and soil type were selected. This was an exciting process, because the concept ‘soil quality’ has different meanings in different disciplines, which sometimes resulted in firm discussion. Furthermore, this was as yet unexplored territory. The selections were combined to form ‘biological soil quality references’.

This report is translated from a Dutch version (Rutgers et al. 2007). The set of ten references published in this report is a first cautious step on the path to the production of a standard for sustainable land use. It is expected that more data on the biological, chemical and physical status of the soil from more locations in the Netherlands, as well as increased expertise in the field of soil quality, will make it possible to improve and expand the number of references in the future.

The extensive soil database was produced with the assistance of many people, all of whom made essential contributions to the planning and implementation of the sampling campaigns, analysis of the soil samples and interpretation of the results. We would like to thank the following people for their contributions:

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Summary

Soil is used intensively for different purposes, for agriculture, housing, work, transport, nature and recreation, which makes demands on the soil quality. The soil provides public services, ‘ecosystem services’, which are often essential to the land use. Soil is not always used in a sustainable way, which can result in a current depletion of ecosystem services, which can hold sometime and even occur elsewhere. A change in soil policy has been announced in the major policy proposals of the Ministry of Housing, Spatial Planning and the Environment (VROM), for example in the Fourth National Environmental Policy Plan, the Future Environment Agenda and the revised Dutch Soil Policy Letter (VROM 2003), and this is: *land use must be sustainable!*

Standards and monitoring systems are required in order to assess soil quality and the sustainability of land use (TCB 2003). These standards and the related monitoring systems are currently under development (Rutgers et al. 2005). The biological soil quality reference is a part of these standards. The reference describes a soil which, according to current knowledge, is considered to be of good quality, as derived from biological, chemical and physical parameters.

RIVM and other institutes have derived ten references for good biological soil quality. The references are specific to ten combinations of land use (e.g. dairy farms, arable fields and heathlands) and soil type (sand, peat, clay and loess). The abiotic and biological soil monitoring data have been obtained from the Netherlands Soil Monitoring Network (LMB). Participants from various backgrounds selected locations which they consider to be of relatively good quality, seen the monitoring data. These selections were then combined to form references. Averages and frequency distributions (percentiles) of the biological, chemical and physical data from ten years of biological soil monitoring are also provided. The references and averages form a soil ecosystem profile and are intended to be used as part of an instrument for sustainable land use in the Netherlands.

In selecting the references, the participants made use of specific expertise in soil quality management (crop rotation, soil cultivation methods, fertilizer application and pesticide application) and soil ecology (stability, biodiversity, functional diversity, ecological processes and soil organisms). Ten years of biological soil monitoring within the LMB has provided data from a total of 285 locations, spread across ten categories of land use and soil type. The locations are representative of a farm (roughly 10 to 40 hectares), a park (1 to 5 hectares) or a nature reserve with uniform vegetation (2 to 10 hectares). The following categories were sampled and analysed within the framework of the monitoring programme:

- 87x cattle or dairy farms on sand,
- 50x cattle or dairy farms on clay,
- 34x arable fields on sand,
- 30x arable fields on clay,
- 20x mixed woodland on sand,
- 19x cattle or dairy farms on peat,
- 11x cattle or dairy farms on loess (Limburg clay),
- 10x heathlands on sand,
- 10x semi-natural grassland on sand,
- 14x municipal parks.

Molehills are a sign of life in the soil

Participants determined a reference for each category. A description and the averages and range of the biological, chemical and physical data from all locations for each category are also given in this report. Taken in combination, this information forms a profile of the most commonly occurring soil ecosystems in the Netherlands.

Amoeba charts are useful for summarising the performance of the soil. It is possible to show each separate biological, chemical and physical parameter in an amoeba chart, and yet retain an overview. It is also possible to summarise the outputs of separate ecosystem services in an amoeba chart by combining the values for subsets of biological, chemical and physical parameters (Breure et al. 2004, Schouten et al. 2004, Rutgers et al. 2005).

The biological soil quality references have been selected based on the data available and the expertise of the participants involved. New references will be determined as soon new data become available concerning existing or new categories. A few participants noted that the category ‘cattle or dairy cattle farm on clay’ should be split into two categories, i.e. on marine clay and on river clay.
Differing evaluations made it difficult to choose a well-defined reference for some categories, such as mixed woodland on sand and municipal parks.

Finally, some categories are very much under-represented as far as the number of sampled locations is concerned, hindering the choice of location with a good soil quality (e.g. heathland, semi-natural grassland and cattle farms on loess). The difficulties encountered in the current selection of references and the method used to combine the assessments of the different participants are to be evaluated and adapted in the near future.

The intention is that the references and averages are used to encourage sustainable land use in the Netherlands. They make it possible to assess soil quality transparently and in quantifiable terms. The condition at a particular location can be compared with the average condition in the Netherlands and with the biological soil quality reference. The reference represents a soil of relatively good quality, as derived from biological, chemical and physical parameters.

The precision of a particular reference from the present set of ten may be inadequate for some purposes. New references will be determined whenever additional data becomes available. Nevertheless, it may be that there is no suitable reference because of site-specific circumstances or because of a new category which is not included in the LMB monitoring programme, such as dune soils. In such a case, it may be decided to determine a new region-specific or location-specific reference, which may provide the extra precision required.

A reference from the current set of ten is representative of an existing good quality soil, based on its biological, chemical and physical parameters. This does not mean that these existing soils: 1) perform maximally in theory, or 2) perform maximally for each separate ecosystem service, or sub-aspect of the soil ecosystem, in practise. The fact that selection of a reference is based on existing locations within the LMB plays a role in the first point. It is very possible that sites are to be found outside the LMB which have better soil quality, but from which no data have yet been obtained. The fact that selection of reference locations is based on an integral assessment of soil quality plays a role in the second point. This means that the performance of all ecosystem services taken together is optimal in the reference situation and less at all other locations in the LMB. It does not exclude the fact that one or more ecosystem services may function better than at the reference location (see Rutgers et al. 2007 for examples).

The biological soil quality references are a part of a standard for soil quality assessment within a framework for sustainable land use. Such a framework is only of practical use to land users if it is possible to improve soil quality by actually increasing the sustainability of the land use. In other words, a route for action is required, or ‘handles’ to influence soil quality through soil quality management. So far, little attention has been given to this in the definition of the biological soil quality references. We believe that an integrated and consensus-based vision is currently lacking as far as the relationship between soil quality management measures and the effect on the performance of specific ecosystem services is concerned. As a first step, a number of rules of thumb given in the grey literature have been included in this report for the soil ecosystem profile concerned. The relationships between soil quality management measures and the way in which the ecosystem services perform are the subject of a follow-up study.

The biological soil quality references are consistent with the approach as adopted in the EU Water Framework Directive (WFD) and its Good Ecological Status (GES). Conditions for surface waters representative of the GES are described in the WFD, within the boundaries of desirable human influence. The biological soil quality references can be seen as a description of the good ecological status of a soil, within the boundaries set by the land use. It is therefore very possible that the references will gain significance within the future EU Soil Framework Directive (SFD).

The biological soil quality references are part of a framework for sustainable land use. We believe that the introduction of these biological soil quality references is a cautious but significant first step towards the integrated quality assessment of the soil. The proposed method for the assessment of soil quality is an entirely new one, also at an international level. In theory, it is an alternative to the classic and more thematically-oriented soil policies which focus on threats and soil protection (including soil pollution, fertilizer use and pesticide application). This method does not yet replace this thematically-oriented approach, as it still requires further refinement. Furthermore, the Ministry of Housing, Spatial Planning and the Environment and the Ministry of Agriculture, Nature and Food Quality are not yet prepared to give sustainable land use a more normative character, so that the less informal thematic policy remains necessary.

Because we are at the first step in the process, more data and experience will quickly result in changes and improvements in the references and the framework for sustainable land use. The proposed changes to Dutch and European soil policy will stimulate developments which contribute to an integrated soil quality assessment.

We would be very interested in sharing experience, knowledge and expertise with any land users or participants who are working on determining the overall quality of their soil and on making land use more sustainable.

Structure of the report

The report provides information on the following fields of activity: ‘soil quality management in practise’, ‘developments in soil policy’, ‘the soil ecology of semi-natural ecosystems and agro-ecosystems’ and ‘stress ecology’. Depending on the reader’s background and interests, various parts of the report will be relevant and, hopefully, interesting, whilst other parts may be superfluous. This report is not the final product in the development of a framework for sustainable land use, but should be seen as an account of a step in the right direction, i.e. an initial set of ten biological soil quality references. Many more such steps will need to be made in order to achieve a fully-operational and reliable set of instruments with which to support sustainable land use. Practical experience needs to be supplemented with research results and further data concerning the soil biological status of the Netherlands as far as soil quality management is concerned. This will require intensive collaboration in the years to come, between land users, soil scientists and policy developers.

The following information can be found in this report in various chapters and sections.

- Chapter 1 provides an introduction to life in the soil and the significance of this life to humans and society. This information, which can be obtained from the standard text books, is provided here as a summary. Attention is given to a rational relationship between the various soil ecology disciplines.
- The state of soil in the Netherlands is summarised in chapter 2. This is based on data from ten years of monitoring of biological, chemical and physical parameters in the Netherlands Soil Monitoring Network (LMB).
- Chapter 3 outlines policy developments and the intention to stimulate sustainable land use. The perspectives of users on both small and larger spatial scales are dealt with. Ecosystem services are a key to the effective assessment of soil quality in relation to the sustainability of land use on various spatial scales.
- Chapter 4 is the core of the report, i.e. the ten soil ecosystem profiles in the Netherlands. Ten tables and amoeba charts are given, together with averages and frequency distributions for biological, chemical and physical data concerning soils found in the Netherlands and the reference quality. Ten separate descriptions are also given of the characteristics of the land use and soil type, including an account of the process leading to selection of the reference. No analysis is carried out in this report into the relationships between the references or the differences between the good quality as hypothesised by the scientists and the average condition in the Netherlands. The actions to be taken by soil managers in order to positively influence soil quality are outlined only partially and indicatively in this report. This too is a subject for further research.
- A list of concepts and a more detailed definition of ecosystem services is given in the Appendices.

1 Introduction to the living soil

1.1 The many faces of the living soil

People in the Netherlands are becoming increasingly conscious of the fragility of the environment and of the negative impact of human activities on the living environment. The question is no longer ‘whether’, but ‘to what extent’ we influence our living environment, and how far we can go before we cause irreversible damage to our life support system. Air and water have long been the focus of attention, as witnessed by the discussions concerning climate change and measures to reduce nutrient and pollution loads in surface waters.

Soil, however, has lagged behind in this respect. Although most people in the Netherlands are concerned about soil pollution, they are not really very aware of the fragility of the soil as a part of our living environment. The soil is however far more than a dumping ground for all kinds of pollutants. The soil lives, thanks to all kinds of soil organisms and soil processes which ensure that plants and animals can grow, that the climate remains pleasant, that a farmer can produce, plants can adorn as ornaments in our gardens and natural systems can develop into resilient yet beautiful and diverse landscapes. Unlike air and fresh water, unfortunately, the soil is impenetrable to the naked eye, and the life within it is usually hidden from view. Furthermore, soil processes take place relatively slowly, so that a long time passes before any problems become apparent. It takes decades for a complete soil system to develop and maturation will continue for millennia. In fact, from a land user’s point of view, soil is a natural resource which is almost non-renewable.

There are numerous threats to the soil. Agricultural soil is in danger of losing certain features of healthy soils as a result of the increased scale and intensification of the agricultural sector. The excessive application of fertilizers, pesticides and soil cultivation techniques are used to compensate for losses resulting from the depletion and compaction of the soil, which damages healthy soil. Sealing the soil with roads, buildings, infrastructure, greenhouses and maintenance-friendly gardens adversely affects the water storage and drainage and the natural attenuation capacity of the soil, resulting in flooding and a poor urban climate. Soil cultivation techniques and the lowering of the water table result in the loss of stable organic matter in the soil, resulting in a reduction in water storage capacity, as well as the extra emission of CO_2, an important greenhouse gas. This is especially problematic in peaty soils.

However, positive developments are also taking place. For example, there is an increasing awareness of the vulnerability of soil in the Netherlands. There are regulations limiting the application of pesticides and fertilizers, to prevent food quality problems and reduce nutrient and contaminant loads on groundwater and surface water. There is a steady increase in organic farming, with a focus on a healthy soil. People are starting to realise that land use should be sustainable, and that there should be balance in the exploitation of the environment and the economic and social benefits.The prevention of future problems also plays a role. In 2003, the Ministries of Housing, Spatial Planning and the Environment (VROM), Agriculture, Nature and Food Quality (LNV) and Transport, Public Works and Water Management (V&W) sent a policy letter to the House of Representatives, setting out Dutch soil policy for the coming decade (VROM 2003) and stating that attention should be given to sustainable land use, and not just to the effects of soil pollution and other threats. This is based on the natural capacity of the soil to provide society with services, such as to support agricultural production through the supply of nutrients, a good soil structure for a healthy root system and natural resistance to disease and pests. These ‘ecosystem services’ may be fully used by a land user, as long as this is done in a sustainable manner. The capacity of the soil to provide ecosystem services should therefore remain intact, if not rather be enhanced. These ecosystem services are described in chapter 3.

1.2 Soil, soil processes and soil organisms

The soil is a dynamic system over a long time scale. It takes tens of thousands of years for the soil profile to form, according to a cycle of creation and destruction. Once mineral particles have been deposited by wind, water or ice, the development of vegetation is an essential element in the formation of soil. ‘Young’ soils have a large mineral and lime content, but contain little organic matter unless they were rejuvenated by ice ages. Organic matter as a final product of photosynthesis is the primary source of carbon and energy in the soil system. The root structure of plants is very important to the soil architecture as they allow a humus profile to build up so that the soil becomes increasingly fertile. In older soils, the lime disappears, acidification takes place and the soil becomes again more compact.

Soil is not only an essential link in our living environment; it is also a living system in its own right. An unimaginable amount of life is to be found in the top layer of the soil. The biomass of all the organisms in a hectare of topsoil from a healthy field is comparable with that of sixty sheep or five cows; often even higher in the case of grassland. The diversity of soil life is also overwhelming. The biodiversity in a spade of fertile garden soil is comparable with that above soil in the Amazon rainforest. All this life together forms the soil system: a complex of mutually-connected organisms in a dynamic environment, connected through interactions such as predator-prey relationships and the conversion of energy and elements.

1.3 The soil food web

Each organism in the soil system has a function and a place in the food web (Figure 1). For example, large groups of organisms have specialised in the decomposition and dispersal of dead organic matter. Other groups of organisms feed on bacteria (bacterial-feeders), fungi (fungal-feeders), plant roots (microherbivores) or animals (predators and top predators). Some soil organisms are very selective and feed only on a few other species, whilst other species, the omnivores, exploit various food sources. There are various ways of examining the soil food web, for example the relationship between the food groups, the carbon and energy flows or the balance between small and large organisms. The difference in size between a bacterial cell and an earthworm is roughly five orders of magnitude (a factor of 100000). A balanced soil contains many small organisms and a few large organisms, according to their body size.

1.4 Organisms by group

1.4.1 Bacteria

With a size of a few micrometers (1/1000 mm; Figure 2), bacteria are the smallest and most abundant organisms, and can be found almost everywhere. A few billion bacteria, made up of tens of thousands of different species, are to be found in just a teaspoon of fertile soil. The concept of ‘species’ does not have the same meaning as it does for higher organisms. Most bacteria reproduce asexually, but are capable of exchanging genetic material in other ways. Bacteria are primarily classified based on the way in which they convert organic compounds. Though most species are still unidentified, much knowledge has been gathered concerning the significance of bacteria to the soil ecosystem. Because of their small size, they are able to absorb nutrients very effectively and to compete with plant roots for minerals. They are directly involved in almost every biogeochemical cycle, such as the carbon, nitrogen, phosphate, iron and sulphur cycles. As a result, they have an important influence on the supply of nutrients to plants and bacteria themselves are a source of nutrition to many other animals. The soil would cease to function without the presence of bacteria. Important bacteria groups are the decomposers of organic matter, such as cellulose. Some bacteria are able to degrade pollutants, such as oil and pesticides.

It is actually possible to view the soil as a large bioreactor in which the bacteria are responsible for the majority of the conversions which take place, though in contrast to a bioreactor, the soil is poorly mixed and extremely heterogeneous. This means that there are innumerable gradients and microniches, so that biodiversity can be enormous. Some bacteria are able to multiply very quickly and so react rapidly to changes in the environment and the availability of nutrients, such as fertilizer. Bacteria multiply less quickly in acidic and nutrient-poor soils.

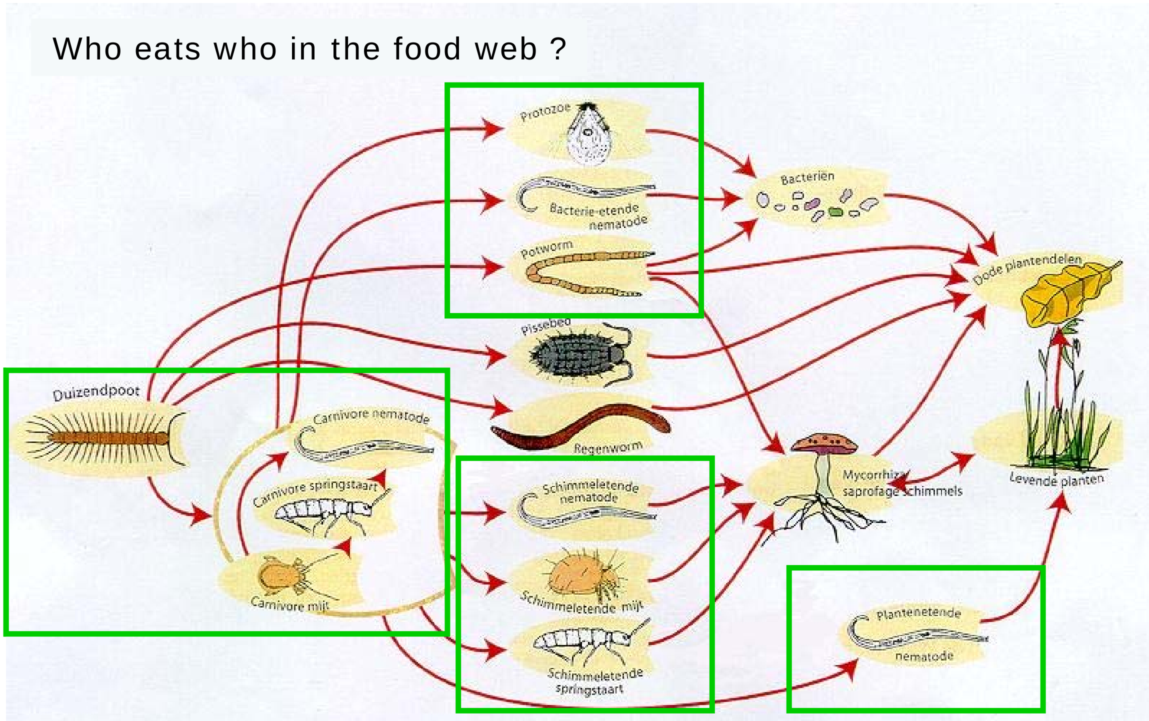


Figure 1. Diagram of the soil food web

The groups not shown in a box are those involved in decomposition processes and primary production. The groups in green boxes represent microherbivores, fungal-feeders and bacteria-feeders. The last box on the left represents the predators and top-predators (figure from R. de Goede).

1.4.2 Fungi

Fungi are another group of micro-organisms (Figure 2). Fungi form threads (hyphae) which have a diameter of just a few micrometers and a length of a few metres. These threads allow fungi to absorb nutrients and water from different places, which makes them better able to withstand dry and nutrient-poor conditions. They also cope better with acidic soils than bacteria. In contrast to bacteria, most fungi are not able to grow in anaerobic conditions, such as wet soil. Intensive cultivation of the soil also causes fungi to disappear. Most fungi are not visible above ground level, with the obvious exception of mushrooms, which grow on the ground in order to spread larger amounts of spores. Most of the fungi however is found below ground level, as mycelium. Natural soils, such as in heathlands, woodlands and semi-natural grasslands, contain more fungi than agricultural soils. Fungi are important in the breakdown of difficult to decompose organic matter, such as lignin, a constituent of plants. Free-living fungi are found in the soil, as well as fungi which form a relationship with plant root cells, the 'mycorrhizas', a relationship which is advantageous to both the plant and the fungi. The plant is able to absorb more water and minerals because the hyphae increase the efficiency of the entire root system and, in return, the fungi receive nutrients form the plant host in the form of sugars. Fungi are also a source of nutrition to many other soil organisms.

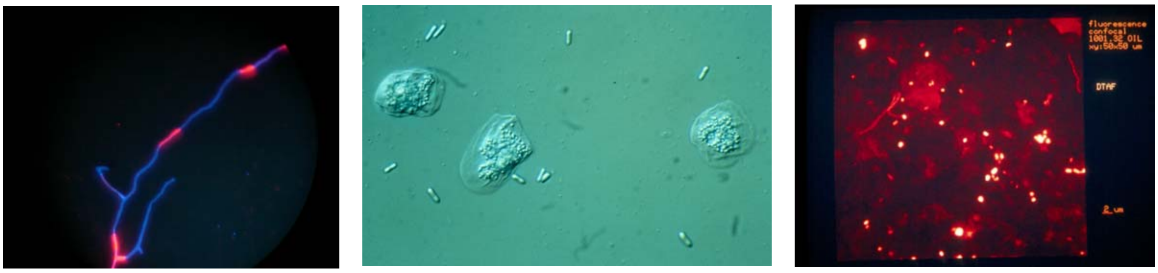


Figure 2. Three groups of micro-organisms

Left: fungal threads (active and non-active parts are shown in different colours, magnification 400x);
Middle: protozoa (amongst smaller bacteria; magnification 800x);
Right: bacteria (fluorescent colour, bright dots amongst other soil particles; magnification 1000x).

1.4.3 Protozoa

Protozoa are microscopically small, single-celled animals with a size of 5 to 500 micrometres (Figure 2). They are unable to cope with drought and, like bacteria, live in the layer of water surrounding and filling the spaces between soil particles, and in organic matter such as plant remains. Unlike larger bacteria-feeders, they are able to find their way into the very smallest pores in the soil. When they decompose, minerals such as nitrogen and phosphate are released, and are therefore again available for plant growth (the nutrient cycle). Protozoa can grow almost as quickly as bacteria and are therefore capable of keeping bacterial numbers under control. This feeding stimulates bacterial activity, in the same way as mowing a lawn stimulates the growth of grass. Protozoa are in turn eaten by larger animals, forming a link in the food web.

1.4.4 Eelworms (nematodes)

Nematodes, also called eelworms, are found in all types of soil. Between 2000 and 10000 nematodes can be found in 100 grams of soil, and between 20 and 60 species. Most eelworms are 0.2 to 3 millimetres long and just 0.01 to 0.06 millimetres in diameter (Figure 3). They are either transparent or pale, and under the microscope look like tiny eels.

Nematodes feed on bacteria, fungi, small invertebrates and plants. The functional groups are classified according to their primary food source: bacterivore, fungivore, carnivore, omnivore, yeasts and algae-feeding or herbivore nematodes. In many cases, it is possible to determine to which functional group a species belongs by studying the form of the mouth and the specific differentiation of the mouth morphology and the stylet. Nematode fauna can also be classified according to other ecological characteristics, such as the 'life history traits'. These traits concern the way in which an organism reacts to its surroundings. For example, species which are able to respond quickly to sudden nutrient-rich conditions are called 'colonisers', due to their fast reproduction. There are also 'persister' organisms, which have long life cycles, low reproduction rates and make specific adaptations to the surroundings. This ecological classification is the basis for the nematode maturity index (MI; Bongers 1990). Environmental factors such as food availability, vegetation composition and abiotic conditions (soil type) determine which combination of nematode species and functional groups are present.

Because of the economic significance, much research is being carried out worldwide into species with pathogenic properties such as parasitic behaviour on agricultural crops. Agricultural infestations can take place if the balance in the ecosystem is disturbed. It is only in the last 20 years that ecological nematode research has reached significant proportions. Nematodes contribute to the ecological function of the soil. For example, microbivore nematodes influence the mineralization of nutrients by feeding on bacteria and fungi and herbivore nematodes feed on cell sap from plant roots and therefore influence primary production in the terrestrial ecosystem.

Figure 3. Nematodes (eelworms)

Nematodes come in all shapes and sizes, but are often identified by the mouth parts. From a slightly greater distance (centre) they look like small worms.

1.4.5 Potworms (enchytraeids)

Potworms, or enchytraeids, are small pale worms which are related to the earthworm (Figure 4). They differ from earthworms in their size (up to 2 cm long and only 1-2 mm in diameter) and their white colour. Potworms are found in almost all soils, with a density varying from a few hundred to a few million per square metre. About 50 different species are found in the Netherlands. Their importance in the soil is comparable with that of earthworms, though their small size means that the scale on which they influence the soil differs, so that they supplement the earthworm activity. Potworms feed on plant and animal remains and are therefore found mainly in the uppermost layers of the soil and in forest litter. Like earthworms, they are able to burrow and move actively through the soil, and therefore play a role in mixing organic matter through the soil profile. Furthermore, their wormcasts form small particles of soil aggregate which, together with the organic matter they carry into the soil, contribute to the soil structure. Each type of potworm has its own preference for a certain type of soil or vegetation. The various species also differ in their preference for the soil layer in which they are found and it is these differences, and our knowledge of them, which make potworms such useful bioindicators.

1.4.6 Earthworms

Everybody knows the earthworm. Unlike many other soil organisms, their size makes earthworms easy to observe ('macrofauna'; Figure 4). About 25 species are known to exist in the Netherlands, though most are rarely observed and only a few are very common. Earthworms can be classified into three ecological groups, based on their choice of food, their behaviour and where they are found in the soil. The importance of earthworms to the soil functioning is strongly related to these differences. 'Deep burrowers' are large earthworms which make mainly vertical burrows and carry litter deep into the soil. They increase the organic matter content and improve soil fertility and its capacity for drainage. Species which create a network of burrows at the soil's surface help compost plant remains and improve soil aggregate stability. Their wormcasts contain large amounts of nitrogen, phosphate and potassium. Worms which live deeper in the soil do not create a network of burrows, but constantly eat their way through the soil. This 'bioturbation' stimulates microbial activity and promotes aeration of the soil. The presence of earthworms is dependent on soil properties such as acidity, moisture level, temperature and texture. There must also be sufficient food available. Earthworms are very sensitive to soil cultivation, such as ploughing and manure injection, as well as to soil pollution.

Figure 4. Earthworm and potworm

The earthworm (left) is one of the largest soil organisms and is considered a 'soil engineer'. Earthworms play a key role in the decomposition and fragmentation of organic matter and in the formation of a good soil structure. Worms often form the staple diet for small mammals and birds. The potworm (right) is much smaller but also plays an important role in decomposition.

1.4.7 Mites and springtails

After bacteria, protozoa and nematodes, mites and springtails are the most commonly-found small animals in the soil. Mites roughly resemble spiders, and springtails are fast-moving little insects. Between 40 000 and 120 000 individuals can be found living in one square metre of soil in the Netherlands. Most types are very active and spread bacteria and fungal spores through the soil either on their feet or via their waste. At least 600 species are found in the Netherlands, classified for research purposes according to what they feed on or their life cycle. For example, fungal-feeders take bites of growths of fungi, eating whole threads at a time. They need a soil rich in fungi, though they only eat the contents of the fungi, by piercing the threads and sucking them dry. This means that they are able to take immediate advantage of the nutritious content, but that their contribution to nutrient flows is limited as the threads are left behind, undigested. There are also various predators, for example nematode-feeders. Examples of life cycle groups are phoretic and asexual species. Phoretic species are able to adapt to a changing environment. If the surroundings become inhabitable, they clamp onto a larger insect, such as a midge or fly, and are quickly transferred to a new habitat. In contrast, certain groups of the asexual species are actually dependent on a stable environment, where it is an advantage for the offspring to be identical to the parents. Food groups and life cycle groups are valuable tools for gaining insight into the ecological quality of the soil.

Figure 5. A mite (left) and a springtail (right)

1.5 Soil processes

Soil can be regarded as a large, complex, poorly mixed bioreactor. Macro elements and energy are the primary constituents of the living soil system and of all life on earth. The following macro elements are often identified: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phoshorus (P), potassium (K) and sulphur (S). Carbon chains form the building blocks of molecules from which life is built, and in which energy from the sun is stored. Above-ground, water and CO_2 are converted into sugars through photosynthesis. The sugars are converted into starch, protein and other cell materials. As a result of eating and being eaten (the food web), carbon and energy flow through the ecosystem. Life therefore revolves around the carbon cycle and the resulting energy flows.

The cycles of other important elements are also linked to the carbon cycle, and the transport of many elements takes place through water. Hydrogen, oxygen and carbon are key elements in the bulk of this transport and in the utilisation of energy by life on earth. Nitrogen is an important element in proteins, biomolecules which are responsible for all biological conversions. Phosphorus is the most crucial element in DNA molecules and in oxidative phosphorylation, the process by which cells convert and store energy. Potassium regulates the energy and electrolyte balance in cells. Sulphur is an essential component of many proteins, and is also important in the supply of energy in some organisms.

As well as the macro elements named above, there are many other elements which are important to the functioning of the soil system. Iron is a key element in various biomolecules, including chlorophyll, which is involved in the capture of energy from the sun through photosynthesis. Manganese, copper, nickel, molybdenum and other metals are components of proteins or involved in certain oxidation and reduction reactions in the soil.

A number of specific characteristics for the most important soil processes are given below.

1.5.1 Carbon and energy flows

Reduced carbon is transferred into the soil from dying plants, excretion from roots or from animal manure. This reduced carbon is the main source of carbon and energy in the soil system. Bacteria, fungi and the whole soil food web, up to and including earthworms, use oxygen and oxidation reactions to produce biomass from this reduced carbon, during the process of which a lot of CO_2 is also formed. The decomposition of organic carbon to CO_2 is also called C mineralization, and is easily measured as soil respiration (O_2 depletion and CO_2 production). Under anaerobic conditions, methane (CH_4) can also be produced by methanogenic bacteria, especially in wet peat soils (marsh gas). Methane is a much more active greenhouse gas than CO_2 (23 times). In well-drained peat soils and mineral soils (sand, sandy clay and clay), methane-oxidizing bacteria again convert methane into the less harmful CO_2. Some organisms, such as nematodes and fungi, are able to use living plant roots for their carbon and energy requirements.

1.5.2 Nitrogen cycle

Nitrogen enters the soil from fertilizers and plant remains. In addition, air pollution implies the transfer and deposition of nitrogen (atmospheric deposition). Some species of bacteria (nitrogen fixers), which usually live in the tubers of legumes such as clover, are able to bind atmospheric nitrogen and convert it into organic nitrogen. Organic nitrogen produced by the remains of soil organisms, fertilizer and plant remains is broken down throughout the soil food web and secreted in a mineral form as ammonium (N mineralization), which is strongly adsorbed by soil particles. Through certain bacteria (nitrifiers) ammonium is converted into the much more mobile nitrate, which is easily transported through water. Plants are therefore able to absorb it rapidly, but it also means it can leach into groundwater and surface water. This means that the nitrogen is lost to the plants, and that the groundwater becomes contaminated. In anaerobic conditions, many bacteria use nitrate for respiration, which reduces nitrate to gaseous nitrogen (N_2). This is the process of denitrification. Nitrogen is transferred to the atmosphere and is again lost to the plants. N_2O (laughing gas) is also released as a by-product during nitrification, and is a powerful greenhouse gas, 300 times more active than CO_2. Because nitrogen is so mobile and so easily lost from the soil, it is often a limiting factor in plant growth and an important factor in the application of fertilizer. Nitrogen mineralization from organic matter is an important process in fertile soil.

1.5.3 Water

The largest transporter of matter and biomolecules is water. Soil organisms are largely composed of water. The water balance and the water cycle are crucial to life on earth. The soil influences this cycle, and vice versa. The water cycle in the soil is important to the living environment, on both a local and larger spatial scale.

Water leaves the reservoir, the ocean, as a result of evaporation and begins a long cycle via precipitation, absorption in the soil and absorption by plants and animals, to ultimately return to the ocean through evaporation, transportation and/or precipitation. On a small scale too, it is possible to identify evaporation, precipitation, absorption and local transportation in the soil and organisms as a part of the larger cycle. A water molecule can therefore pass through many organisms before returning to the ocean.

Moisture conditions vary in the soil as a result of climate factors such as temperature, wind, atmospheric humidity, precipitation and drought, as well as the water requirements of the terrestrial ecosystem and the mobility of the water molecules. The soil is sometimes dry, sometimes much too wet and, rarely, exactly right. Even in dry conditions, water is usually present in the smallest pores, though plants and animals find it difficult to extract. The soil acts as a sponge which absorbs water in times of excess, and slowly releases water to the terrestrial ecosystem in times of drought. The soil structure is a crucial factor in this process.

1.5.4 Structure formation

The soil structure and the soil’s capacity to retain water and nutrients are improved by fungi and bacteria, which form aggregates from soil particles. Bacteria and fungal activity is stimulated by the predation by nematodes, microarthropods (mites and springtails), potworms and earthworms. The casts and the burrowing behaviour of earthworms improves porosity and soil aeration and promotes the growth of roots, enabling the growth of stronger and more productive crops. The soil structure is improved through the burial of plant remains by certain species of earthworms, i.e. the transport of organic matter, because this results in better water retention. Excess rainwater is primarily drained away through the deep vertical tunnels made by the deep burrowing earthworm species. Soil cultivation and fertilization have a direct influence on earthworms and micro organisms and therefore determine soil structure and soil fertility.

2 The state of soil in the Netherlands

2.1 The Netherlands Soil Monitoring Network

The Netherlands Soil Monitoring Network (LMB) was established in 1993. Its original purpose was to provide a national overview of pollutant concentrations in the soil. There are 200 locations in the LMB; 20 locations in each category, each having a unique land use and soil type combination. Biological monitoring in the LMB was begun in 1997 (Schouten et al. 1997, 2002), for which an additional 180 locations were selected which are of interest from a soil ecology point of view, such as nature reserves, municipal parks and organic farms. All 380 locations are sampled once every six to seven years. The distribution of the sampling locations throughout the Netherlands is shown in Figure 6. Data from at least one sampling round are now available for each location.

In addition to a standard soil analysis using a set of chemical parameters, the soil is also analysed using the Biological Indicator for Soil Quality (BISQ) and a number of additional physical characteristics, including bulk density, penetration resistance and moisture content. BISQ is a very useful way of measuring soil organisms and soil processes. Soil quality management and farm management data are also collected. BISQ provides indicators for the following organisms and processes (Schouten et al. 1997, 2002):

- Carbon cycle and nitrogen cycle
- Bacteria and fungi (microbes)
- Eelworms (nematodes)
- Potworms (enchytraeids)
- Earthworms (lumbricids)
- Mites and springtails (microarthropods)

Protozoa were not analysed due to problems with the methodology. Indicators are determined for most organisms, based on biomass, abundance, composition and species diversity data. Species identification takes place up to genus or species level. Earthworms are handsorted, while enchyhtraeids, nematodes and mictroarthropods are extracted from the soil. Several methods for microbial analysis are used, such as fungal and bacterial biomass determination by microscopic techniques and image analysis, microbial activity measurements, carbon and nitrogen mineralization rates, and diversity parameters (denaturing gradient gelelectrophoresis, and catabolic profiling with Biolog® plates). For more details the reader is referred to Schouten et al. (2002).

For earthworms, six 20x20x20 cm cubes of soil were dug at random locations. For potworms and the mites and springtails, 6 cores were taken (length 15 or 7.5 cm; diameter 5.8 cm). For nematodes, bacteria, fungi, soil characteristics and process parameters, about 320 samples of 10 cm deep were taken using a soil core sampler, then mixed together. The BISQ sampling programme takes place in the months April and May as the various soil ecosystems are then active and relatively stable, and the moisture and nutrient levels fairly constant and relatively independent of weather conditions. A detailed description of the biological soil analysis with the BISQ is given by Schouten et al. (2002).

The LMB is implemented at ‘farm level’ as data on substance flows (supply and transport) are already collected for the agricultural sector as a whole by the Agricultural Economics Research Institute (LEI). These data enable the calculation of balances and soil and groundwater loads. It is uncommon to carry

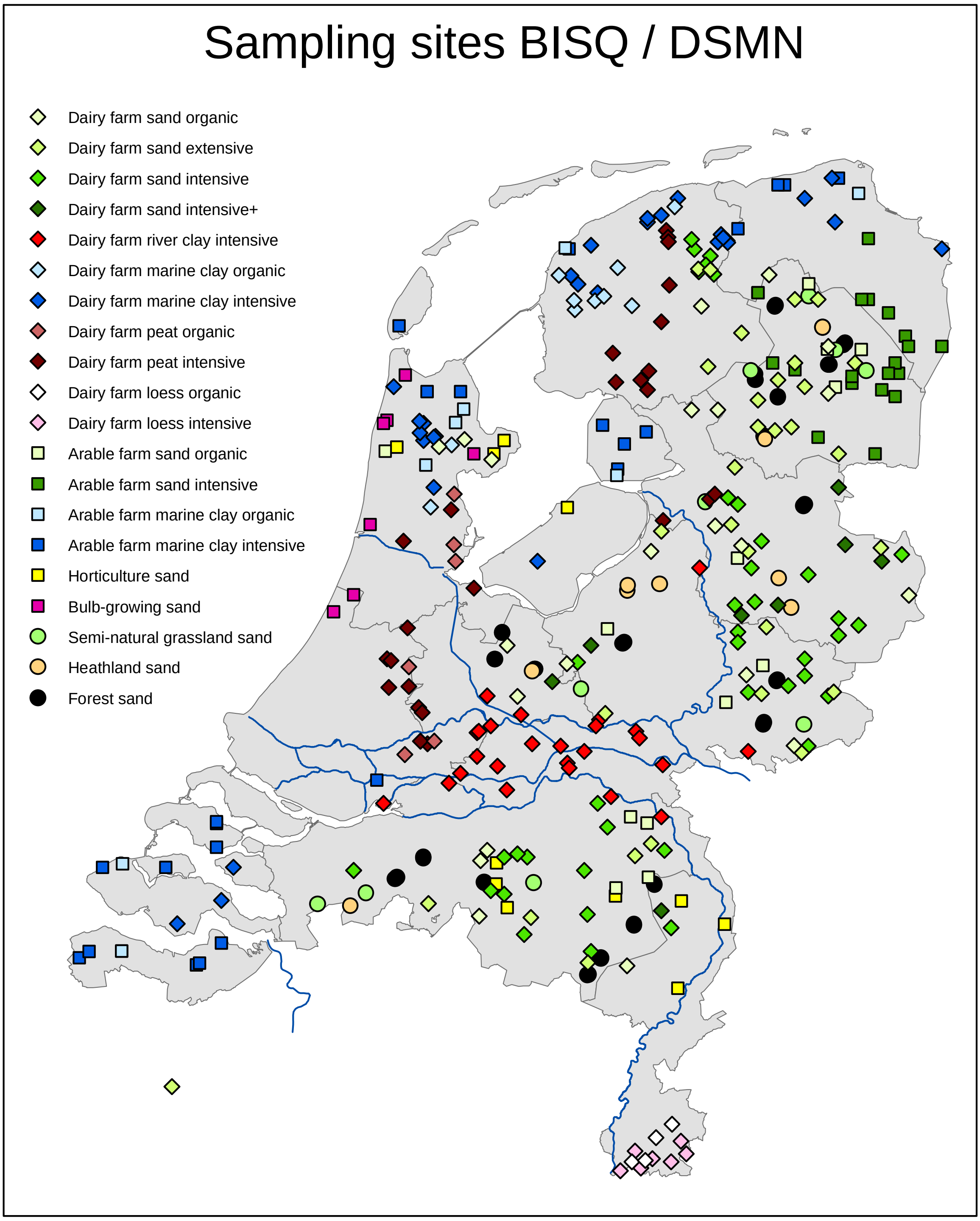


Figure 6. Biological soil monitoring locations in the Netherlands Soil Monitoring Network (LMB)

Land use and soil type combinations are each given a unique symbol and colour: dairy cattle and cattle farms (◊), arable land (□), natural areas (O), sand (green/beige), clay (blue/red), peat (brown) and loess (white/pink).

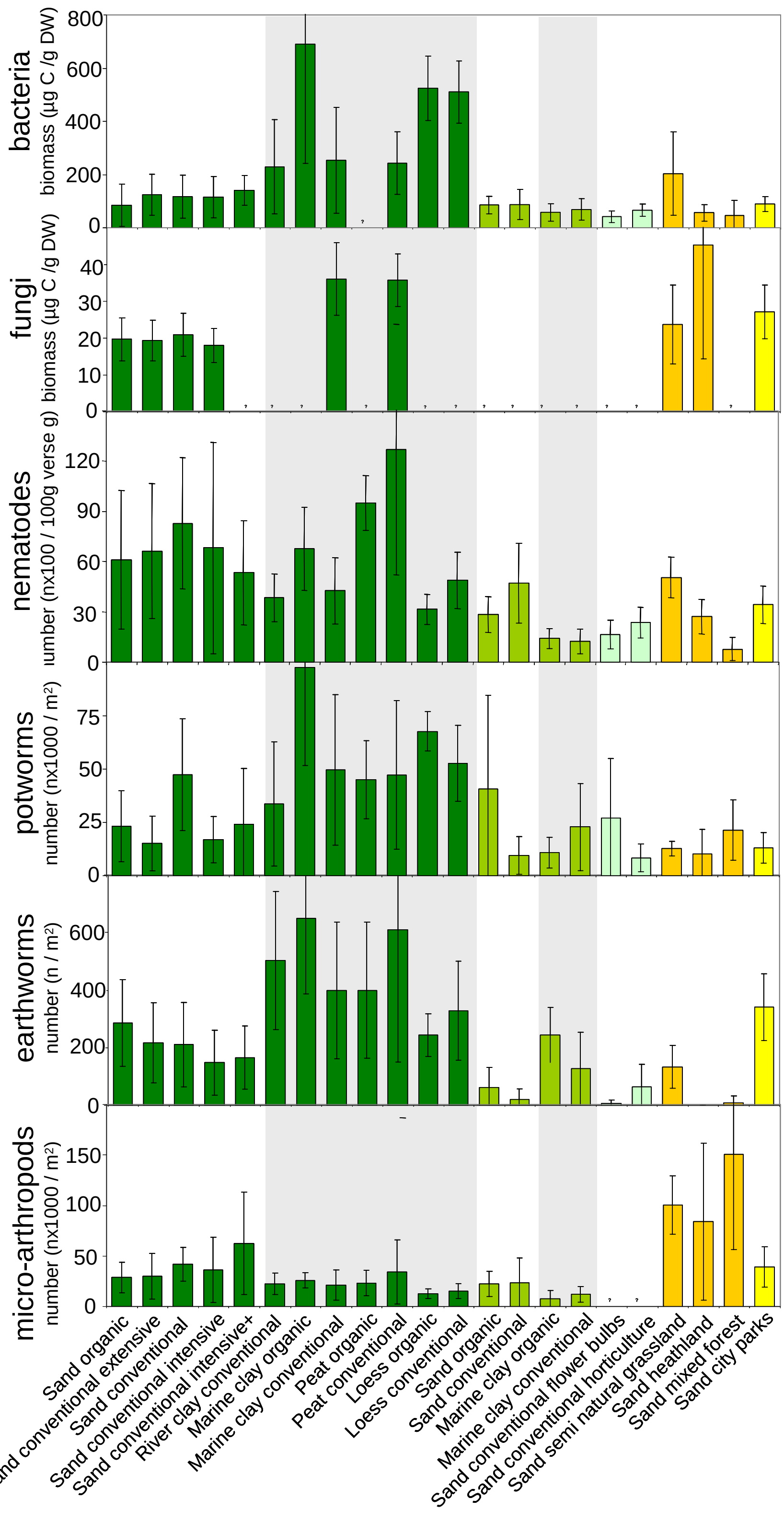


Figure 7. Number or biomass of soil organisms for certain land use and soil type combinations

Data are obtained from ten years of monitoring. The colour of the bars indicates the land use: dark green - cattle or dairy farming, light green - arable farming, light blue - horticulture and bulb growing, orange - natural areas and yellow - urban green (parks). A white background is used for the soil type sand, a grey background for clay, loess or peat. Error bars are standard deviations. Micro-arthropods in mixed forest are determined also in organic layer, while nematodes and bacteria were determined in the mineral layers out biological soil analyses over such large areas. The heterogeneity of the soil and the differences in cultivation techniques were regarded as a problem. However, the aim of the LMB, BISQ and Biological Soil Quality Reference is to provide a picture of soil quality at a national level, broken down into categories where necessary and possible. This is basically an ecological soil typology, but one which is determined by the most important land use forms and the identification of measures which promote sustainable land use. This requires that samples can be taken from a representative section of the land use category. The LMB approach, to do this using farms, is a very practical one.

There are however a number of land-use forms which do not lend themselves to this 'farm approach', such as woodlands, heathlands, natural grasslands, and municipal parks. These four forms have usually clear boundaries, but are less homogeneous in terms of vegetation cover than farms. It was therefore decided not to include any unmanaged area in the LMB, but to limit it to areas with rather uniform canopy or structure. The LMB methodology was applied as accurately as possible in these areas.

2.2 Results of ten years of monitoring

Biological, chemical and physical soil parameters were monitored and analysed over a ten year period and the results were input into an extensive database. As data are added, the size of the database and its significance to policy and research increases year by year. A number of biological soil parameters are summarised for different land use and soil type combinations in Figure 7. Some of the conclusions which can be inferred from the data are:

- Land use, soil type and soil management all influence the density and composition of soil organisms.
- There are more mites and springtails found in 'natural' areas than in other areas. The possible explanation is that mites and springtails are more sensitive to soil disturbance than other animals.
- Far fewer earthworms are found in nature reserves than in agriculturally-managed grasslands. A fair number of earthworms are found in semi-natural grasslands. Woodland and heathland soils contain very few earthworms, if any at all. The low pH is known to be one of the reasons for this.
- There is much less life in soil under arable land compared with that under grassland, as shown by the reduced biomass and numbers for almost all soil organisms. Intensive soil cultivation techniques are thought to be one of the most important reasons for the reduction in organic matter and soil organisms.
- The most potworms and earthworms are found in cattle and dairy cattle farms on clay, loess and peat.
- The total biomass of bacteria is highest in clay and loess soils. Nematodes are most abundant in peat.

As well as the land use and soil type, the intensity of the land use also determines the composition of the soil ecosystem. The management intensity on dairy cattle farms (grassland, sometime rotated with maize) on sandy soils varies greatly within the monitoring network. This is because 87 locations are sampled, spread over four management categories, i.e. organic, extensive, conventional and extra intensive. This last category describes dairy farming supplemented with another type of farming, such as pig or poultry farming. The results show that the biodiversity of eelworms in the soil in dairy farms decreases with increasing management intensity, expressed as the number of livestock units per hectare. The number of fungal-feeding eelworms shows a sharp decrease (Figure 8). The relationship between cattle density and the composition of nematode communities was analysed by Mulder et al. (2003, 2005b).

Many of the results from ten years of biological soil monitoring have been published in different reports by various institutes (for example Schouten et al. 1997, 2000, 2001, 2002, Van der Waarde et al. 2002, Van Eekeren et al. 2003, Mulder et al. 2004, Bloem et al. 2004, Breure et al. 2004, Smeding et al. 2005 and Rutgers et al. 2002, 2005, 2007) and in scientific journals (for example Didden 2003, Mulder et al. 2003, 2005a, 2005b, 2005c, 2005d, 2006, Schouten et al. 2004 and Bloem et al. 2006).

The effect of changes in the soil ecosystem on ecosystem services, in terms of processes and organism numbers, diversity and activity, is not addressed in this report. Rutgers et al. (2005, 2007) have established a relationship between these changes and ecosystem services for specific cases, an example of which is given in chapter 3.

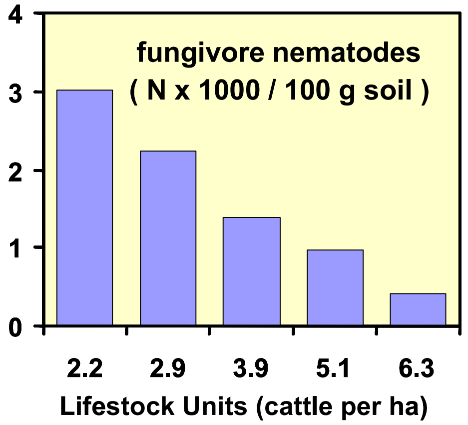


Figure 8. Decrease in fungal-feeding nematodes

Relationship between soil management intensity (expressed as livestock units per hectare) and the number of fungal-feeding nematodes.

3 Towards more sustainable land use

3.1 Sustainable soil

Land users and land use experts, especially in the agricultural sector, often have a good understanding of soil quality and how to use the land in a sustainable manner (Koopmans et al. 2006, 2007, Oenema 2003). The Ministries of LNV and VROM recently conducted a study into the sustainability of land use in agriculture (Van Dam et al. 2006, Bodem+ 2006). The quality of the soil for farming is determined by the organic matter content, drainage, the capacity to supply moisture, the bearing capacity, nutrient supply and low weed pressure. Fertilization, soil cultivation techniques, crop rotation and water table management all play an important role in determining these properties. Farmers and agricultural advisors are of the opinion that sustainable land use is only possible if the following management measures are applied:

- The nutrient supply and organic matter balance should be maintained through the application of solid organic fertilizer and, where necessary, the surface application of slurry.
- Light machinery should be used on the land, with a low load and low tyre pressure and this should be done at times when the soil is not sensitive to compaction, i.e. during dry periods.
- Non-intensive crop rotation, limited and shallow soil cultivation techniques and a high percentage of grassland.
- Limited pesticide application.

Trying to achieve higher production, for example by choosing a certain crop rotation, threatens the sustainability of land use. The conclusion drawn is that Dutch agriculture is relatively sustainable, but that there are specific areas which require improvement, such as using machinery on the land which is too heavy, or used at the wrong time. The sustainability of land use is assessed in this study from the point of view of agriculture (Bodem+ 2006). A step towards more sustainable land use is aimed for by this report, for all land users and on various spatial scales.

3.2 Soil’s contribution to society

The concept ‘soil quality’ plays an important role in sustainable land use. It is a directional concept; it allows evaluation of the soil and can therefore be used in improving soil management practices towards more sustainable land use. The Ministries of VROM and LNV do not propose a normative character within the policy framework of sustainable land use and the preservation of soil quality.

Soil quality, sometimes also called ‘soil health’, can be determined through assessment of the soil’s ‘ecosystem services’. The soil provides ecosystem services which can be exploited by the land user, within certain sustainability limits. For example, ecosystem services ensure that plants can grow, that water is drained and made available and that pollutants are broken down to produce non-noxious compounds. This description of ecosystem services is based on the assumption that they are a final product of the soil ecosystem. Ecological functions differ from ecosystem services in that a function is never a final product.

Although soil quality management takes place primarily on a local scale, land use and the associated soil ecosystem services are of significance on many different spatial scales. Local land use, for example, may focus on good and healthy agricultural production, whilst other interests may play a role on a larger scale, such as groundwater and surface water quality, water storage capacity or climate-regulating capacity.

Soil quality should be determined according to the performance of the ecosystem services (TCB 2003). Though soil quality is a general term, identification of the soil quality attributes, or ecosystem services, makes it possible to weigh up the various interests of the land users so that priorities can be set for the implementation of soil quality management measures. The ecosystem services have been taken from the TCB (2003) and adapted by a working group to produce four basic services (Rutgers et al. 2005). These are:

1. Services which have a shaping influence on the soil as supplier of products: the production function. For agricultural land use, this includes the classic term soil fertility. The soil structure and capacity to suppress disease also play a large role in agriculture. In the wider context, nature's 'production' also falls under this category, by providing a living environment for various plant and animal species in a varied landscape. Soils in gardens and recreational areas must be able to produce healthy ornamental plants.
2. Resistance and flexibility. The soil must be able to offer resistance to stresses and make a change in land use possible. This ecosystem service also involves the aspect of time, as it takes into account future events which may take place on or in the soil, such as disasters, climate change and land use changes.
3. The soil's environmental services which provide a living environment for humans. These are strongly related to the cycle functions of the soil (elements, water and air) and to the climate regulation function, and are also referred to as the buffer function and reactor function of the soil (TCB 2003). The most important processes are the fragmentation and mineralization of organic matter, natural attenuation, water retention and the various climate functions.
4. The soil's habitat function. The soil has an intrinsic quality which represents a value independent of the land use. This value, which is not mentioned in soil policy, can also be protected, as may be expected of a responsible stewardship. This includes protection of the soil biodiversity (protection of species).

A more detailed description and further classification of the soil's ecosystem services are given in Appendix 2, as well as a questionnaire for use in interviews with land users.

It is assumed that a more sustainable land use results in the improved performance of ecosystem services. Ecosystem services are also evaluated within the limits of socially-acceptable land use, as a farmer must still be able to farm. Agricultural grassland, for example, must not be assessed based on ecosystem services which are related to semi-natural grasslands. The concept of sustainability should address aspects of people, planet and profit, and needs specification by type of land use and stakeholding party.

The land use and soil management determine the performance of ecosystem services. If the ecosystem services perform well overall, then the soil quality and sustainability of the land use are, according to these standards, 'good'. Recognition and appreciation of the separate ecosystem services are key to the involvement of all land users in agreements concerning soil quality criteria for a specific plot of land, farm or region. The interests of the various land users are usually in agreement with one another as, for example, a good soil quality for farming is also a good soil quality for the region. For instance soil structure improves plant growth and avoids overloads of runoff water to ditches. However, this may not always be the case, so that the various interests sometimes need to be assessed and choices made.

3.3 Soil, land use and spatial planning

Almost nowhere in the world is the use of space as tightly organised and planned as in the Netherlands. Every square metre of ground has a purpose, and even natural areas are planned and developed using ecoducts, meadow bird population control, heathland management, the construction of permanent side channels and river banks, et cetera. Spatial planning focuses primarily on the system above ground level, both in terms of the social and the natural aspects, whilst almost no planning takes place for the topsoil system. Exceptions are hydrological aspects which affect the water table and the allocation of water extraction areas. The soil ecosystem is not planned, but is strongly influenced by the spatial planning which takes place above ground level. For example, covering the soil with buildings or infrastructure has severe consequences for the soil ecosystem, as it almost completely removes the supply of energy and nutrients, so that the soil ecosystem becomes marginalised and is barely able to continue to provide ecosystem services. The result is a large reduction in natural attenuation and water retention.

Soil ecosystem data from the Netherlands Soil Monitoring Network (LMB) shows clearly that the land use and the soil quality management play a decisive role in the presence of soil organisms (Figure 7). It may be expected that they will also have a large influence on the functioning of the soil ecosystem, because most functions are directly dependent on the presence and activity of the soil organisms. The soil properties (soil type) also play a very important role, as clay, peat and sand each provide a unique habitat for life in the soil. Moisture and nitrogen also play an important role. Although it is not easy to change the soil type according to need, land use and soil management can be planned and influenced by man.

3.4 Performance of ecosystem services

Soil management influences the soil ecosystem, and therefore soil quality. This is a logical conclusion, drawn from the results of ten years of biological soil monitoring and from the principles for sustainable land use set by the ministry of VROM (VROM 2003), as previously described. It is therefore possible that, under certain circumstances, the ecosystem services may come under increasing threat. Region-specific research carried out in the Hoeksche Waard in the Netherlands, for example, shows that the performance of ecosystem services varies from farm to farm (Rutgers et al. 2007) and that it is possible to relate the differences to specific soil management. For example, organic farms which took the organic matter content in the soil into consideration scored relatively well on ecosystem services related to the amount of organic matter in the soil. Nutrient retention and disease and pest suppression in the soil was relatively better on small-scale conventional farms than on other farms. Ecosystem services on large-scale arable farms in the Hoeksche Waard performed in general lower than the other farms.

Land users in the Hoeksche Waard indicated in a questionnaire that ‘nutrient retention’, ‘water retention’ and ‘habitat function’ are the three most important ecosystem services for their arable land. Compared with the national reference, the clay soils of the Hoeksche Waard perform relatively poorly for these three ecosystem services (Figure 9).

Research carried out in the Hoeksche Waard also showed that, on average, ecosystem service performance is lower than the national reference for biological soil quality (Figure 9). It is however possible using this method for one or more ecosystem services to perform better than the national reference. The data from the Hoeksche Waard depict a convincing example of this, as the 'natural attenuation' and 'climate function' soil ecosystem services score better than the national reference. These are exactly the ecosystem services to which land users in the Hoeksche Waard attach the least importance or, in other words, their good performance was possibly already assumed implicitly (Rutgers et al. 2007).

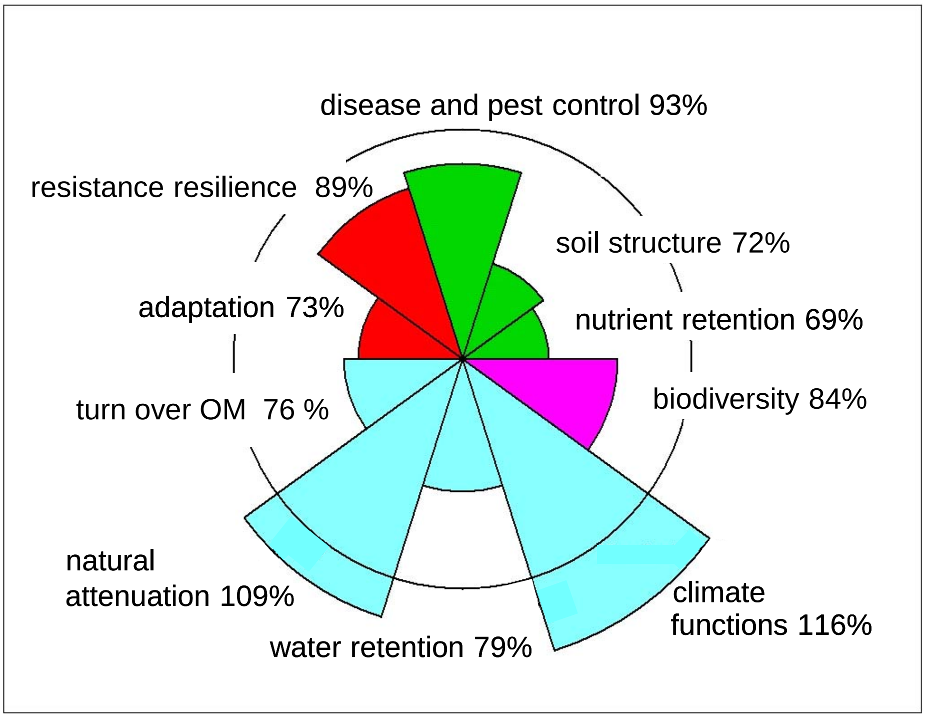


Figure 9. Amoeba chart for the Hoeksche Waard

Amoeba chart showing the average output of the ten ecosystem services for four farms in the Hoeksche Waard, compared with the national reference for arable farmland on clay (100% circle).
It is fairly easy to see that the nutrient supply service, for example, has a score of just below 70% relative to the sustainable reference. On the other hand, the soil's climate function and natural attenuation are better on these farms than in the national reference. The same study also showed that differences in ecosystem service performance between farms are probably related to the specific type of farm (Rutgers et al. 2007).

3.5 Route for action for land users

The determination of the soil quality in soil management is only of practical significance if land users are able to influence this quality. Until now, no clear relationship has been established between land use, sustainable land use measures and ecosystem service performance. It is also still unclear how improvements in ecosystem service performance will result in improved production and other benefits. This is an important subject for further research.

So what is known? Rural managers are often very aware of the effects of measures on the soil quality. Farmers also know the problems of their land, with careless management, lack of knowledge or incorrect advice often being the cause of such problems. Examples are loss of structure as a result of heavy machines riding on the land, a loss of natural resistance due to poor rotation schemes and a loss of production as a result of inadequate application of fertilizers. The solutions to these problems are based on many years of practical experience. Less well-known are the effects of soil quality management on non-production related soil ecosystem services, such as soil habitat function (biodiversity) and the natural attenuation and water storage capacity of the soil. The relationship between soil quality management and ecosystem services for other forms of land use such as nature, recreation and gardens is also largely unknown.

Koopmans et al. (2006) made an inventory of measures which help increase the sustainability of land use. The effect of a number of measures on the soil's production service is evaluated based on data gathered from the literature and from specific research carried out during field experiments. Specific recommendations were made for the 'fertilizer type' measure in cattle farming and arable farming and the 'crop rotation' (the rotation of grassland and 'green' maize) measure in cattle farming, along with an estimate of the increase in profits and extra management costs. The effects of specific soil management on the performance of ecosystem services will receive more attention in the years to come. Without a route for action, the quantification of ecosystem services is however only useful as an instrument for generic environmental monitoring.

3.6 Sustainable references and soil ecosystem profiling

This report provides soil ecosystem profiles for the Netherlands. The biological, chemical and physical status of the soil is given as an average and a range for the various land use and soil type categories found in the Netherlands. The abundance and diversity of soil organisms are included in this profile. As well as the average, a 'Biological Soil Quality Reference' is also given. This reference may be regarded as a soil ecosystem in which the soil ecosystem services are good as far as the Dutch situation is concerned, based on the assessment by various experts of the biological soil monitoring data currently available. A description is also given of specific soil characteristics and local soil management measures, and an estimate is made of the opportunities available for positively influencing the soil system. This is therefore the first time that a consistent overview has been made of the most commonly-occurring soil ecosystems in the Netherlands, based on data collected in a systematic manner.

A similar philosophy was applied in the 'Handbook of target nature types in the Netherlands' (in Dutch: *Handboek Natuurdoeltypen*; Bal et al. 2001). This is an important reference book in nature development, primarily aimed at nature reserve managers and policy advisors. It offers advice for the future planning, organisation and management of natural areas in the Netherlands. The book provides information on 92 target nature types, such as wet heathlands, marshland and drift sand. As well as information about the landscape in which the target types are found, the book also includes information on the cultural-historical and geological aspects. Descriptions of the relevant plant and animal species are also given, as well as their protection status. The environmental conditions required for the target nature type are described, as well as the management measures necessary to maintain or further develop this target nature type.

The ‘Eco atlas’ is used in water management, and includes surveys of fish, aquatic plants, phytoplankton, zooplankton and invertebrates in the Netherlands (Knoben and Peeters 1997). This approach is also in keeping with the Water Framework Directive, in which the concept of ‘Good Ecological Status’ plays an important role. It is possible that this will also apply to the future Soil Framework Directive.

There is as yet no complete reference work available for soil, in which all the facets of the soil system and the soil ecosystem are described for soils representative of those found in the Netherlands. There are however references available which apply to some aspects of the soil. For example, Van Delft (2004) has produced a practical field guide for the recognition of humus profiles in Dutch soils. This guide provides instructions on how to extract a humus profile and determination keys for classification of the profiles. The humus profile is not classified in the biological soil monitoring programme, mainly because disturbed agricultural soil covers large surface areas, and because it is relatively expensive to determine an average humus profile for a farm or a region.

Ten land use and soil type categories are identified within the LMB. Together with the extra locations selected for the biological soil monitoring programme, these are representative of about three quarters of the uncovered surface of the Netherlands. VROM and LNV have proposed setting up ‘Biological Soil Quality References’ for the most important forms of land use (agriculture, nature and other ‘green’ areas) and for the most important soil types (sand, clay, peat and Loess). These references can be used by land users wanting to increase the sustainability of their soil. The references show what a healthy soil should be like, within the limits of the land use and soil type. A summary is given in Table 1, with a further classification of essential land use and soil type sub-categories.

Table 1. Land use and soil type categories

Categories and sub-categories for which biological soil quality references have been or will be produced. Category 4 has not been implemented. References are determined in this report for ten categories, for which data are available from ten years of biological soil monitoring.

Land use		***Soil type***
1. nature	heathland	sand (wet, dry)
	semi-natural grassland	sand, clay, peat
	woodland	sand
2. agriculture	cattle and dairy cattle farming	sand, clay, peat
	arable farming	sand, clay
3. other ‘green’ categories	greenbelts, green recreational areas, buffer areas within the National Ecological Network, allotments, gardens, parks, green areas surrounding infrastructure, businesses and industrial areas	sand, clay, peat
4. asphalted, buildings, greenhouses: covered soil (not included)		X

4 References and soil ecosystem profiling

4.1 Introduction

References are determined and the results of the monitoring programme summarised for ten land use-soil type combinations. The references are based on criteria for a ‘healthy’ soil, these criteria being taken from different disciplines, and on existing data from the Netherlands Soil Monitoring Network (LMB) biological soil monitoring database. This has the advantage that the references are based on the biological status of soil at existing locations and therefore reflects the real situation. The disadvantage, however, is that the soil quality may not be optimum at the reference locations, as it is possible that data which represents the optimum state are not included in the database. The database currently contains measurements on the biological, chemical and physical status of all locations in the LMB and the BISQ project. Although the database is considered the most extensive of its kind, the knowledge base is still actually relatively small for the representation of a complete and finalised system. There is also very little data available for some land use-soil type combinations, certainly a point for consideration as far as these locations are concerned.

The tables provide information on the references and on the average and frequency distribution of the biological, chemical and physical parameters for the category concerned. The frequency distribution is expressed as the fifth and ninety-fifth percentiles. For clarity, information about the species composition of the various soil organisms has not been included in the table, as this would result in an enormous table of almost 1000 parameters. This information can be obtained from the authors.

The various parameters used in the profiling are derived from the Biological Indicator for Soil Quality (BISQ). These data are taken from direct measurements such as organism numbers or total biomass, or sometimes from lumped data, such as slopes or indices, as in the case of allometric regression (Mulder et al. 2005a, 2006). The parameters are summarised below, together with a short explanation and the units used:

1. Bacterial biomass. The total biomass of the bacterial community is calculated using measurements made under the microscope of the numbers and dimensions of bacterial cells. The unit is µg C per gram dry soil.
2. Bacterial activity. This is determined by the rate at which thymidine molecules are incorporated into bacterial DNA, which is proportional to the production of new cells. The unit is picomoles per gram dry soil per hour.
3. Bacterial diversity. Species diversity can be determined from the number of DNA bands made visible using gel electrophoresis.
4. Potential C mineralization. O_2 depletion and CO_2 production are measured over a six week period. This is expressed in mg mineralized carbon per kg soil per week.
5. Potential N mineralization. The amount of mineral nitrogen produced in a six week period is measured and expressed in mg N per kg soil per week.
6. Functional diversity. This is an integrated measure for bacterial community diversity. It is determined using 31 conversion reactions in Biolog® multiwell plates. A low number corresponds to a high functional diversity.
7. Functional activity. The output of the conversion reactions was also determined in the same plates, and expressed in µg of soil required to convert 50% of the total substrate.

8. Fungal biomass. The total fungal biomass is calculated based on measurements of hyphae length, determined using the microscope. The biomass is expressed in µg C per gram dry soil.
9. Nematode density. Once the nematodes have been extracted and concentrated in a small amount of water, the number of nematodes per 100 g of fresh soil is counted using a microscope.
10. Nematode diversity. Having identified about 150 organisms in a sample, the number of taxa and the species composition is determined.
11. Potworm density. These are counted under the microscope after extraction from undisturbed soil cores. The unit is number per m^2.
12. Potworm diversity. The potworms are also identified and the number of taxa determined.
13. Earthworm density. The number of earthworms per m^2 is determined simply by counting the number of worms in a cube of soil.
14. Earthworm diversity. The earthworms are identified by eye or using a dissecting microscope. The juveniles are identified up to genus level and separately recorded.
15. Microarthropod density. These are counted under the microscope after extraction from undisturbed soil cores. The density is expressed as number per m^2.
16. Microarthropod diversity. About 70 mites and springtails are identified after having been cleared using lactic acid.
17. Stability using allometric (M,N) regression. This is the slope of the regression line obtained by setting the logarithm of specific density per taxon against the logarithm of the average adult body mass.
18. Total biodiversity. This is the total number of observed taxa. The numbers are simply added together.
19. Percentage grassland (%). On cattle farms, grassland is often part of a rotation system, alternated for example with maize. This is the percentage of grassland at the time of sampling.
20. Livestock density. This is a measure of cattle density on a farm. The unit is number of livestock units per hectare.
21. pH. A measure of the pH of the soil is the H^+ ion concentration in an extraction with 1M KCl.
22. Organic matter. The total amount of organic carbon is expressed as the weight percentage of dry ground. No distinction is made between different organic matter fractions.
23. Water-soluble P (Pw). The amount of phosphate that can be extracted using water. The unit is mg P_2O_5 per liter.
24. Extractable P (PAl). This extraction represents a larger phosphate supply in the soil. The unit is mg P_2O_5 per 100 g of dry soil.
25. Lutum. The number of particles smaller than 2 µm is expressed as a weight percentage of dry soil. This is the only parameter which it is not possible to directly influence through soil quality management measures, unless large amounts of clay material is added.

More information about the parameters and measurement methods can be found in chapter 5. The above information gives a summary of parameters included in the tables and amoeba charts, and uses the same numbering. Not all data were available for all land use-soil type combinations (e.g. fungal biomass) and some parameters are sometimes irrelevant, such as livestock density for arable land. These are indicated as ‘nm’ (not measured) and ‘na’ (not applicable), respectively.

4.2 Method and reference selection

The sustainable references are selected based on expert’s assessments of the measured biological, chemical and physical parameters at the locations and specific soil management characteristics

(Table 2). The individual and independent assessments were collated using simple multi-criteria decision analysis to produce a ranking over all the locations. Between three and eight locations were selected to form the reference for each category. The following participants contributed to the selection of one or more sustainable references: C. ter Berg, J. Bloem, N. van Eekeren, R. de Goede, G. Jagers op Akkerhuis, H. Keidel, G. Korthals, C. Mulder, M. Rutgers and T. Schouten. The disciplines which contributed to the selection of the sustainable references are shown in Table 2. Some references have already been published (Rutgers et al. 2005, 2007).

Table 2. Summary of the selection process

A summary of the reference selection process for ten land use-soil type combinations. The table shows the date of selection and the assessment criteria.

land use and soil type category	selection date	expertise applied in the selection of the sustainable reference								
		evaluation of farm management, soil management and other characteristics of the semi-natural ecosystem*	diversity and food web	microbiology	earthworms	mites and springtails	potworms	nematodes	biological processes	organic material
cattle or dairy farms on sand	3-11-2005	external hectare*								
semi-natural grassland	3-11-2005	vegetation**								
arable land on clay	15-11-2006	rotation***								
heathland on sand	29-5-2007	vegetation**								
woodland on sand	29-5-2007	type of woodland								
arable land on sand	19-10-2007									
cattle or dairy farms on clay	19-10-2007	external hectare*								
cattle or dairy farms on peat	26-10-2007									
cattle or dairy farms on Loess	26-10-2007									
municipal parks, other green	26-10-2007									

* 'external hectare' is a method which enables the inclusion of external inputs (fertilizer application, fossil fuels, concentrates) in farm management decisions (Iepema and Baars 2005).
** the vegetation is compared with the target nature type and its diversity evaluated.
*** long rotation cycles were positively assessed.

4.3 Biological soil quality references

The ecosystem profiles and the ten biological soil quality references in table format are given in the next section of this report, in the following order:

1. arable land on clay,
2. cattle or dairy farms on clay,
3. cattle or dairy farms on loess (Limburg clay),
4. cattle or dairy farms on peat,
5. arable land on sand,
6. cattle or dairy farms on sand,
7. semi-natural grassland on sand,
8. heathland on sand,
9. mixed woodland on sand,
10. municipal parks.

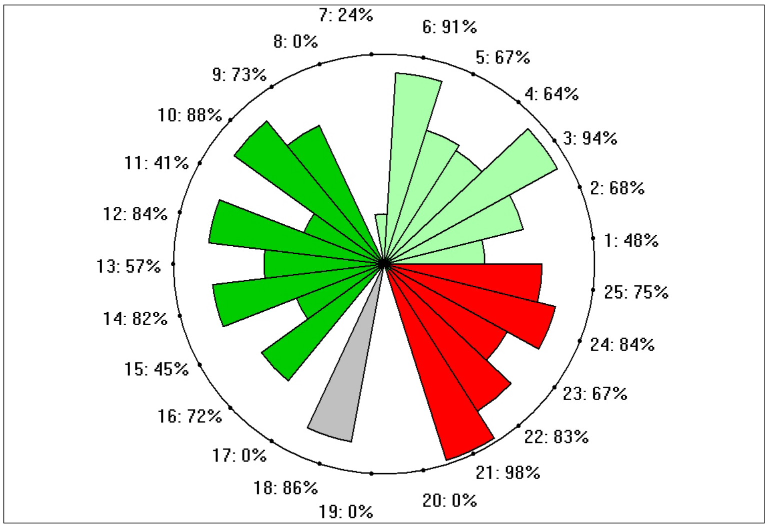
This order has been chosen to allow sub-classification according to soil type and so that the most productive soil in the Netherlands, arable land on clay, comes first. An amoeba chart is shown below each table, with the sections numbered according to the list of parameters on pages 39 and 40: light green (1 to 7) are the microbial parameters, yellow (8) the fungal biomass, dark green (9 to 16) the microfauna and macrofauna parameters, grey (17 and 18) the integrated biodiversity parameters and red (19 to 25) the chemical and physical parameters and soil quality management data.

The national average of each parameter is shown in the amoeba chart, and comparison made with the absolute deviation from the reference (based on 100%; the circle). This is to prevent the extremes producing a moderate average. This form of presentation is better suited for showing the averages of biological soil data from various locations in the database, rather than relative deviations. The advantages and disadvantages of the various amoeba charts are discussed in Rutgers et al. (2005).

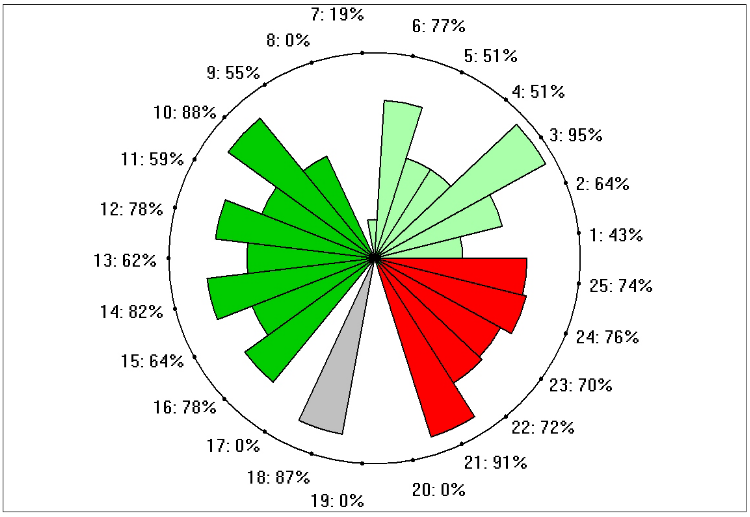
The differences in biological, chemical and physical soil characteristics between the Dutch average and the selected reference have not yet been evaluated. This will be addressed in the further development of the framework for sustainable land use.

A discussion of the ecosystem types follow the tables, with a description of the soils, ecosystems, land use and indicative soil quality management measures. Some information was taken from the book ‘The soil under the landscape’ (in Dutch: ‘De bodem onder het landschap’; Bokhorst 2006). Three references and two soil ecosystem profiles have already been published (Rutgers et al. 2005, 2007).

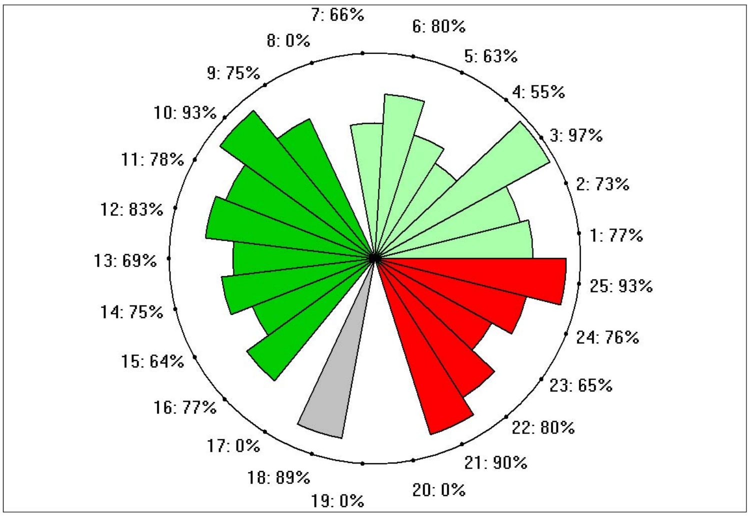
1. Arable land on clay	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=6)	(n=24)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**51**	66	*7.5*	*162*
Bacterial activity (thy-uptake; pmol/g.h)	**151**	122	*59*	*219*
Bacterial diversity (number DNA bands)	**61**	64	*60*	*71*
Potential C mineralization (mg C/kg.wk)	**18**	22	*9*	*48*
Potential N mineralization (mg N/kg.wk)	**2.0**	2.0	*0.5*	*3.7*
Functional diversity (AWCD curve gradient)	**0.65**	0.66	*0.58*	*0.79*
Functional activity (µg soil/50%conv)	**2700**	1150	*14*	*3960*
Fungal biomass (µg C/g dry soil)		(nm)		
Nematode density (n/100g fresh soil)	**1290**	1270	*660*	*2190*
Nematode diversity (number of taxa)	**33**	32	*25*	*44*
Potworm density (n/m^2)	**17500**	19200	*1510*	*53800*
Potworm diversity (number of taxa)	**6.3**	6.0	*4.0*	*8.0*
Earthworm density (n/m^2)	**200**	212	*12*	*440*
Earthworm diversity (number of taxa)	**4.2**	4.4	*1.3*	*7.9*
Microarthropod density (n/m^2)	**11070**	6180	*1610*	*16200*
Microarthropod diversity (number of taxa)	**18**	16	*9.3*	*29*
Stability (allometric M,N regression)		(nm)		
Biodiversity (total, number of taxa)	**61**	59	*46*	*75*
Percentage grassland (%)		(na)		
Livestock density (LU/ha)		(na)		
pH (pH-KCl)	**7.6**	7.5	*7.3*	*7.7*
Organic matter (% dry matter)	**2.2**	2.5	*1.6*	*3.6*
Water-soluble P (Pw, mgP_2O_5/l)	**70**	62	*33*	*96*
Extractable P (PAl, mg P_2O_5/100g)	**47**	47	*31*	*62*
Lutum (% dry matter)	**20**	17	*9*	*25*



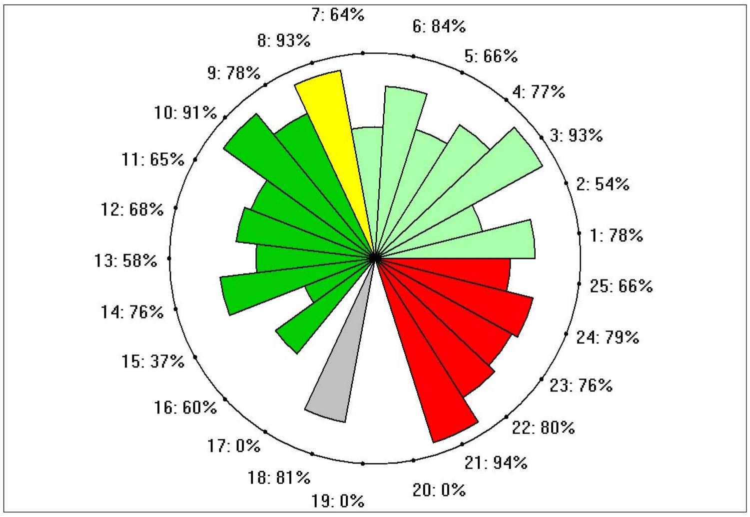
2. Dairy farming on clay	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=8)	(n=42)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**634**	322	*38*	*844*
Bacterial activity (thy-uptake; pmol/g.h)	**436**	362	*115*	*718*
Bacterial diversity (number DNA bands)	**62**	61	*56*	*67*
Potential C mineralization (mg C/kg.wk)	**142**	80	*25*	*154*
Potential N mineralization (mg N/kg.wk)	**7.9**	4.2	*1.3*	*8.9*
Functional diversity (AWCD curve gradient)	**0.35**	0.45	*0.30*	*0.62*
Functional activity (µg soil/50%conv)	**117**	8592	*1.6*	*3150*
Fungal biomass (µg C/g dry soil)		(nm)		
Nematode density (n/100g fresh soil)	**6137**	3595	*2170*	*7260*
Nematode diversity (number of taxa)	**29**	29	*21*	*36*
Potworm density (n/m^2)	**78500**	65140	*8724*	*139860*
Potworm diversity (number of taxa)	**6.4**	6.2	*4.0*	*9.0*
Earthworm density (n/m^2)	**743**	474	*126*	*804*
Earthworm diversity (number of taxa)	**8.3**	7.2	*5.0*	*9.0*
Microarthropod density (n/m^2)	**22330**	20640	*6910*	*37760*
Microarthropod diversity (number of taxa)	**31**	26	*16*	*38*
Stability (allometric M,N regression)		(nm)		
Biodiversity (total, number of taxa)	**74**	68	*47*	*83*
Percentage grassland (%)		(na)		
Livestock density (LU/ha)		(na)		
pH (pH-KCl)	**6.5**	6.5	*5.2*	*7.4*
Organic matter (% dry matter)	**9.1**	7.6	*3.4*	*13.5*
Water-soluble P (Pw, mgP_2O_5/l)	**50**	43	*17*	*80*
Extractable P (PAl, mg P_2O_5/100g)	**40**	37	*19*	*57*
Lutum (% dry matter)	**32**	31	*11*	*47*



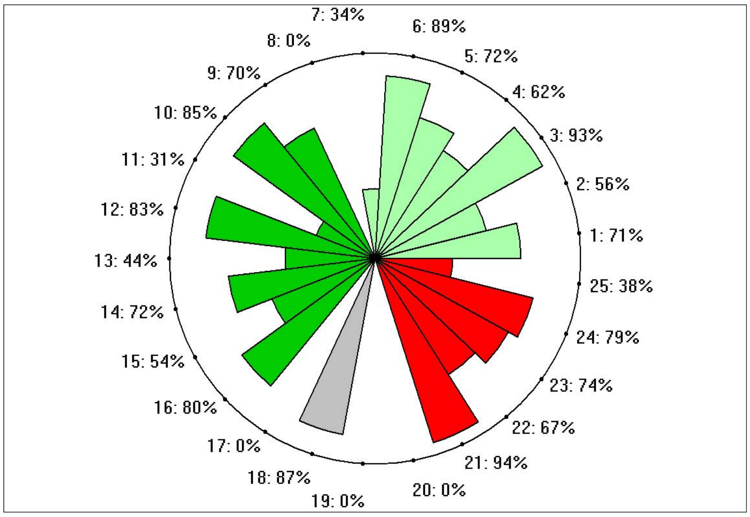
3. Dairy farms on Loess	**Reference**	The Netherlands		
	average	average	*percentiles*	
	(n=3)	(n=8)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**620**	476	*410*	*593*
Bacterial activity (thy-uptake; pmol/g.h)	**108**	78	*62*	*94*
Bacterial diversity (number DNA bands)	**59**	58	*55*	*60*
Potential C mineralization (mg C/kg.wk)	**65**	37	*23*	*62*
Potential N mineralization (mg N/kg.wk)	**5.9**	3.7	*2.3*	*4.8*
Functional diversity (AWCD curve gradient)	**0.45**	0.57	*0.46*	*0.65*
Functional activity (µg soil/50%conv)	**341**	430	*226*	*939*
Fungal biomass (µg C/g dry soil)		(nm)		
Nematode density (n/100g fresh soil)	**4817**	4045	*2242*	*5800*
Nematode diversity (number of taxa)	**27**	29	*26*	*32*
Potworm density (n/m^2)	**46850**	62360	*45560*	*83340*
Potworm diversity (number of taxa)	**7.3**	6.9	*5.4*	*9.0*
Earthworm density (n/m^2)	**336**	283	*148*	*502*
Earthworm diversity (number of taxa)	**7.0**	5.5	*3.4*	*7.3*
Microarthropod density (n/m^2)	**16590**	13800	*5129*	*23040*
Microarthropod diversity (number of taxa)	**32**	27	*19*	*37*
Stability (allometric M,N regression)		(nm)		
Biodiversity (total, number of taxa)	**74**	68	*61*	*79*
Percentage grassland (%)		(nm)		
Livestock density (LU/ha)		(nm)		
pH (pH-KCl)	**5.8**	6.4	*5.5*	*7.2*
Organic matter (% dry matter)	**5.3**	4.3	*3.6*	*5.5*
Water-soluble P (Pw, mg P_2O_5/l)	**24**	42	*25*	*60*
Extractable P (PAl, mg P_2O_5/100g)	**25**	34	*23*	*47*
Lutum (% dry matter)	**15.3**	16.0	*14.4*	*19.6*



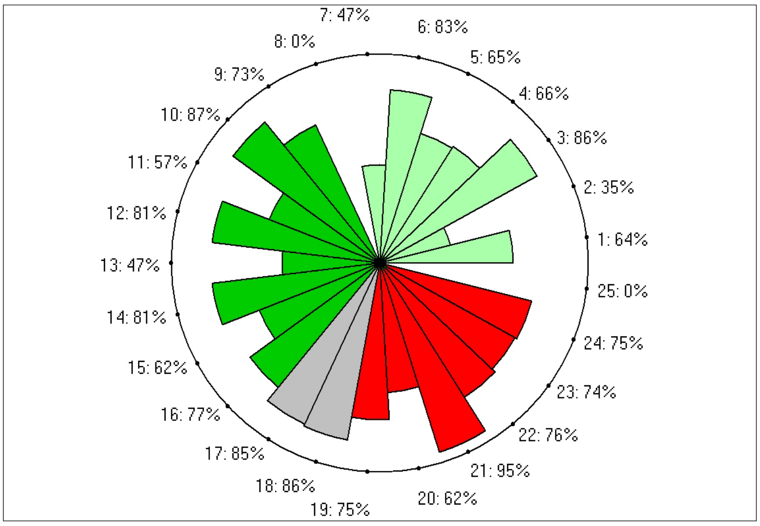
4. Dairy farms on peat	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=4)	(n=15)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**215**	208	*124*	*271*
Bacterial activity (thy-uptake; pmol/g.h)	**115**	210	*35*	*648*
Bacterial diversity (number DNA bands)	**56**	61	*57*	*66*
Potential C mineralization (mg C/kg.wk)	**303**	290	*126*	*412*
Potential N mineralization (mg N/kg.wk)	**28.2**	21.4	*-5.1*	*46.2*
Functional diversity (AWCD curve gradient)	**0.30**	0.35	*0.27*	*0.45*
Functional activity (µg soil/50%conv)	**76**	118	*43*	*335*
Fungal biomass (µg C/g dry soil)	**38**	38	*35*	*42*
Nematode density (n/100g fresh soil)	**9363**	10065	*6459*	*16150*
Nematode diversity (number of taxa)	**30**	31	*27*	*37*
Potworm density (n/m^2)	**31700**	40260	*13760*	*71210*
Potworm diversity (number of taxa)	**10.4**	8.7	*5.2*	*16.3*
Earthworm density (n/m^2)	**336**	530	*96*	*1133*
Earthworm diversity (number of taxa)	**7.0**	6.5	*3.6*	*9.0*
Microarthropod density (n/m^2)	**70735**	26060	*12700*	*49380*
Microarthropod diversity (number of taxa)	**40**	25	*10*	*43*
Stability (allometric M,N regression)		(nm)		
Biodiversity (total, number of taxa)	**87**	71	*46*	*89*
Percentage grassland (%)		(nm)		
Livestock density (LU/ha)		(nm)		
pH (pH-KCl)	**4.5**	4.7	*4.2*	*5.5*
Organic matter (% dry matter)	**35.5**	30.1	*19.9*	*40.7*
Water-soluble P (Pw, mg P_2O_5/l)	**40**	36	*22*	*50*
Extractable P (PAl, mg P_2O_5/100g)	**52**	44	*31*	*58*
Lutum (% dry matter)	**33**	27	*11*	*48*



5. Arable land on sand	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=6)	(n=28)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**81**	88	*25*	*145*
Bacterial activity (thy-uptake; pmol/g.h)	**105**	59	*25*	*105*
Bacterial diversity (number DNA bands)	**68**	68	*59*	*75*
Potential C mineralization (mg C/kg.wk)	**50**	42	*11*	*92*
Potential N mineralization (mg N/kg.wk)	**5.6**	4.3	*3.0*	*6.6*
Functional diversity (AWCD curve gradient)	**0.52**	0.56	*0.46*	*0.66*
Functional activity (µg soil/50%conv)	**486**	1614	*187*	*3597*
Fungal biomass (µg C/g dry soil)		(nm)		
Nematode density (n/100g fresh soil)	**4240**	3605	*1475*	*6331*
Nematode diversity (number of taxa)	**29**	26	*19*	*32*
Potworm density (n/m^2)	**32505**	20126	*2270*	*82156*
Potworm diversity (number of taxa)	**8.7**	7.9	*5.4*	*10.7*
Earthworm density (n/m^2)	**77**	30	*0*	*118*
Earthworm diversity (number of taxa)	**2.8**	1.8	*0.0*	*4.7*
Microarthropod density (n/m^2)	**20660**	23511	*3851*	*72605*
Microarthropod diversity (number of taxa)	**24**	22	*11*	*31*
Stability (allometric M,N regression)	**-0.89**	-1.01	*-0.80*	*-1.21*
Biodiversity (total, number of taxa)	**64**	58	*44*	*70*
Percentage grassland (%)		(na)		
Livestock density (LU/ha)		(na)		
pH (pH-KCl)	**5.3**	5.1	*4.6*	*5.6*
Organic matter (% dry matter)	**6.9**	7.6	*3.3*	*16.2*
Water-soluble P (Pw, mg P_2O_5/l)	**78**	62	*39*	*102*
Extractable P (PAl, mg P_2O_5/100g)	**62**	54	*34*	*75*
Lutum (% dry matter)	**4.5**	2.3	*1.0*	*6.7*



6. Dairy farms on sand	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=6)	(n=81)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**132**	146	*40*	*293*
Bacterial activity (thy-uptake; pmol/g.h)	**77**	65	*3*	*215*
Bacterial diversity (number DNA bands)	**57**	51	*38*	*65*
Potential C mineralization (mg C/kg.wk)	**61**	66	*21*	*127*
Potential N mineralization (mg N/kg.wk)	**12**	9	*3*	*17*
Functional diversity (AWCD curve gradient)	**0.48**	0.52	*0.34*	*0.74*
Functional activity (µg soil/50%conv)	**300**	590	*40*	*1670*
Fungal biomass (µg C/g dry soil)		(nm)		
Nematode density (n/100g fresh soil)	**5990**	4850	*2450*	*7760*
Nematode diversity (number of taxa)	**31**	34	*27*	*42*
Potworm density (n/m^2)	**20700**	24800	*4550*	*60500*
Potworm diversity (number of taxa)	**8.5**	8.2	*4.0*	*12.0*
Earthworm density (n/m^2)	**64**	163	*24*	*388*
Earthworm diversity (number of taxa)	**4.8**	4.6	*3.0*	*7.0*
Microarthropod density (n/m^2)	**43500**	44700	*14700*	*123000*
Microarthropod diversity (number of taxa)	**24**	27	*15*	*41*
Stability (allometric M,N regression)	**-1.00**	-0.86	*-1.00*	*-0.75*
Biodiversity (total, number of taxa)	**51**	52	*39*	*68*
Percentage grassland (%)	**70**	77	*36*	*100*
Livestock density (LU/ha)	**1.6**	2.6	*1.4*	*4.1*
pH (pH-KCl)	**5.2**	5.2	*4.7*	*5.8*
Organic matter (% dry matter)	**6.8**	6.4	*3.8*	*11.2*
Water-soluble P (Pw, mg P_2O_5/l)	**41**	44	*20*	*78*
Extractable P (PAl, mg P_2O_5/100g)	**43**	54	*30*	*90*



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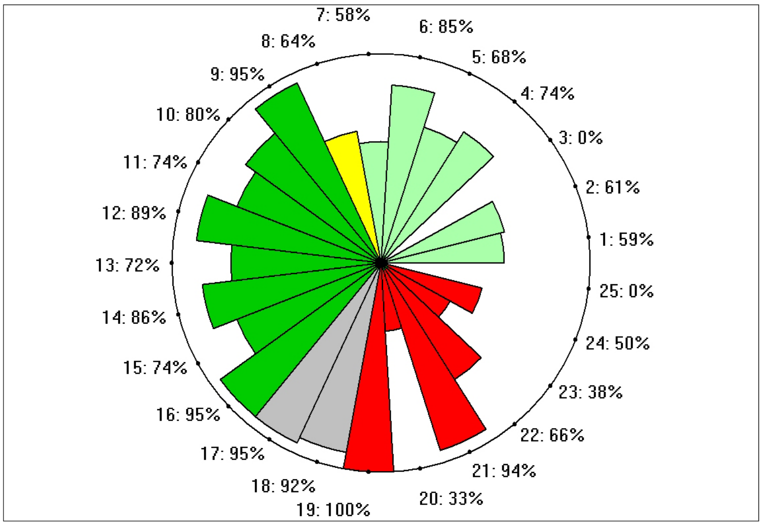
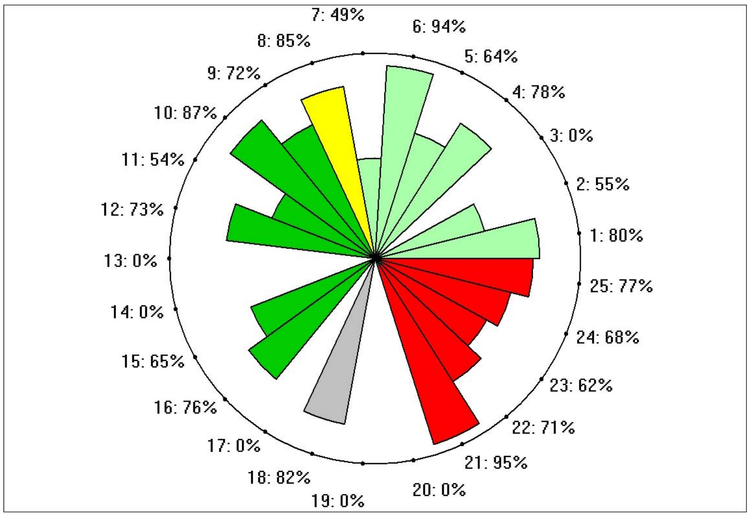
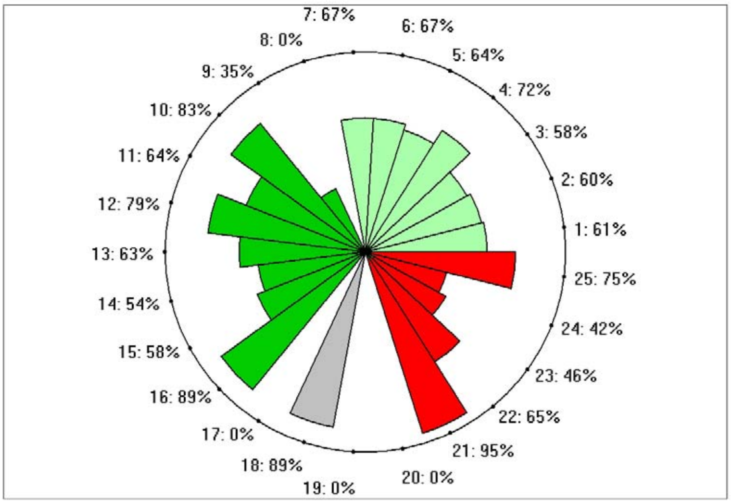
7. Semi-natural grassland on sand	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=6)	(n=4)	*5%*	*95%*
Bacterial biomass (μg C/g dry soil)	**142**	297	-	-
Bacterial activity (thy-uptake; pmol/g.h)	**20**	12	-	-
Bacterial diversity (number DNA bands)		(nm)	-	-
Potential C mineralization (mg C/kg.wk)	**104**	117	-	-
Potential N mineralization (mg N/kg.wk)	**10**	14	-	-
Functional diversity (AWCD curve gradient)	**0.34**	0.36	-	-
Functional activity (μg soil/50%conv)	**350**	290	-	-
Fungal biomass (μg C/g dry soil)	**23**	25	-	-
Nematode density (n/100g fresh soil)	**4960**	5190	-	-
Nematode diversity (number of taxa)	**36**	37	-	-
Potworm density (n/m^2)	**14200**	10500	-	-
Potworm diversity (number of taxa)	**14.0**	13.0	-	-
Earthworm density (n/m^2)	**150**	108	-	-
Earthworm diversity (number of taxa)	**7.0**	6.5	-	-
Microarthropod density (n/m^2)	**87900**	120000	-	-
Microarthropod diversity (number of taxa)	**24**	23	-	-
Stability (allometric M,N regression)	**-1.01**	-1.10	-	-
Biodiversity (total, number of taxa)	**59**	57	-	-
Percentage grassland (%)	**100**	100	-	-
Livestock density (LU/ha)	**0.3**	0.1	-	-
pH (pH-KCl)	**4.6**	4.3	-	-
Organic matter (% dry matter)	**7.9**	11.4	-	-
Water-soluble P (Pw, mg P_2O_5/l)	**26**	10	-	-
Extractable P (PAl, mg P_2O_5/100g)	**34**	17	-	-



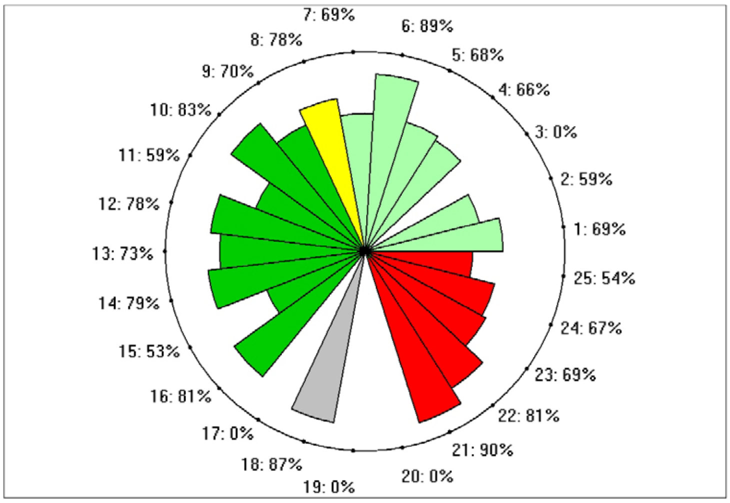
8. Heathland on sand	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=4)	(n=6)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**79**	73	*48*	*94*
Bacterial activity (thy-uptake; pmol/g.h)	**3.3**	4.4	*1.7*	*6.3*
Bacterial diversity (number DNA bands)		(nm)		
Potential C mineralization (mg C/kg.wk)	**86**	86	*48*	*122*
Potential N mineralization (mg N/kg.wk)	**2.0**	3.3	*1.7*	*5.5*
Functional diversity (AWCD curve gradient)	**0.40**	0.42	*0.40*	*0.45*
Functional activity (µg soil/50%conv)	**13400**	6540	*1280*	*12700*
Fungal biomass (µg C/g dry soil)	**54**	53	*41*	*71*
Nematode density (n/100g fresh soil)	**1840**	2200	*1380*	*3080*
Nematode diversity (number of taxa)	**24**	21	*16*	*24*
Potworm density (n/m^2)	**8310**	17850	*5275*	*42350*
Potworm diversity (number of taxa)	**7.3**	5.5	*4.0*	*7.5*
Earthworm density (n/m^2)	**0**	0	*0*	*0*
Earthworm diversity (number of taxa)	**0**	0	*0*	*0*
Microarthropod density (n/m^2)	**190500**	135000	*68700*	*214000*
Microarthropod diversity (number of taxa)	**25**	20	*15*	*25*
Stability (allometric M,N regression)		(nm)		
Biodiversity (total, number of taxa)	**56**	46	*41*	*53*
Percentage grassland (%)		(na)		
Livestock density (LU/ha)		(nm)		
pH (pH-KCl)	**3.1**	3.2	*2.9*	*3.5*
Organic matter (% dry matter)	**6.8**	7.7	*3.6*	*13*
Water-soluble P (Pw, mg P_2O_5/l)	**4.5**	5.3	*2.0*	*10*
Extractable P (PAl, mg P_2O_5/100g)	**2.1**	1.9	*1.5*	*3.4*
Lutum (% dry matter)	**2.3**	2.2	*1.3*	*3.0*



9. Mixed woodland on sand	Reference	The Netherlands		
	average	average	*percentiles*	
	(n=4)	(n=16)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**28**	51	*11*	*162*
Bacterial activity (thy-uptake; pmol/g.h)	**3.3**	1.7	*-5.9*	*5.4*
Bacterial diversity (number DNA bands)	**27**	24	*3.8*	*44*
Potential C mineralization (mg C/kg.wk)	**29**	25	*12*	*38*
Potential N mineralization (mg N/kg.wk)	**1.4**	2.4	*1.3*	*3.6*
Functional diversity (AWCD curve gradient)	**0.81**	0.55	*0.38*	*0.76*
Functional activity (µg soil/50%conv)	**35500**	40760	*13510*	*83500*
Fungal biomass (µg C/g dry soil)		(nm)		
Nematode density (n/100g fresh soil)	**1420**	560	*183*	*1680*
Nematode diversity (number of taxa)	**28**	24	*19*	*30*
Potworm density (n/m^2)	**15050**	22950	*7800*	*45500*
Potworm diversity (number of taxa)	**4.3**	4.8	*3.0*	*7.0*
Earthworm density (n/m^2)	**6.3**	9.3	*0.0*	*33*
Earthworm diversity (number of taxa)	**0.8**	0.7	*0.0*	*2.0*
Microarthropod density (n/m^2)	**157700**	148000	*36430*	*309400*
Microarthropod diversity (number of taxa)	**58**	59	*46*	*70*
Stability (allometric M,N regression)		(na)		
Biodiversity (total, number of taxa)	**91**	85	*63*	*99*
Percentage grassland (%)		(na)		
Livestock density (LU/ha)		(na)		
pH (pH-KCl)	**3.2**	3.2	*2.9*	*3.5*
Organic matter (% dry matter)	**4.5**	6.0	*1.9*	*10.3*
Water-soluble P (Pw, mg P_2O_5/l)	**11**	7.6	*0.5*	*19*
Extractable P (PAl, mg P_2O_5/100g)	**4.8**	2.7	*1.0*	*7.3*
Lutum (% dry matter)	**2.8**	2.7	*1.8*	*4.3*



10. Municipal parks on sand	**Reference**	The Netherlands		
	average	average	*percentiles*	
	(n=4)	(n=10)	*5%*	*95%*
Bacterial biomass (µg C/g dry soil)	**107**	90	*52*	*144*
Bacterial activity (thy-uptake; pmol/g.h)	**44**	70	*35*	*110*
Bacterial diversity (number DNA bands)		(nm)		
Potential C mineralization (mg C/kg.wk)	**59**	73	*29*	*103*
Potential N mineralization (mg N/kg.wk)	**8.0**	8.1	*3.7*	*15.1*
Functional diversity (AWCD curve gradient)	**0.60**	0.59	*0.47*	*0.71*
Functional activity (µg soil/50%conv)	**1277**	1640	*714*	*2985*
Fungal biomass (µg C/g dry soil)	**26**	28	*16*	*35*
Nematode density (n/100g fresh soil)	**2770**	3694	*2154*	*4755*
Nematode diversity (number of taxa)	**41**	35	*31*	*41*
Potworm density (n/m^2)	**11100**	15610	*4100*	*28700*
Potworm diversity (number of taxa)	**13.2**	13.4	*8.5*	*18.1*
Earthworm density (n/m^2)	**367**	356	*165*	*547*
Earthworm diversity (number of taxa)	**5.3**	5.6	*3.0*	*8.6*
Microarthropod density (n/m^2)	**56460**	30018	*5600*	*45650*
Microarthropod diversity (number of taxa)	**26**	21	*16*	*26*
Stability (allometric M,N regression)		(nm)		
Biodiversity (total, number of taxa)	**86**	75	*67*	*85*
Percentage grassland (%)		(na)		
Livestock density (LU/ha)		(na)		
pH (pH-KCl)	**6.5**	6.5	*4.8*	*7.2*
Organic matter (% dry matter)	**5.0**	6.0	*4.0*	*9.6*
Water-soluble P (Pw, mg P_2O_5/l)	**50**	51	*19*	*93*
Extractable P (PAl, mg P_2O_5/100g)	**52**	41	*17*	*75*
Lutum (% dry matter)	**6.0**	7.0	*2.5*	*15.4*



4.4 Arable land on clay

Arable land on marine clay - Strijensas (ZH) 2006

4.4.1 Introduction to arable land on clay

During the Holocene, the sea broke through the line of dunes which lay in a broad strip along the coast, leaving behind clay particles in the inlets and floodplains. The result was the deposition of calcareous clay by sedimentation. It is possibly to classify this deposition according the period when it occurred (old and young marine clay) and the region (the Southwest of the Netherlands, the North of the Netherlands and reclaimed land in peat areas and the IJsselmeer polders). Once the coastal area had stabilised, dykes were constructed and the clay soils could be drained for agricultural use. The first clay soils which were used for this purpose date from a few hundred years BC (Bokhorst 2006). There are large differences between old and young and northern and southern marine clay areas (Pols et al. 2005).

Marine clay areas are well suited to water management and their soils are extremely nutritious and have a high bearing capacity. Local problems with soil compaction, structure deterioration and salinization aside, the marine clay areas are, from an economical point of view, the most vital of the agricultural areas: they have good to optimum hydrology, are extremely fertile, efficiently parcelled and suited to almost all forms of agriculture. The more sandy areas are even suitable for growing bulbs, and form a separate category in the LMB. Arable farming is the most dominant function by far. Agriculture is also the reason this landscape was created, as the land was drained to make agricultural production possible. This took place until well into the twentieth century: the young marine clay polders in the provinces of Zeeland and Zuid-Holland were drained until the end of the nineteenth century, and the IJsselmeer polders are the youngest of the polders. The good soil fertility and the modern agricultural system would now seem to provide the right preconditions for sustained agricultural use: agriculture will not disappear from the marine clay areas for a long time to come.

4.4.2 The clay below the arable farms

Arable farms on marine clay which are included in the Soil Monitoring Network (LMB) are spread throughout the coastal areas of the Netherlands. Most of the farms are situated in the provinces of Zeeland, Noord-Holland and Friesland, and a few farms were sampled in Groningen and the Noordoost polder. Land use on marine clay is unchanging, with arable land on the lighter and drier fields and grassland in the wetter areas. The relatively young soils are very productive, partly because the calcareous deposits are still present. These ensure a higher pH (LMB average pH(KCl) = 7.5), which encourages organic matter to be quickly broken down. This means that the organic matter content is low, i.e. 2.4% on average. It is the lighter clay soils in particular which are used for arable land. The average lutum content is 18%, which in fact indicates that this soil is sandy clay and not clay. Of note are the low numbers of microarthropods in species-poor communities in the clay soils of the LMB.

In theory, the open structure means that roots can easily grow in the layer beneath the topsoil, which is the result of old plant remains dating from the time that the clay was deposited. If the land is managed using heavy machinery under wet conditions, the soil can become compacted just below the topsoil. This almost impermeable, humus-rich layer has a negative influence on root growth. In the case of excess rainfall, the land becomes flooded with water as the water cannot be absorbed. According to Bokhorst (2006), however, deep tillage is counterproductive.

The occurrence of pathogenic and parasitic organisms can be the result of too short or careless rotation cycles and result in an irreversible decrease in production. Severe measures sometimes need to be taken against pathogens and parasites in the soil, such as fumigation or the flooding of whole areas of land. Short rotation cycles and a limited range of crops mean that pesticide application is an essential part of farming. Unfortunately, farmers prefer high-yield crops, such as vegetables, which have a negative effect on soil structure. Cereals have a lower yield, but ensure a better soil structure.

4.4.3 Selection of the arable land on clay reference

Thirty farms were sampled in 2002 within the arable land on clay category; twenty conventional farms and ten organic farms. Twelve farms are located in the province of Zeeland, six in Noord-Holland, five in Groningen, four in Friesland and three in Flevoland. Six farms were selected which satisfied the criteria for sustainable arable farming; three organic and three conventional farms. The criteria are described as follows:

1) The size of the farm is around 25 hectares. The organic matter content is at least 2% and lutum is distributed evenly over the area. The cropping plan is non-intensive, with a maximum of one in four being potatoes. The proportion of root vegetables is not too large (i.e. <30%). Grass and grass-clover rotations are a positive factor. Organic fertilizer and green fertilizers are a part of soil management. The cropping plan and crop succession are non-intensive and carefully chosen.
2) The condition of the soil ecosystem gives the experts reason to believe that it represents an active and relatively stable system. There is good soil biodiversity, assessed using a large set of biological soil parameters:
    a. microbiology: activity and diversity;
    b. nematodes, including plant parasitic nematodes;
    c. potworms;
    d. earthworms;
    e. mites and springtails;
    f. soil processes (N cycle).

Of the total set of thirty, six locations (farms) were selected which had a maximum score for the groups and processes named above. The assessment of aspect 1 (soil management) weighed three times as heavily as the sub aspects of 2 (soil ecology). Three farms in the reference are organic farms, and three conventional. The sustainable reference was determined by calculating averages of the data from these six farms. The data from the other 24 farms were used to calculate the average for the Netherlands and the fifth and ninety-fifth percentiles.

4.4.4 Soil ecosystem service performance in the Hoeksche Waard

The soil quality at four farms in the Hoeksche Waard area was determined in a pilot project (Rutgers et al. 2007). A set of biological, chemical and physical parameters was sampled and analysed four times at the four farms. Based on significant differences and similarities in the soil parameters, it was possible to identify three groups with a distinct soil quality. Two farms had a comparable soil quality. The soil quality was compared with the national reference for biological soil quality and expressed as ecosystem service performance. The three groups were characterised by relatively good: 1) disease and pest resistance and biodiversity (two farms), 2) natural attenuation and climate functions (one farm) or 3) nutrient retention and supply (one farm). Compared with the national biological soil quality reference, the soil in the Hoeksche Waard has on average a poor score for ‘soil structure’ and ‘nutrient retention and supply’, and an average score for ‘climate functions’ and ‘natural attenuation’. One of the conclusions drawn from the study is that the national reference is useful in the assessment of soil quality at a particular location but that, due to local soil properties, it may sometimes be necessary to determine an area-specific reference.

4.5 Cattle or dairy farms on clay

Dairy farming on clay – Oosterend (Fr) 2003

4.5.1 Introduction to cattle and dairy farms on clay

There are two dominant types of clay soil in the Netherlands, river clay and marine clay. The history of the development of the marine clay areas is described in ‘arable farms on clay’. River clay is extensively deposited in the river valleys of the Meuse, Rhine and IJssel. The rivers carry sand and clay particles, which are deposited when the rivers flood and when flow velocity falls. The heaviest clay minerals are deposited at the lowest flow velocity. River clay areas have a more heterogeneous soil profile than marine clay areas, resulting from the meandering of rivers, the more irregular flow patterns and differences in altitude. Marine clay is a mixture of very fine sand and clay, whilst river clay is a varying mixture of coarser sand and heavier clay (Bokhorst 2006).

The spatial composition of the river landscape is straightforward: the river, summer dykes, riparian meadows, winter dykes, natural levees, ‘donken’ (mounds of sand deposited during the Pleistocene) and alluvial ridges, with trees and buildings. Furthest from the river are the basin soils: grasslands which have now been improved by land restoration and drainage. Excellent agricultural soils are found in the younger and drier areas of the river clay area. According to fruit specialists, the best fruit is grown on river clay in the Betuwe area. The soil in the river valleys is fertile, thanks to centuries of vegetation growth which has provided a steady supply of organic matter. Thanks to soil organisms, a very deep humus profile has developed. The top horizons are mostly decalcified, but lime is often still found at greater depths. Humus and lime in the deep horizons explains why the soil allows good root growth, making it very suitable for the cultivation of fruit. Other forms of agriculture, such as arable farming and cattle and dairy farming, also occur in these areas.

4.5.2 The clay below the dairy farms

The dairy farms on river clay and marine clay in the Soil Monitoring Network (LMB) are spread throughout the coastal areas of the Netherlands and the river valleys of the Meuse, Rhine and IJssel. Although there is good reason to make a distinction between river clay and marine clay, the data have been merged together. There were data from twenty conventional farms on marine clay, twenty conventional farms on river clay and ten organic farms on marine clay. The average pH of the clay under dairy farms in the LMB is 6.5 (pH-KCl). The pH of river clay is on average 0.7 pH units lower than that of marine clay. The organic matter content of river clay is a little higher than that of marine clay, at 8.0% and 6.3% respectively. Soils from organic farms on marine clay have a higher organic matter content, i.e. 10.6%. The grasslands of these farms are older and are ploughed less often.

Local problems with soil compaction, structure deterioration and salinization aside, the marine clay areas are, from an economical point of view, the most vital of the agricultural areas; they have good to optimum hydrology, are extremely fertile and suited to almost all forms of agriculture.

4.5.3 Selection of the cattle and dairy farms on clay reference

Fifty farms were sampled within the cattle and dairy farms on clay category, in 2002 and 2003.
Eight farms were selected which satisfy the criteria for sustainable soil: three conventional farms (one on marine clay and two on river clay) and five organic farms (all on marine clay). The selection criteria are described as follows:

- The ‘productivity’ of the soil ecosystem, based on soil organism abundance and other soil properties such as potential N mineralization in relation to the organic matter content. These aspects are related to good productivity.
- Soil quality management focuses on a reduction in fertilizer application and a transfer to organic manure types.
- The amount of ‘external hectares’ on a farm must be in balance with the farm productivity (Iepema and Baars 2005). This index is unknown for many farms.
- Grassland is ploughed less than once every five years.
- The condition of the soil ecosystem gives the expert reason to believe that it represents an active and relatively stable system. There is good soil biodiversity, according to a wide set of biological soil parameters:
    a. microbiology: activity and diversity;
    b. nematodes, including plant-parasitic nematodes;
    c. potworms;
    d. earthworms;
    e. mites and springtails;
    f. soil processes (N cycle).

A few participants noted that the marine clay soil ecosystem is clearly different from that of the river clay. The fact that these categories have been treated as one has therefore probably resulted in a reduction in accuracy and so the references given here will sometimes not be optimal. This is a challenge for the next round of reference selection. Some data are still missing from organic farms, which is needed in order to be able to determine a reliable reference for cattle farms. Of the total set of fifty locations (farms), eight were selected which had a maximum score for the points mentioned above. The sustainable reference was determined by calculating averages of the data from these eight farms. The data from the other 42 farms was used to calculate the average for the Netherlands and the fifth and ninety-fifth percentiles.

4.6 Cattle or dairy farms on loess (Limburg clay)

Dairy farm grassland on loess - Epen (Li)

4.6.1 Introduction to loess

The chalk and loess landscape of south Limburg is part of the extensive Ardennes and Eifel range, the northern foothills of which lie in the Netherlands. The landscape is made up of fairly flat plateaus, dissected by stream valleys, dry valleys and slopes. The layer of loess deposited in this area during the last Ice Age is relatively fertile and easy to cultivate, but contains little lime. Although much more loess is found in neighbouring areas in Belgium and Germany, it covers a relatively small area in the Netherlands. Loess is not a formal category within the LMB, but was selected as an additional category in 2003.

The hills of south Limburg used to be a traditionally managed landscape, with much open agricultural land and grassland (Pols et al. 2005). Due to the influence of mining and changes in agriculture, the landscape of Limburg underwent many changes during the last century. Land consolidation also had a large impact on the landscape in the last half of the previous century. Investments were also made in recreation and in improvements to the landscape, partially to compensate for the effects of mine closures. Because of the importance of the hills of Limburg for recreation and tourism, the focus on natural and scenic values took place earlier than in other areas of the Netherlands. There are small areas of woodland on the steep slopes, and nutrient-poor grasslands surround the streams. The geographical relief and the attractive mosaic of land use with its regional crops make it an attractive landscape for tourists. There is now less agriculture carried out here and much of the farmland is now owned by nature organisations. The stream valleys and surrounding slopes are part of the National Ecological Network. The most useful and fertile soil for agriculture is found on the higher plateaus.

4.6.2 The loess below cattle farms

Seven conventional and four organic dairy farms on loess were sampled in 2003 as an extra category within the LMB. The pH of the soil is 6.2 on average (pH-KCl). The organic matter content is on average 4.6% and the lutum content 15.8%. The total P content was 690 mg/kg.

4.6.3 Selection of the cattle farms on loess reference

Only a limited number of cattle farms on loess were analysed with biological soil monitoring. It is therefore a small category, making the selection of a good reference uncertain. From the available set of eleven farms on Loess there were, according to the experts, three which performed considerably better than the others: two conventional farms and one organic farm. Assessment parameters for potential N mineralization, functional diversity and the earthworm community resulted in an above-average score.

The area of loess in the Netherlands is limited. No attention has yet been given to an assessment of potential measures which could increase the sustainability of land use on loess. This will be considered in future versions of this report.

4.7 Cattle or dairy farms on peat

Dairy farming on peat - Zegveld (Ut) 2003

4.7.1 Introduction to cattle farms on peat

Rising sea levels during the Holocene period resulted in a growth in the peat landscape behind the shoreline of the west coast of the Netherlands. Peat is able to retain so much water that it becomes independent of the water table level and can grow metres higher than the surroundings, creating the nutrient-poor moors. The more nutrient-rich fens were influenced by the sea or the rivers; these soils contained more lime and silt and were more suitable for agriculture than the peat moors. Moors have not yet been investigated within the framework of the biological soil monitoring programme. Fens were initially used for cattle farming, but soil subsidence meant that it was no longer possible to compete with the better drained clay and sand soils and so the farmers in the fens shifted to pasture lands.

The lay-out of the current fen peat landscape is determined by the polders; higher water storage basins and water courses, dams, long ditches and a variety of small woodland areas. The landscape also includes many cultural-historical elements. The ecological significance of the area is very much interwoven with farming: it is a ‘semi-natural’ landscape which is of great significance, also at an international level, for example for meadow birds. The peat pasture areas are highly valued cultural landscapes, so much so that a tunnel was built underneath the ‘Green Heart’ area in the centre of the Netherlands for the high speed train link to pass through.

The future of the fen landscape is now uncertain. Modern agriculture in the area is under threat, as centuries of drainage have resulted in oxidation of the peat and major soil subsidence amounting to a few metres. The fens used to be relatively elevated, sometimes a few metres above sea level, but now all lie below sea level, a process which continues unabated. Continuing drainage will result in serious water management, security and water quality issues in the long term, which will ultimately result in hydrology problems for all functions, including urban functions which in the west of the country make up a significant proportion of the land use.

4.7.2 The peat soil below cattle farms

The most important fens are found in the provinces of Utrecht, Noord-Holland and Zuid-Holland, and in Friesland and the northern part of Overijssel. The average pH of the soil in sampled farms is 4.7 (pH-KCl). The organic matter content is high, 31% on average, as is the average lutum content (28%).

4.7.3 Selection of the cattle farms on peat reference

The sampling and biological soil analysis of cattle farms on peat had its setbacks. The LMB sampling cycle meant that it was the turn of peat soils in 2001, though unfortunately an outbreak of foot and mouth disease meant that sampling had to be cancelled in Spring 2001. The LMB abiotic sampling was carried out in 2001, but was unsuitable for biological soil analysis. Information was nevertheless collected in a number of other ways concerning the biological soil condition of cattle and dairy farms on peat. Six conventional farms within the LMB and five organic farms were sampled in 2003. These eleven farms are situated in the provinces of Noord-Holland, Zuid-Holland and Utrecht. Three areas of grassland on peat which were heavily contaminated with heavy metals were analysed in 2003 using BISQ within the framework of the Dutch Stimulation Programme System-Oriented Ecotoxicological Research (SSEO; Posthuma et al. 2007, Rutgers 2008). Centuries of soil improvement using urban waste, amongst other things, means that there is now a young layer of 15 to 50 cm of soil contaminated with heavy metals in these areas, called a *toemaakdek*. The farm belonging to the family Spruit in Zegveld (Zuid-Holland) was sampled and analysed in 2004. Various aspects of farm management and the effects on the environment were evaluated on this farm, including the soil ecosystem, in relation to the prohibited surface application of organic fertilizer (Sonneveld and Bouma 2005). Four dairy cattle farms were sampled in Friesland in 2005 as part of the Northern Frisian Forests programme (a continuation of the VEL-VANLA programme).

Four farms were selected which had a relatively healthy soil compared with the other locations. Of the four farms selected for the reference, two farms are situated in the province of Utrecht, one in Noord-Holland and one in Friesland. Of note amongst the farms selected is the high quality of the mite and springtail community but moderate quality of the nematode community. The *toemaakdek* areas and areas with high concentrations of heavy metals received the lowest scores from most experts.

4.7.4 Measures for sustainable cattle and dairy farms on peat

Many nutrients are released when peat oxidises which, in theory, benefits many different forms of agriculture, though there are also disadvantages. Where once the fen peat areas lay above sea level, they are now all below sea level and the subsidence continues by a few centimetres every year in the most severely drained areas. Oxidation of organic matter means that heavy metal concentrations will increase, which is a problem for the *toemaakdek* areas which are already seriously contaminated with heavy metals. The soil is also often damaged by intensive grazing and the use of heavy machinery. Measures which focus on water management, the loss in organic matter and a reduction in soil compaction are expected to make a positive contribution to soil quality.

4.8 Arable land on sand

Arable land on sand - Schoonoord (Dr) 2006

4.8.1 Introduction to arable land on sand

There are large areas of sandy soil in the north, east and south of the Netherlands. These soils were created during the Würm ice age, between 70,000 and 10,000 years ago. As it was then too cold for a dense vegetation canopy, the large sand flats of the then dry sea (Doggerbank) drifted with northwest winds as far as Germany. Large amounts of sand were transported to form an extensive layer of sand over northwest Europe. 15,000 years ago more sand was deposited from dry riverbeds and banks.

Because the sandy soils are relatively old, the lime has leached out and the soil has become more acidic. In natural conditions, podzol would be formed and dark, humus-like and unstable elements would leach from the soil to collect again in deeper horizons. The dark humus is then stable and can become thousands of years old. In dry conditions, forests (oaks, beech and pines) provides a black acidic humus which collects in characteristically thin horizons. These intact podzol humus profiles are still recognisable below heathland. In wet conditions a brown and more homogenous humus is formed.

Man-made soils which have been built up using fertilizer containing sand have a humus topsoil of up to 80 cm thick. These are called '*enkeerd*' soils. There are large differences between these soils, depending on how the century-old agricultural tradition of cutting turf from heathland, woodland or stream valleys to improve the soil was carried out. The height of the soil increased in total by 1 mm each year; 50 cm of topsoil therefore took 500 years to create. The oldest signs of arable land on sandy soil date from around the first century A.D.

4.8.2 The sandy soil below the farms

An frequently-quoted Dutch saying regarding sandy soil is, ‘only by ploughing does the farmer get fertile soil’. Dry sandy soils are not a good basis for high-production arable farming and arable farming is therefore often alternated with green fertilization. The application of lime, crop residue and organic fertilizer accelerates the dynamics of the organic fertilizer and is used to increase soil fertility. The arable land analysed has an average pH of 5.2 (pH-KCl). The organic matter content is relatively high, with an average of 5.2%. This is because many sites in the LMB are situated in the province of Drenthe and therefore have peat origins. The lutum percentage is on average 2.6%.

4.8.3 Selection of the arable farms on sand reference

34 arable farms on sand were sampled and analysed in 2001 and 2002. These were 20 conventional and 14 organic farms. Most farms are situated in the province of Drenthe (17) and often have a peat origin. The other farms are situated in the provinces of Gelderland, Overijssel and Noord-Brabant. Seven farms were initially selected for the reference. One farm was not included in the reference as the lutum content was too high (10%). Of note is that the earthworm, potworm and nematode groups were given a unanimously positive assessment by the experts. No earthworms were found at 12 of the 34 farms, an aspect which was considered a negative influence on soil quality. One farm with no earthworms scored so well for the other parameters that it was nevertheless selected for the reference.

4.8.4 Measures for sustainable arable farming on sand

Sandy soils are not the most ideal for arable farming. A lack of moisture, nutrients, air and the acidic conditions have a negative influence on soil fertility. Ploughing the soil can sometimes help in the case of an unworkable, compressed soil with black humus particles, but can also destroy the local vertical burrowing structure provided by earthworms. The supply of sufficient organic fertilizer, green fertilization, the use of light machinery, rotation with grass or grass-clover and limited soil cultivation techniques are positive factors for more sustainable soil quality management.

4.9 Cattle or dairy farms on sand

Dairy farming on sand - De Lutte (Ov)

4.9.1 Introduction to dairy farms on sand

Dairy farmers manage about 65% of the agricultural land in the Netherlands and develop and maintain a large proportion of the landscape. 25 000 dairy farmers produce over 10 million tonnes of milk per year in the Netherlands, on over 1.2 million hectares and from 1.4 million cows. The number of farms has been on the decrease for a few years, as has the number of cattle, but milk production remains more or less constant and the farms are increasing in size.

Traditional dairy farming focuses on the maximisation of milk production per hectare and per cow. In the past this resulted in excessive fertilizer application, both artificial and organic, and the use of additives for cows whenever milk production fell as a result of decreased production from pastures and roughage. As a result of overproduction and environmental policy developments, the focus in Europe is now on protecting environment and sustainability. The use of additives has therefore shown a sharp decrease, whilst milk production shows a slight decrease. The sector also makes a considerable contribution to processing society's waste products and by-products into high-quality food and the purification of polluted water. Energy use in the sector is low in comparison with the total energy requirement of the Netherlands (< 0.5%), and dairy farming provides an open and varied landscape.

There are also some well-known and less well-known environmental problems related to this sector. For example, nitrates leach into the upper groundwater as a result of excessive fertilizer application, resulting in a loss of nitrogen. The use of fertilizers and concentrates such as soya is only possible if this is imported from other countries, which means that the ecological footprint as expressed in external hectares is often many times greater than the area of the farm (Iepema and Baars 2005). This one-sided focus on milk production has a negative effect on soil quality which, for example, results in reduced soil biodiversity (Schouten et al. 2001, Mulder et al. 2003, 2005b).

4.9.2 Sandy soil below cattle farms

Farms in the dairy farms on sand category are situated on dry sandy soils in the centre, east and south of the Netherlands, the '*enkeerd*' soils, '*holt*' and '*field*' podzols. The soil is predominantly sandy (90% > 50 µm) with little loam and clay (5% < 2 µm), organic matter (3.8%) and nutrients. The potential pH is naturally low, but is often artificially increased by liming (average pH-KCl = 5.2). The water table level is relatively low (about 1 metre below ground level; water table class 3 to 5). Grassland is sometimes ploughed and resown and some plots are, sometimes temporarily, used for maize production. The average proportion of agricultural land, including maize fields, as a percentage of the total farm area for dairy farms in the Netherlands is about 23% (data from the BISQ database, 15 October 2005). The vegetation is largely determined by the farmer, and is primarily a mixture of different kinds of *Lolium perenne* and *Phleum pratense*. The land is increasingly sown with white clover (*Trifolium repens*) to increase the amount of nitrogen in the soil. *Poa pratensis* and *Lolium multiflorum* are also encounterd, although to a lesser extent.

4.9.3 Selection of the cattle and dairy farms on sand reference

Soil data for dairy farms on sand in the monitoring programme (Schouten et al. 2002) and the Biological Indicator for Soil Quality covers 87 locations, or farms. These are categorised as follows:
- Certified organic farming (mixed biodynamic), using compost/farmyard manure and no use of biocides, averaging 60 ha and 1.7 livestock units;
- Conventional farming, using mineral fertilisers, a much smaller amount of farmyard manure, averaging 45 ha and 2.4 livestock units;
- Semi-intensive farming, using both organic and mineral fertilisers, averaging 25 ha and 3.2 livestock units;
- Intensive (or even intensive+) farming, using biocides and fertilisers, averaging 20 ha and 5.1 livestock units,

and modelled by Generalized Linear modelling in Mulder et al. (2003).

Soil data from the 81 farms (about 20 farms in each category) are available in the BISQ database (dated 15 October 2005). A selection was made of the farms on which the soil is probably 'healthy'. The following criteria were used for soil health:
- the 'stability' of the soil ecosystem. Stability is defined from allometric relationships in the soil food web (Mulder et al. 2004, 2005a, 2006). In sustainable conditions, an allometric relationship for the average adult weight of the soil organisms plotted against the specific population density results in a log-log regression line with a slope of -1. Integrated over all layers of the soil food web, the preys become in a stable steady state with their predators only under such a biomass distribution (Mulder 2006).
- the 'productivity' of the soil ecosystem, based on soil organism abundance and other soil properties related to the productivity.
- soil quality management focuses on a reduction in the use of additives (sort and type of fertilizer) and pesticides.
- the 'external hectares' on a farm must be between -10% and 50% of the farm's surface area.
- grassland has to be ploughed less than once every five years.
- percentage of agricultural land. The percentage of agricultural land (usually maize) on a farm must be less than 25%.

Of a total of 81 locations, six farms were chosen which satisfied five of the six criteria for sustainability as listed above: four organic farms and two conventional farms. No farm satisfied all the criteria for sustainability. The sustainable reference was determined by calculating averages of the data from these six farms. The data from the other 75 farms were used to calculate the average for the Netherlands and the fifth and ninety-fifth percentiles.

According to the opinion of the experts, the numbers of earthworms in the dairy farms on sand category is rather low, and very low in the reference, since 200 earthworms (or even more) per square metre occur often.

4.9.4 Measures for cattle and dairy farms on sand

Introduction
An evaluation of soil health and the sustainability of land use is only of interest to land users if, in addition to the evaluation method, practicable measures for soil quality improvement can be implemented. This requires sufficient knowledge of the relationship between management and/or operations and the response of the soil ecosystem. Much of this information is, in theory, available in the BISQ dataset, though operational data are unfortunately incomplete and far too general. One start was made in 2004 to fill this knowledge gap, by carrying out more focused research in field experiments. A number of practical experiments were selected in which different fertilization and soil cultivation techniques could be compared. Information about the farms was also collected in a more systematic way from all locations which had also been sampled for biological soil analysis. The relationship between farm management and biological soil aspects was investigated in the Soil, Farm, Biodiversity (In Dutch: *Bodem, Bedrijf, Biodiversiteit*) project (Koopmans et al. 2006). These data enable us to determine 'habitat response relationships' for land use within a few years, as is possible for abiotic characteristics (Mulder et al. 2005d).

Grassland versus arable land for cattle and dairy farms on grassland
The difference in the effect of grassland or arable land on life in the soil is even greater than the difference between different soil types. More soil life is generally found in grassland than in arable land as ploughing turns the living conditions and nutrient supply quite literally upside down.

Measures for continuous maize cultivation
The continuous cultivation of maize makes it difficult to positively influence life in the soil using management measures. Obvious measures are 'fertilizer type' and 'green fertilizer cultivation'. An experiment was carried out over several years at the Aver Heino Research Station on the continuous cultivation of maize, in which various quantities of fertilizer were applied each year in combination with winter fallow and a second crop of winter rye as green fertilizer. After sixteen years, fertilization and green fertilization was found to have no obvious effect on bacterial biomass. Of note was that fertilizer or green fertilizer ensured an increase in bacterial biomass in comparison with no fertilizer, but that a combination of fertilizer and green fertilizer had almost no effect. The average bacterial biomass was however less than half that which would normally be found on arable land. The number of worms was also extremely low, only 10 per m^2 on average, with both fertilization and green fertilization having no substantial influence on worm numbers. One of the methods available for evaluating soil life activity is the respiration test or carbon dioxide production. Most soil organisms produce carbon dioxide (CO_2) and high carbon dioxide production therefore represents high activity. The average activity in the field experiment was low, though both fertilization and green fertilization had a positive effect on respiration. The absolute differences were however small (Van Schooten et al.

2006). Crop rotation of arable land with grassland seems to be the only measure able to positively influence soil life in arable land.

Crop rotation
Ploughing for crop rotation disturbs the living conditions and nutrient supply of life in the soil. Micro-organisms and nematodes are able to recover relatively quickly, although soil cultivation is disastrous for earthworms. Their numbers drop quickly in arable land and recovery in young grassland to the level of old grasslands takes at least five years. This all has an directional effect on the grass roots $\leftrightarrow$ soil life $\leftrightarrow$ soil cycle. The ecosystem services provided by earthworms suffer in particular: the improvement in soil structure, the supply of water to plants resulting from improved water infiltration and opening up of the deeper soil layers to enable root growth. The role of soil life in structure improvement is especially important in the case of permanent grassland, which is not ploughed every year.This would argue the case for maintaining grassland for as long as possible, as long as the cycle between crop and soil is going well. This means that as much organic matter as possible is accumulated, which can also be used to increase the capacity of grassland to supply nitrogen and increased moisture. If the cycle stops, it may be given a boost by grassland aeration/topsoil tillage or ploughing. It may be possible to grow maize for one year as part of a reseeding plan.
As far as maize cultivation is concerned, it is clear than crop rotation with grass or grass-clover has the best influence on soil quality. On a farm with 70% grass and 30% maize, the rotation of grass with maize is however carried out at the expense of the permanent grassland. This would seem to support the argument for keeping the grassland phase in the rotation as short as possible in the cultivation of maize. In this grassland phase of one or two years, light organic matter is able to accumulate and life in the soil can make a slight recovery. This is a plus point in favour of maize production. As the grassland is ploughed again anyway after one or two years, the earthworms underneath the temporary grassland are less vital to structure improvement and water infiltration (Van Eekeren et al. 2007).

Compaction in grasslands
Compaction is not a management measure, but is often regarded as one of the reasons for the decrease in life in the soil underneath grasslands. In a comparative experiment at the Aver Heino Research Station, different soil parameters were measured in and next to the track, one and nine weeks after driving in the tracks. Driving in tracks had no effect on soil density (0-30 cm), moisture content (0-30 cm), visual soil structure (0-20 cm), number of roots and macropores (0-20 cm), bacterial and fungal biomass (0-10 cm), number of earthworms (0-20 cm), number and feeding groups of nematodes (0-10 cm) and potential C and N mineralization. The penetration resistance (0-60 cm) was consistently higher in the track; though the difference was only significant in the 10-20 cm layer. Nine weeks after trafficking, the earthworm biomass in the track was reduced in comparison with outside the track (78 vs. 131 g/m^2 in 0-20 cm). Driving in tracks significantly increased the bacterial cell volume, which may indicate reduced predation from protozoa and nematodes in the subsoil food web. British research also showed that riding just once over the land had no significant effect on the number of worms ten months later, but that riding ten consecutive times over the land resulted in an obvious decrease in worm numbers (Aritajat et al. 1977). A five year research project on sandy soil in the Wieringermeer area showed that frequent trafficking resulted in an increase in the number of herbivore nematodes in the 0-10 cm layer, possible due to an increase in root growth in this layer (De Boer and Van Eekeren 2007).

Grassland age
Delaying the renewal of grassland and allowing grass to become older is an important measure for encouraging an increase in life in the soil. The bacterial biomass and the N mineralization in 5 to 17

year old grassland on the so-called ‘Cow and Opportunities’ farms (in Dutch: *Koeien en Kansen-bedrijven*) were two to three times higher than in one year old grassland. It is therefore possible for life in the soil to make a substantial recovery in five year old grassland (unpublished data 2004). It was found in the Bioveem project that plots of land older than six years were significantly different from land aged between one and three years or three to six years (De Vries et al. 2007).

Grass versus grass-clover

Pure white clover is recognised to be a crop with a less developed root system than grass. Clover was shown in an experiment to have a root biomass of one ton of dry matter per hectare in the 0-10 cm layer, compared with 5.8 tonnes of dry matter for unfertilized grassland. This less developed root system expresses itself in a poorer structure (fewer granules) under clover compared with under unfertilized grass or grass-clover. Another phenomenon is however that the biomass of worms under pure clover is double that under unfertilized grassland, resulting in more macropores. A combination of grass and clover would seem to combine the best of both worlds. Both the granule structure and the number of macropores score well under grass-clover. The introduction of grass-clover is therefore an important measure for improving life in the soil and its ecosystem services (Van Eekeren et al. 2006, Van Eekeren et al. 2007).

Fertilizer type and level

In grassland on sand, the large input of organic matter from the crops resulting from root exudation, roots and crop remains seems to have a larger effect of life on the soil than the type or level of fertilization. After five years of fertilizer application with various types of fertilizer, an experiment on sandy soil in Bakel showed that differences in the physical and biological parameters were only seen between the application of organic fertilizer and no fertilization or fertilization using artificial fertilizer. The differences were however small, mostly insignificant and were expressed primarily in a slightly higher abundance and activity of microfauna and mesofauna in the case of organic fertilizers and a positive effect from compost and farmyard manure on the penetration resistance and from farmyard manure on the bulk density (De Boer et al. 2007).

4.10 Semi-natural grassland on sand

Semi-natural grassland on sand - (Dr) 2004

4.10.1 Introduction to semi-natural grassland on sand

There are many different kinds of semi-natural grassland. The characteristic composition of plant species ultimately depends on the combination of abiotic conditions (wet versus dry, nutrient-richness, pH, soil type, former land use, surface area and topography) and biotic interactions (vegetation, fauna and landscape). Sub-types within a certain category are often the result of differences in land use management, such as mowing or grazing.

The soil ecosystem profile for semi-natural grassland, together with the sustainable reference, should be seen as representative of a 'natural' form of grassland in the Netherlands. It should be noted that many semi-natural grasslands in the Netherlands are still in a transition phase and were taken out of production only a relatively short time ago. Grasslands used for production fall under the cattle and dairy cattle farms land use category. One difference which may be expected between dairy farms and semi-natural grasslands is that the production objective means that soil quality management has a levelling effect on life in the soil. In other words, 'natural' differences in soil life are reduced as a result of soil management practises which focus on production. To give an example, careful drainage and groundwater management means that soil moisture levels in production farms will vary much less than soil moisture levels in semi-natural grasslands, and moisture level is known to have some effect on the soil ecosystem.

The semi-natural grassland profile is intended for use as an evaluation tool in the transition of dairy farming to semi-natural grassland, or to dairy farming with an extra nature target. The choice of land for the extra nature target is partly based on the soil 'health', which can be measured based on the semi-natural grassland reference and profile. Compared with the dairy farms on sand profile, the semi-natural grassland profile is less robust as less locations were analysed (10 semi-natural grassland locations compared with 81 dairy farms) and there is much more variation in semi-natural grasslands than in dairy farms. This should be taken into account when applying this profile, for example in the development of a new profile based on new and/or site-specific data.

4.10.2 Management of semi-natural grassland on sand

All the locations investigated are managed by the Provincial Landscapes (in Dutch: *Provinciale Landschappen*) and the Dutch Forestry Commission (in Dutch: *Staatsbosbeheer*). A number of locations were taken out of agricultural production a relatively short time ago, i.e. a few years ago, and are now in a transition phase. One or more forms of grazing take place at over half the locations, and sometimes an area is leased to a farmer for extensive cattle grazing. As there are no precise data for livestock numbers and the area of land used for grazing, it is only possible to make a rough estimate of the cattle density. This is done as much as possible based on information from the nature manager and on field observations. It is unclear at a few locations whether any grazing does in fact take place. In addition, different forms of mowing were found. The variation in these factors is too large to introduce separate categories within the limited dataset.

4.10.3 Selection of the semi-natural grassland on sand reference

Selection of the reference for semi-natural grasslands has been previously published in a report by Rutgers et al. (2005). The number of semi-natural grasslands in the BISQ database is limited. The ten locations are selected from the National Monitoring Network for Flora, Environmental and Nature Quality (LMF; De Knegt et al. 2003). The locations are largely from the groups ‘wet, moderately nutrient-rich grassland (nature target type 3.32) and ‘grassland with herbs in sandy and peat areas’ (nature target type 3.38). As the biological soil research is carried out over areas of about ten hectares, there is a large degree of heterogeneity in plant composition over such an area. The flora published by Rutgers et al. (2005) is therefore only meant as a general indication. Unlike plant sociology surveys, which assess the extent of ground cover from ‘barely present’ to ‘very frequent’, the presence of a plant species does not say anything about the quantity (density and cover) of the species at that site. The advantage is that floristic surveys are relatively easy to carry out and can therefore be compared and used to make a qualitative evaluation of reference locations. The floristic composition gives a picture of the soil condition and information about possible disturbance. We used surveys which are classified as follows:

- Physical Geographical Region (in Dutch: Fysisch Geografische Regio): nine locations on higher sandy soils (HZ 1-4) and one in a riparian area.
- According to the IPI classification, two locations are situated in the agricultural areas category (411), one in rather wet sedge meadows (IPI-242), six in semi-natural moist to wet grasslands on moderately nutrient-rich soils (243) and one is a semi-natural dry grassland on moderately nutrient-rich soil (245).

The reference locations are selected based on the vegetation: could it be considered semi-natural, or does the area still have too many characteristics of a production grassland? The selection of reference locations is also based on the stability of the soil food web. Simply, this is expressed in terms of the inverse linear relationship between abundance and body mass of all the soil organism groups investigated. In the optimum situation, the relationship between M(ass) and N(umber) results in a log-log regression line with a coefficient (slope) of -1.

These applied criteria have resulted in the selection of six locations (of a total of ten), which together form the reference. More data for the semi-natural grassland category are required. The amoeba chart for semi-natural grasslands gives an idea of the parameters in which the average indicator values for the references differ from the other locations. These parameters appear to be primarily in a number of microbiological and chemical aspects. Of note is that the average livestock density and phosphorus concentration in the soil at the reference locations are estimated higher than at the other semi-natural grassland locations.

4.10.4 Semi-natural grassland vegetation

Yorkshire fog (*Holcus lanatus*) is one of the most prevalent grasses in the Netherlands. *Lolium perenne* and *Dactylis glomerata* may characterise the landscape as well. Together with *Alopecurus geniculatus* and *Poa trivialis*, which show a slight increase in numbers as a result of seeding, these grasses mark a qualitative decline in nutrient-poor environments, partly because nutrient-rich environments are mainly found in areas in which nutrient-poor environmental conditions were previously dominant. Herbaceous plants are also showing a severe decline, and even the foxglove (*Digitalis purpurea*) has disappeared from the south eastern edge of the Veluwe area. Orchids, such as *Dactylorhiza maculata* (found twice) and *D. majalis* (found once) were sporadically found in wet, nutrient-poor and sometimes weakly acidic soils.

4.10.5 Semi-natural grassland management

Land with relatively nutrient-poor soil is the most suited to making the transition from dairy farming to semi-natural grassland. Because of the amount of seeds stored in the soil, a former species-rich grassland helps achieve the nature targets quickly. The proximity of other semi-natural grasslands increases the possibility of colonisation of the land with species no longer found there. Impoverishment of the soil takes place more quickly in sandy soils than in peat and clay soils.

The measures which can be taken in order to achieve impoverishment of the soil and the required nature development are largely dependent on the nutrients present in the soil, the soil cultivation techniques and groundwater management. In general, it is best to focus on impoverishment, which means: do not fertilize, possibly grow one crop of maize to encourage earlier impoverishment, possibly removing the top nutrient-rich layer (not recommended), the removal of grass cuttings, not mowing more often than necessary, not applying dredged sludge to the land, possible extensive grazing (less than 0.5 LU per hectare as an alternative to mowing) and increasing the water table level.

4.11 Heathland on sand

Heathland – Balloërveld (Dr) 2004

4.11.1 Introduction to heathland

Natural plant growth on dry podzol consists mainly of deciduous trees, but burning, major tree felling in the Middle Ages and centuries of intensive grazing means that the forests have been driven back, and heather has grown in its place (Vera 2000). Heathland in the Netherlands is therefore a cultural landscape, only maintained by intensive grazing. Cutting dry heather for animal stables around farms also produced drift sand on a large scale, so that the soil deteriorated even further.

As well as heather (*Calluna vulgaris*), a limited number of other species are found on dry heathland, such as *Deschampsia flexuosa*, *Molinia caerulea* and other grasses and juniper (*Juniperus communis*). Heathland in the Netherlands is under increasing threat, partly due to the competition for space from recreational and military activities, roads, homes and agriculture. In addition, heathlands are being 'grassed over' by the dominant *Deschampsia flexuosa* and *Molinia caerulea* (Mulder and Janssen 1999). Many herbaceous plant species, lichens and mosses are also disappearing from dry heathlands. This reduction in biodiversity above ground level has a direct influence on the fauna, both above and below the ground. For example, far fewer lepidopterans are now found in the heathlands of Dwingeloo (Mulder and Breure 2006). In order to maintain the heathlands at their current level, or for them to recover, intensive management is required.

4.11.2 The soil below heathland

Sandy soil under dry heathland is characterised by its infertility and low pH. The average pH is 3.2, partly explaining the soils high organic matter content (average total content is 7.3). The phosphate content is low: total P is an average of 9.2 mg per 100 g dry soil. Dry heathland has an intrinsically low water table. As in woodland, there are no earthworms present. The fungal biomass is fairly high and nematodes, mites and springtails are found in higher numbers.

4.11.3 Sampled locations and selection of a sustainable heathland

Ten formerly dry heathland areas were sampled in 2004: five in the province of Drenthe, three in Gelderland, one in Utrecht and one in Noord-Brabant. Most areas had a heather-broom association (*Callunetum*), sometimes mixed with a cross-leaved heath-heather association (*Ericetum* and *Callunetum*) or with broom (*Genistion*).

Standard sampling was carried out for the BISQ analysis. Sampling over the whole area (analogous to on a farm) was not possible on heathlands, where the landscape changes between areas of woodland and open terrain. Pools and wet areas are also found at a number of locations. Soil samples were only taken from below heathland vegetation. If it was not possible to take samples over an area due to difficult access, six samples were taken over a hectare around the point of the single sample (for earthworms, potworms, microarthropods, et cetera). These sample points were chosen to be distributed throughout the area.

Four locations were selected for the reference, based on assessment by the experts. Three of these selected heathland areas were situated in the province of Drenthe and one in Gelderland. All the heathland areas had a heather association.

4.11.4 Heathland management measures

Although the best heathland management measure is regular cutting, this is expensive and therefore not often implemented. Cutting is not good for the soil fauna as it severely damages the soil structure, but it often introduces new opportunities in terms of allowing new plants to take hold. It should therefore take place on a small scale. The implemented cutting policy, in which large areas of heather are removed mechanically at the same time, also put reptile populations under threat. These animals prefer a structured environment, with open and possibly wet areas in addition to the older heathland. Before carrying out cutting, a minimum precaution should be to look at where these reptiles are found so that these areas can be left undisturbed as much as possible.

A more rigorous measure is that as carried out on the Banisveld (an area of the Kampina in the province Noord-Brabant) concerning soil quality management on former agricultural soils which are again to become heathland. The nutrient-rich and much fertilized top layer of the soil is then often largely or completely removed up to a depth of 40 cm, with much loss of soil structure and soil life. It is difficult in such cases to encourage heathland to develop, because the soil needs a lot of time to develop into a system suitable for heathland (Van der Wal 2007). The soil quality under heathland at Banisveld is currently being investigated, by looking at the time sequence of agricultural land which has recently had its topsoil removed.

4.12 Mixed woodland on sand

Mixed woodland on sand – Salland ridge (Ov)

4.12.1 Introduction to mixed woodland

Natural woodlands no longer exist in the Netherlands. The last of the primeval forests, the legendary Beekbergerwoud, was felled between 1869 and 1871 (Van Lohuizen 1980). Although the situation reached a dramatic low in the middle of the 18^{th} century, when there were just 50 000 hectares of woodland left in the Netherlands, the area of woodland in the Netherlands has now been on the increase for 250 years. Since the 1970s, Dutch woodland has often been managed as a single ecosystem. The heavy storms of 1972 and 1973 resulted in much damage to the single species, vulnerable ‘plantations’. The objective is often a species composition and woodland structure which is as natural as possible, and predominantly deciduous. From a farming point of view, forestry is no longer profitable in the Netherlands, and the government has therefore provided numerous subsidies to encourage forestry.

In 2002, there were only 360 000 hectares of woodland in the Netherlands, or 11% of the country’s total surface area. High population pressure in the Netherlands in particular has played a large role in deforestation, as a lot of space is required for agriculture and livestock farming (this was the reason for the initial creation of the heathlands in the south and east of the Netherlands), for housing, roads and for industry. A lot of woodland was also cut down for human use: cooking and heating (firewood), furniture and wood products (e.g. paper), ship building and, historically, mining. Some natural processes have also resulted in deforestation, for example many woodlands were drowned during the creation of the peat moorland areas, resulting in carrs.

Four different woodland categories have been identified: production woodland, protection woodland (woodland which aims to offer protection from noise, wind, water or erosion), estate woodland and spontaneous woodland. Production woodland is the largest group by far; in 1985 it formed 57% of the total woodland area. This type of woodland was primarily established on heathland during the 19th century and the first half of the 20th century. The oldest production woodland dates however from the 16th century, and is mainly found in the province of Noord-Brabant. Over half the production woodland dates from 1900 or later. Most woodland is made up of exotic species such as Norway spruce, silver fir and Douglas fir. Of the four native tree species – larch, yew, juniper and the Scots pine – only the Scots pine has been planted in large numbers. One problem with production woodland is the similarity in the woodland structure resulting from the planting: all the trees are of the same species and planted at the same time, so that they also have the same age. The woodland is also characterised by rectangular plots of land with straight lanes running through it, to make the production as efficient as possible. The focus has now however shifted to recreation, necessitating diversification in the planting, i.e. the planting of different species and ages of trees, mixed through one another.

The oldest woodlands were primarily mixed deciduous woodland. Most deciduous woodland is native, unlike many coniferous species which were introduced later. Most of the woodlands planted in the 19th and early 20th century are coniferous. Significant mixed woodland is only found on private estates, where the owners have aimed for the largest species diversity possible. Production woodland planted in the polders is often composed of fast-growing, exotic poplars. Because of the single species composition, vulnerability and environmental problems associated with coniferous woodlands, primarily deciduous trees have been planted in recent decades in existing woodlands, so that the area covered by deciduous woodlands has shown a strong increase.

The most important trees in 2002, in order of the area they cover are Scots pine (36.9%), oak (17.4%), larch (7.3%), Douglas fir (7.2%), poplar and willow (6.3%), Norway spruce and silver fir (4.4%), birch (3.7%), beech (3.0%), ash (2.7%), red oak (2.3%), maple (1.1%) and alder (1.0%). Compared with the situation in 1982, the amount of native species such as oak and beech have clearly increased, but so too have numbers of Douglas fir.

4.12.2 The woodland soil

Like many other soils, woodland soils are layered, with an organic and a mineral layer. The structure of these horizons is determined by a combination of soil properties, vegetation and climate. The classic forms are mor, moder and mull soils. A mor humus develops on sandy, nutrient-poor and acidic soils planted with coniferous trees. The dead organic matter, i.e. fallen pine needles, does not decompose very well and collects in the form of a litter layer. This organic layer is usually between 5 and 10 cm deep. The height of the litter layer is partially determined by the speed of supply and decomposition, and different stages of decomposition can be seen within the litter layer. At the top are the freshly fallen leaves, which are broken down into increasingly smaller pieces as a result of the activities of soil fauna, micro-organisms and the weather. This produces a middle layer of increasingly small fragments, where many fungi and soil fauna can be found. Finally, most of the organic matter is decomposed and converted. A thin amorphous humus layer remains, which lies on top of the transition to the mineral layer. The humus slowly leaches into the mineral layer or is mixed into the mineral layer as a result of soil fauna activity. If the pH is low, podzol soils can develop. A mull horizon forms under deciduous trees, especially on less acidic and more fertile soils. Organic matter decomposes rapidly and is well mixed, partly due to the presence of earthworms. The litter layer is thin in this type of woodland and the leaves which fall in the autumn have almost completely disappeared by the summer of the next year.

The soil has been ‘dug over’ at many forest locations, either because it was ploughed in the past, or when tree stumps were removed. In some cases, supports were placed in the soil for the planting of young trees. These processes are still clearly recognisable in the soil profile. Pedogenetic processes play a role over a long timescale, i.e. over centuries rather than decades.

The woodland soils analysed within the framework of the BISQ monitoring programme are relatively acidic, with an average pH-KCl of 3.2. The organic matter content is 5.7% on average. The total phosphate content is low, an average of 3.1 mg P_2O_5 per 100 g soil. Heavy metal concentrations are significantly lower than in agricultural soils. The soil ecosystem is very different from that of agricultural soils: there are few earthworms and nematodes though fungi are well-represented. The diversity and numbers of mites and springtails are the highest of all the categories.

4.12.3 Sampled locations and selection of a sustainable woodland soil

Twenty woodlands were sampled and analysed in Spring 2000 within the framework of the BISQ monitoring programme. Six of these were in the province Noord-Brabant, six in Drenthe, three in Utrecht, three in Gelderland and the rest in Overijssel and Limburg. Eleven woodlands were composed almost exclusively of conifers (Scots pine, Douglas fir, larch and Norway spruce), seven contained a combination of deciduous and coniferous trees (with red oak, beech, rowan and juniper) and two were deciduous woodlands (poplar, alder, oak and beech).

Sampling in the woodland areas was adapted to the soil profile. The litter layer and mineral soil was separated for analysis in the LMB. The locations are fairly homogenous, continuous stands, which vary in size from one to several hectares. The mixed sample was obtained by collecting litter over an area of 10x10 cm from forty different places. After removing the litter, four soil samples were taken in the remaining hole using a soil core sampler with a diameter of 2.3 cm. The samples from the organic and mineral horizons were mixed separately for use in the various analyses. The other BISQ samples were collected from six different places at the location, with no distinction made between soil and litter. The potworms were extracted from the soil every 2.5 cm, in the process separating the horizons. The mites and springtails were from samples taken at a depth of 7.5 cm, which is composed primarily of litter material. Samples for earthworms were collected together with the litter layer.

It proved difficult for the various experts to select locations with a healthy soil. In other words, the experts did not agree on the locations with relatively good soil quality. It was noted that some forest soils were more similar to agricultural soils than others and that locations in the south were different from locations located further to the north. The locations with the best scores were included in the reference. The woodland category is however very diverse and should really be subdivided, but this will only be possible when more data are available. Four locations were chosen for the reference, and the others were used to calculate the national average.

4.13 Municipal parks

A municipal park on sand – Leeuwarden (Fr) 2006

4.13.1 Introduction to municipal parks

Green spaces in and around urban areas are of vital importance in providing a good quality living environment. Rural green spaces such as woodlands and natural, recreational and agricultural areas are also very important but can not replace urban green spaces. The reverse is also true. Urban and rural green spaces each have their own purpose and value and are not interchangeable. The quantity and quality of green spaces in and around urban areas have declined considerably in recent decades, partly a result of the policy of constructing compact urban areas. Sports fields and allotments have been moved to the outskirts and high land prices mean that new houses are built closely together and with small amounts of green. Especially in the 'Randstad area', there is a serious shortage of green surrounding the urban centres. The green spaces that do exist often fail to match to the requirements of their users and are fragmented by barriers such as railways, roads and motorways.

The government is concerned about this development. The need for green spaces in and around urban areas is growing. Various sections of the urban population are dependent on green areas in and around urban areas for their recreational needs. Also, an increasing number of people want to live and work in green surroundings. Green spaces are important for economy and the welfare and health of local residents, and one of the critical factors in the quality of life in the urban environment. Finally, green spaces regulate the urban climate, absorb pollutants and limit nuisance from wind and noise.

In order to be able to guarantee the sustainable implementation of green spaces it is very important to focus on their management. It is of crucial importance that a municipality knows the various users and their requirements, as the value associated to green spaces and the use made of them varies greatly depending on culture and age. The soil type should also be taken into account, as well as the nutrient status and hydrology , since not any type of green space can be planned for any type of soil. The biological soil quality references might be useful in dealing with the various options for sustainable use of soil below municipal parks.

4.13.2 The soil below the parks

Fourteen municipal parks and urban green spaces were sampled in 2006 within the framework of the biological soil monitoring programme. For this first sampling series only fields or grassy areas were sampled, to increase the compatibility with other monitoring in the LMB (dairy farms on sand and semi-natural grasslands on sand). There was a surprise in store as far as earthworms were concerned: various worms were found which had not previously been seen in the LMB and which could not be named. The diversity of potworms and nematode communities is also amongst the highest of all the categories. The pH is 6.5 on average (pH-KCl) and the organic matter content 5.7%. The lutum content is 5.8%. One park was not included because of its high lutum content (19%). The heavy metal content was fairly high in comparison with many agricultural and natural soils. The concentrations of lead and zinc are on average 70 and 135 mg per kg dry soil, respectively.

4.13.3 Municipal park reference selection

Fourteen parks were sampled, distributed throughout the large cities of the Netherlands. A relatively large amount of parks were sampled in Rotterdam because of an ongoing project in this city. In random order, the parks are: Volkspark (Enschede),Vossepark/Westerpark (Leeuwarden), Zocherplantsoen (Utrecht), Zuiderpark (The Hague), Noorderplantsoen (Groningen), Stadspark (Groningen), Vondelpark (Amsterdam), Rijsterborgpark (Deventer), Genneperparken (Eindhoven), Park de Hey (Rotterdam), Westpunt (Rotterdam-Hoogvliet), Ruigeplaatbos (Rotterdam-Hoogvliet), Polder de Esch (Rotterdam-Kralingen-Crooswijk), Noord-Oost-Abtspolder (Rotterdam-Overschie).

Four parks were selected for the reference, based on the expert judgement.

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Appendix 1. Definitions

Ambition (from the *Beleidsbrief Bodem* (Soil policy letter); VROM 2003): a target set by government authorities or users, based on an assessment of the difference in level between the sustainable situation and the current local situation. An ambition may involve more than simply satisfying the parameters described in a reference, though it can be reduced to this.

Amoeba chart: AMOEBA is the abbreviation for 'general method for describing and evaluating ecosystems' (in Dutch: *Algemene Methode voor OEcosysteem beschrijving en Beoordeling*). The term and evaluation method were first described by Ten Brink and Hosper (1989) and the amoebe approach was initially developed for aquatic ecosystems. The method is based on the depiction in a modified pie chart of a number of strategically chosen target variables, showing the gap between the current situation and a reference or target situation. The value of a reference parameter is set at 100% (the circle). The actual values are represented relative to this, in individual slices.

Biodiversity (characteristic or parameter): expresses an ecosystem in terms of the presence of organism groups, species, numbers and activities, processes and functions, classified in terms of genetic, structural, functional or other forms of diversity. The definition of biodiversity is therefore broader than species diversity.

Biodiversity (ecosystem service): see habitat function.

Biological Indicator for Soil Quality (BISQ): a set of biological parameters selected in order to obtain a good indication of the composition as well as the processes and/or functions of the soil system. This dataset is in use within the Netherlands Soil Monitoring Network (in Dutch: LMB), which analyses the soil once every six years at various locations. BISQ was developed through collaboration with various institutes (Schouten et al. 1997, Schouten et al. 2001, Rutgers et al. 2002).

BISQ: abbreviation for the Biological Indicator for Soil Quality.

Buffer and reactor function (ecosystem service): a collective ecosystem service which comprises the ability of the soil to ensure our living environment remains 'healthy', through the absorption, retention, release, drainage and transformation of endogenous or exogenous elements, including water. All biogeochemical cycles are included in this ecosystem service. There is some overlap with the soil fertility ecosystem service. Components of this service are decomposition and the mineralization of organic matter, natural attenuation, water retention and climate functions.

Chemical, physical and biological parameters (from the *Beleidsbrief bodem* (Soil policy letter); VROM 2003): a metaphor for the way in which various parameters all play a role in the assessment of soil quality, enabling the soil to be acknowledged as a 'dynamic and integrated system'.

Ecosystem service: a public service provided by the soil ecosystem, as recognised by the user, government authorities and society. Four basic services have been determined based on advice given by the Technical Committee on Soil Protection (TCB 2003) (please refer to Appendix 2). These are soil fertility, resistance to stress and adaptation, the soil as buffer and reactor and biodiversity. These basic services can be further divided into a total of ten ecosystem services.

Habitat function: a separate category of soil ecosystem service. Biodiversity is here not related to a clearly recognisable soil function. The consideration of biodiversity as an ecosystem service acknowledges the intrinsic value of the soil ecosystem as a potentially important factor in the framework for sustainable land use. This intrinsic value may either be ignored or included by assessing the soil ecosystem health.

Healthy soil ecosystem: please also refer to soil quality. The condition of the soil which is linked to prolonged sustainable land use. ‘Soil ecosystem health’ is a concept derived from the scientific literature (ecosystem health), and is used to describe the condition of an ecosystem influenced by human activities (Van de Leemkule 2001, TCB 2003). As sustainable land use is a relative concept, soil health is also, in practise, a relative concept. Health is translated in scientific terms as the status of the regulation functions or life support functions (LSF).

Indicative value: an estimate of the extent to which a parameter contributes to the quantification of an ecosystem service or to soil health, compared with other parameters. This estimate is based on the expert judgement of participants and/or on an evaluation of the practical application of the parameter concerned.

Indicator: a selected parameter or set of parameters used in the assessment of a defined aspect of the soil quality.

Life Support Functions (LSF): these are the ecological processes which together contribute to the functioning and stability of ecosystems. Furthermore, they are the basis of the ecosystem services which are important to mankind.

Parameter: a measurable and/or calculable soil property which is believed to be related to soil health or soil ecosystem characteristics. Examples are earthworm biomass, cattle density, crop rotation, organic matter quantity and/or quality, leaching of heavy metals into groundwater and biodiversity indices.

Practical amoeba: a representation of a restricted part of the soil ecosystem profile and sustainable reference, based on a choice of ecosystem services most relevant to the particular land use and parameters which most contribute to the quantification of these services. The number of relevant parameters is therefore very much reduced compared with a complete profile of the soil ecosystem.

Profiling: see soil ecosystem profiling.

Reference (from the *Beleidsbrief bodem* (Soil policy letter); VROM 2003): a resource for government authorities and land users which indicates the suitability of the soil for a particular use, so that choices can be made regarding local soil quality. The reference indicates the suitable sustainable status given a certain land use and soil type, using chemical, physical, biological and other parameters. It is assumed that all ecosystem services are sufficiently safeguarded under reference conditions. The reference is based on the status at one or more locations where the soil is believed to be ‘healthy’ compared with all other locations in the dataset in which the BISQ is monitored.

Resistance to stress and adaptation (ecosystem service): a collective ecosystem service representing the capacity of the soil ecosystem to adapt and to offer resistance to stress. This may be necessary to mitigate the effects of natural incidents or human activities. Resistance may involve the rapid recovery of soil following wet or dry periods or following the application of pesticides. Adaptation may involve the capacity to adjust to changing circumstances, such as changes in groundwater management or climate, or to another land use.

Soil ecosystem: a dynamic complex of ecological communities of plants, animals, soil organisms and their non-living environment, which interact to form a functional unit (from ‘ecosystem’ as defined by Tansley, 1935). The soil ecosystem provides society with ‘ecosystem services’. The term ‘soil ecosystem’ is a compromise, as in practise the term ‘ecosystem’ is insufficiently associated with soil, whilst the term ‘soil system’ is insufficiently associated with the living aspect of the soil.

Soil ecosystem profiling: a qualitative and quantitative description of a soil ecosystem, given a particular land use and soil type. A soil ecosystem profile provides data concerning parameters related to soil quality or ‘health’, as well as other relevant characteristics. The data is compared with the average level for the Netherlands, the fifth and ninety-fifth percentiles and the hypothetical sustainable level (the reference).

Soil quality: the concept of soil quality is directional and is used to define the quality of the soil and the soil ecosystem (VROM 2003). Soil quality is determined by the biological, chemical and physical characteristics of the soil system, as well as the soil quality management factors which influence these characteristics. The concept of soil quality can be implemented through the use of ‘ecosystem services’, which provide a platform for the assessment of the various interests of local, regional and national land users.

Soil fertility (ecosystem service): a collective ecosystem service which comprises the ability of the soil to maintain or support parts of the ecosystem, such as crop production, cattle growth, the presence of key species and target species, the suppression of disease and pest organisms, etc. Nutrient retention and release, soil structure and the suppression of pest organisms are all aspects of soil fertility.

Sustainable land use: utilisation of the opportunities offered by the soil, without affecting or depleting them. The soil must not be allowed to undergo irreparable damage, so that it may also be used for other functions in the future. The inclusion of soil quality and soil quantity in soil management and spatial development decisions contributes to sustainable land use. This process takes place at the local user level as well as at government level (VROM 2003, TCB 2003). Because land use is defined by society, it is not possible to define sustainable land use in absolute terms and the concept should therefore only be used comparatively.

Appendix 2. Ecosystem services

A questionnaire for use by land users to indicate the importance of ecosystem services for the land use concerned (in this case agriculture, nature and other ‘green’ uses) and a description of the ecosystem services (next page).

□* scale 1 (nature conservation, farmer, owner) **□ scale 2 (area, province, municipality)** **□ scale 3 (national, Europe)** * tick the scale which applies **ecosystem service:**		nature	agriculture	other green uses
1. production (e.g. soil fertility)	a. nutrient retention and supply			
	b. soil structure, aggregate stability and soil porosity			
	c. disease and pest suppression			
2. resistance, adaptation and resilience	a. resistance to stress, resilience and recovery capacity			
	b. adaptation, flexibility and changeability of land use			
3. Environment (buffer and reactor function)	a. decomposition and mineralization of organic matter			
	b. natural attenuation, clean groundwater			
	c. water maintenance: absorption, retention, release, drainage			
	d. climate functions (air filter, greenhouse gases, temperature, moisture)			
X. biodiversity (separate category, not an ecological service *sensu stricto*)				

Ecosystem services. The soil ecosystem is a dynamic complex of ecological communities of plants, animals, soil organisms and their environment, which interact to form a functional unit. Through these interactions, the soil ecosystem provides 'ecosystem services', which are used by society. The following ecosystem services are involved (taken from the Soil Protection Technical Committee of the Netherlands (TCB 2003), with some changes):

1. Production function: this collective ecosystem service is important in agriculture and replaces the more classic term 'soil fertility'. Humans are dependent on agricultural for food production. The soil is the basis for the growth of production crops as well as, indirectly, cattle. Good soil fertility is therefore of pivotal importance. Soil fertility is also an important criterion in nature, as it is a determining factor for flora, vegetation and landscape, and for the fauna living in this landscape. Aspects of soil fertility are:
   a. the supply and retention of nutrients and the timing of this supply and retention during the growing and harvesting seasons.
   b. a good soil structure for root growth due to the presence of stable aggregates, opportunities for opening up the soil profile and optimum soil density.
   c. the natural capacity of the soil to suppress disease and pests.
2. Resistance to stress and the capacity to change: soil often has a single function. Sustainability requires the soil be used in a way which safeguards the continuity and flexibility of the soil functions and the land use.
   a. continuity. The capacity to resist threats and the ability to recover within a reasonable time frame following a stress of either natural of human cause.
   b. flexibility. The capacity to also fulfil all potential ecological services in the long term and the ability to adapt to a different land use.
3. Buffer and reactor function: the soil ecosystem is importantly contributing to the environment in which we live, in which air, surface water, groundwater, atmospheric transport and deposition, transport in the soil, et cetera. all play a role. Many processes related to our environment, such as the nitrogen cycle, take place in the soil. Aspects of the buffer and reactor function are:
   a. the decomposition of plant remains, mineralization of organic matter and maintenance of a relatively stable fraction of organic matter in the soil.
   b. the natural attenuation capacity, i.e. pollutants are rendered harmless, natural elemenst are broken down and elements are bound so that the shallow and deep groundwater maintains a good quality and the soil remains 'clean'.
   c. the capacity to absorb, retain, release and transport water. This is important both for plant growth and water processes, also at the catchment area level.
   d. the capacity to buffer and influence the climate. The ability to buffer air moisture and temperature and the filtration of air by vegetation are important on the smaller spatial scale. The fixation of greenhouse gases, for example, plays a role on a larger scale.

- Habitat function: protection of structural, genetic and functional biodiversity is, strictly speaking, not an 'ecosystem service' because it is not directly linked to land use. It is nevertheless labelled a service because of the idea that society is obliged to be a good steward and therefore required to protect the intrinsic value of the soil. Soil also contains as yet unknown properties which will be of use to unknown and unnamed ecosystem services as a future source of biological and genetic material. The awareness of structural, genetic and functional biodiversity is also important as it is believed that there is a positive correlation between biodiversity and soil health.

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