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M. Rutgers et al.

Priority areas in the Soil Framework Directive

The significance of soil biodiversity and ecosystems services

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Abstract

Priority areas in the Soil Framework Directive
The significance of soil biodiversity and ecosystem services

Soil biodiversity decreases when soil organic matter declines or when soil is compacted. A decrease in biodiversity may threaten the performance of ecosystem services such as agricultural production, groundwater and surface water cleaning and climate regulation. This is the outcome of a quick scan that aims to clarify the relationship between organic matter decline, soil compaction and soil biodiversity. The quick scan was based on a combination of information sources, such as literature reviews, biological monitoring data from a nationwide soil monitoring network and best professional judgment.

Seven soil threats are distinguished in the draft text of the Soil Framework Directive of the European Commission. Soil organic matter decline and soil compaction are the most relevant for the Netherlands due to intensive agricultural land management. Loss of soil biodiversity should be considered when identifying priority areas requiring protection from organic matter decline and compaction. This report describes the first steps in clarifying the relationship between soil biodiversity and decline in soil organic matter or soil compaction. The objective is to support the Netherlands in preparing for ratification of the Soil Framework Directive.

Key words:
priority areas, Soil Framework Directive, Thematic Strategy on Soil Protection, soil biodiversity, soil threats, soil organic matter, soil compaction, ecosystem services

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Rapport in het kort

Prioritaire gebieden in de Kaderrichtlijn Bodem
Belang van bodembiodiversiteit en ecosysteemdiensten

Bij een afname van het organischestofgehalte of bij verdichting van de bodem daalt de bodembiodiversiteit. Een daling van de bodembiodiversiteit zal de bodem ook minder goed in staat stellen om zogenaamde ecosysteemdiensten te leveren, zoals agrarische productie, schoon grond- en oppervlaktewater en de regulering van het klimaat. Dit is de uitkomst van een verkenning naar relaties tussen organischestofgehalte, bodemverdichting en de bodembiodiversiteit. De conclusies van de verkenning zijn gebaseerd op een combinatie van informatiebronnen, namelijk literatuuronderzoek, gegevens uit het landelijke meetprogramma met de Bodembiologische Indicator en *best professional judgment*.

In de concepttekst van de Kaderrichtlijn Bodem van de Europese Unie worden zeven bodembedreigingen onderscheiden. Afname van het organischestofgehalte en bodemverdichting zijn de twee bedreigingen die het meest relevant zijn voor Nederland. Ze hangen samen met intensief landbouwkundig bodembeheer. Het behoud van biodiversiteit is een criterium dat een rol speelt bij alle bedreigingen van de bodem. De afname van de bodembiodiversiteit kan een factor zijn bij het aanwijzen van zogenaamde prioritaire gebieden voor deze bedreigingen. In dit rapport is een eerste stap gezet tot opheldering van de relatie tussen de bodembiodiversiteit en een afname van het organischestofgehalte of bodemverdichting. Het onderzoek is bedoeld om Nederland voor te bereiden op de invoering van de Kaderrichtlijn Bodem.

Trefwoorden:
prioritaire gebieden, EU-Kaderrichtlijn Bodem, Europese Bodemstrategie, bodembiodiversiteit, bodembedreiging, bodemorganischestof, bodemverdichting, ecosysteemdiensten

Preface

The exploratory research carried out within the framework of this report builds on a long tradition of cooperation between various centres of expertise and research in the field of soil biology. This cooperative effort is coordinated by the interdepartmental biodiversity consultation groups of the Ministries of Housing, Spatial Planning and the Environment (VROM) and Agriculture, Nature and Food Quality (LNV) and is financed on a project basis by VROM and, through co-financing, by LNV. It concerns the development of the Biological Indicator for Soil Quality (BISQ) and Biological Soil Quality References. The BISQ is used in the Netherlands Soil Monitoring Network (NSMN), in which soil samples are taken every year from between 40 and 50 locations and characterised using an extensive set of biological indicators for soil quality. The Laboratory for Soil and Crop Analysis (Blgg), the Louis Bolk Institute, the Soil Quality Department of Wageningen University, Grontmij, TNO and Deltares are also partners, as well as the authors' research institutes (Alterra and RIVM).

The conclusions drawn in this report regarding soil biodiversity in relation to a possible decline in organic matter content or increase in soil compaction would not have been possible without the data from these partners. The authors would like to thank the following people for their contributions to this report (in alphabetical order): An Vos, Arthur de Groot, Bert van Dijk, Erik Steenbergen, Harm Keidel, Henk Siepel, Jaap Bogte, Jack Faber, Kristel Siepman, Lijbert Brussaard, Marja Wouterse, Meint Veninga, Nick van Eekeren, Niels Masselink, Rob Baerselman, Ron de Goede, Ruud Jeths, Tamas Salanki, Wim Didden (†) and Wim Dimmers.

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Summary and conclusions

This report describes a quick scan of the opportunities for the inclusion of loss of soil biodiversity in the identification of priority areas. Priority areas are a component of the Soil Framework Directive (SFD) and are partly intended to stimulate Member States to develop land management policies (EC 2006, 2009). The SFD requires that priority areas are identified for a number of soil threats, such as soil compaction and decline in soil organic matter content. Climate change, desertification and loss of soil biodiversity should also be taken into account. The research focused on the issues relating to loss of soil biodiversity:

- is soil biodiversity likely to decrease following a decline in organic matter content?
- is soil biodiversity likely to decrease following an increase in soil compaction?
- what will be the effects of a loss of soil biodiversity on the soil function?

The research provided sufficient evidence for the general conclusion to be drawn that there is a loss of soil biodiversity as a result of an increase in the two threats named above. However, this evidence is based on a compilation of fragmented research, such as literature reviews, an explorative analysis of field monitoring data from the Netherlands Soil Monitoring Network (NSMN) and best professional judgments (BPJs). It is also recognised that more specific research is required in order to obtain a better understanding of the relationship between soil degradation and soil biodiversity. The relationship with organic matter is the best studied; nevertheless, good field studies across organic matter gradients are scarce. There is also a lack of knowledge concerning the relationships between the various organic matter fractions (for example, stable soil organic matter and unstable fresh organic matter) and soil biodiversity. This exploratory research should be followed up with a statistical analysis of the data and the patterns found.

There is scientific consensus on a mental model that assumes a relationship between soil biodiversity, soil process function and the corresponding ecosystem services. These are the intentional or unintentional services (functions) that the soil provides society with, such as agricultural products, clean groundwater and surface water and climate-regulating functions. A quantitative exploration of these relationships is still in its infancy and there was no scope within this project to take this further. Based on the BPJs and the literature study, it can be concluded that organic matter decline and soil compaction have a negative effect on soil ecosystem service performance. A general recommendation is that the concept of ecosystem services be better developed; it is relatively new and has not yet received much research focus.

It is reasonable to suggest that soil biodiversity be included in the protocol for the identification of priority areas when formulating the assessment framework (decision instrument). Based on data from the Netherlands Soil Monitoring Network (NSMN), this study shows that there is a clear loss of biodiversity as a result of a decline in organic matter content in clay soils. Biodiversity is also low in intensively managed sandy soils used for agriculture, horticulture and bulb growing (maize production was not included in this study). The general conclusion is that the intensity of land use management influences the loss of soil biodiversity as a result of soil degradation, also in relatively insensitive soils. From a sustainability point of view, it is therefore justified to consider the intensity of land use management when developing an assessment framework, and to not exclude certain soil types that are considered to be insensitive.

The results of the quick scan were subject to a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats), in which different aspects of the conclusions and background information were discussed to obtain a more balanced view of the issue. One of the conclusions drawn from this analysis is that the terminology should be made more consistent, certainly as far as the soil aspects investigated within this study (soil biodiversity, ecosystem services, organic matter and soil compaction) are concerned, to prevent differences in interpretation and semantic discussions.

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1 Introduction

1.1 The Soil Framework Directive

In 2006, the European Commission presented a proposal for a Soil Framework Directive (SFD; EC 2006). This proposal has already resulted in an initial European Parliament position, and it is expected that negotiations between Member States (in the Environmental Council) will be completed in 2010. Following agreement, Member States will have two years in which to incorporate the Directive into national legislation. Two years is not long, and although the wording of the Directive has not yet been finalised, it is already clear that some elements will also be included in the final Directive. This means that research for the implementation of the Directive needs to start now. One necessary area of research concerns the identification of priority areas (previously known as risk areas), taking into account the loss in soil biodiversity.

The SFD is intended to stimulate Member States to develop soil policy and land use management tools. The SFD calls for Member States to identify priority areas requiring protection from a number of soil threats. Six of these are named in the Directive: erosion, organic matter decline, compaction, salinisation, landslides and acidification. The Directive provides a number of conditions for the identification of priority areas: Member States must first determine whether the seriousness of a soil threat at local level requires its identification as a priority area, and may themselves determine the scale, extent and ambition level. Eckelmann et al. (2006) provide general criteria which may be used in this assessment. When identifying priority areas, climate change, desertification and soil biodiversity loss must also be taken into account. Should the identified soil threats negatively affect soil biodiversity, for example, this may be an extra reason for the identification of a priority area. A fragment of the Framework Directive as worded when the research began is shown in Box 1.

This report contains the results of a ‘quick scan’ of existing data and available knowledge concerning the expected effects of threats on soil biodiversity, and starts a discussion of the opportunities for compiling soil biodiversity information and its application in the identification of

Box 1. Fragment from the EU Soil Framework Directive (5-6-2009, 10387/098; EC, 2009).

Article 6. Identification of priority areas requiring special protection from soil degradation processes

1. *Member States shall identify priority areas, as defined in Article 2(9), on their national territory requiring special protection against soil degradation processes defined in Article 2(10).*
2. *By … *, and for the soil degradation processes erosion, organic matter decline, compaction, salinisation, landslides and acidification, Member States shall identify, having regard to paragraph 6, the soil degradation processes which are of relevance for their territory or part of their territory. For such degradation processes, Member States shall, at the administrative level and geographical scale that they consider appropriate:*
   - (a) *evaluate, based on but not restricted to the elements set out in the indicative list in Annex I, the extent to which their national territory is subject or likely to be subject in the near future to, i.e. at risk of, such degradation processes;*
   - (b) *establish the levels of risk acceptability, which can vary from area to area, of the soil degradation processes, having regard to the objective of preserving soil functions pursuant to Article 1(1) and the sustainable use of soil;*
   - (c) *identify priority areas on their national territory […] that exceed the levels of acceptability established in point (b).*
3. *For the purpose of the evaluation carried out under paragraph 2(a), Member States may base the identification of areas on empirical evidence or validated models. Where appropriate existing data, including maps and research, may be used.*
4. *For the purpose of paragraphs 2(b) and 2(c) Member States shall take into account, as far as relevant and feasible, the effects of those processes on greenhouse gas emissions, desertification and soil biodiversity loss.*

priority areas. The emphasis is on the effects of organic matter decline and soil compaction. Little or no attention is paid to erosion and acidification as these threats are considered less relevant in the implementation of the SFD in the Netherlands. Landslides are of no significance in the Netherlands. Salinisation, according to the terminology of the SFD, is limited in the Netherlands, where it is considered a groundwater issue, to be addressed through water policy. Because the decline of organic matter is of particular significance in mineral soils, soil subsidence in the peat meadow areas resulting from the oxidation of organic matter is beyond the scope of this quick scan. A separate policy is to be developed for sustainable soil management in peat meadow areas.

1.2 Soil biodiversity and research criteria

A decrease in soil biodiversity was defined for this project as a decrease in structural elements (species diversity), processes or ecological functions, resulting in a decrease in the functional aspects of the soil. This approach is consistent with the EU project ENVASSO (Environmental Assessment of Soil for Monitoring; www.envasso.com). The ecological functions of the soil were defined in terms of ecosystem services, consistent with the recommendation of the Technical Committee on Soil Protection 'An Ecological Basis for Sustainable Land Use' (TCB, 2003), the approach taken in the Ministry of Housing, Spatial Planning and the Environment project 'Biological Soil Quality References' (VROM, 2005) and the RIVM/Alterra/WUR project using the Biological Indicator for Soil Quality (BISQ) 'Soil Ecosystems and the State of Ecosystem Services in the Netherlands' (Rutgers et al., 2008). These operational definitions are consistent with ideas in the Soil Framework Directive and the Millennium Ecosystem Assessment (MEA, 2005) concerning the role and significance of soil biodiversity, functional properties, ecosystem services and life in the soil, despite the fact that the terms used are slightly different.

From a scientific point of view, no consensus has yet been reached concerning the use of a set of indicators to express soil biodiversity, and there is no clear definition of the term 'soil biodiversity'. Ecosystems, including the soil, are so complex as far as the relationships and processes that take place over varying scales of space and time are concerned, that no solution is expected in the short term ('ecosystems are not more complex than you think, they are more complex than you can think'; Egler, 1977). These limitations in our knowledge and the lack of consensus are ignored for the purpose of this report. Simple 'proxies' (an agreed and accepted quantitative approach, for lack of a better) are therefore used instead for soil biodiversity, to either quantitatively validate or disprove the hypothesised relationships described in the SFD. In other words, we have to do the best with what we've got. The proxies used fall into two categories: a measure of 'system complexity' (species and function diversity) or a – hypothetical – relationship with an 'amount' (biomass, or potential activity). More integrated proxies for soil biodiversity are described in the literature (Markert et al., 2003; Breure et al., 2005; Mulder, 2006), but their application was considered too demanding within the framework of the research described in this report.

The research makes use of the results of measurements made using the Biological Indicator for Soil Quality (BISQ) in the Netherlands Soil Monitoring Network (NSMN). The NSMN represents about 70% of land use-soil type combinations in the Netherlands. From 1997 onwards, biological measurements have been made every year in specific land-use and soil-type

Box 2. The underlying principle (working hypothesis).

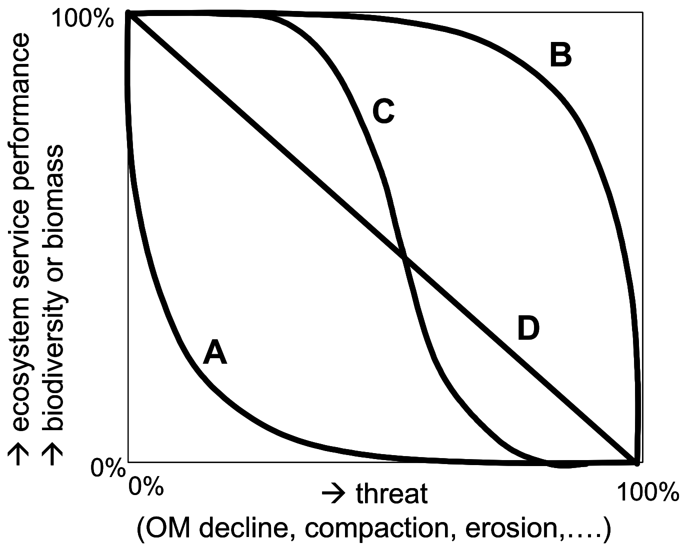
Soil biodiversity and ecosystem service performance decrease as a result of soil threats such as organic matter decline or increasing soil compaction. Theoretically, the absence of a threat means that soil biodiversity and ecosystem service performance are arbitrarily set at 100%. In the case of a theoretically maximum threat, it is assumed that soil biodiversity and ecosystem service performance decrease to eventually reach 0% (see Figure 1).

categories (Rutgers et al., 2005, 2008). Most sampling locations are in agricultural areas (livestock farming and arable fields), semi-natural grasslands, woodlands and heathlands. The data set does not consist of a systematic national inventory (for example using a grid system), but is compiled according to the dominant soil types and land-use categories found in the Netherlands (Spijker et al., 2009).
The results are entered into the BISQ database. It is expected that the second five-yearly soil biology measurement round will be completed in 2010, and this will include an extensive random survey of soil on agricultural land.

Data from the long-term NSMN sample set (Rutgers et al., 2009) were investigated for relationships between threats and soil biodiversity. Various components of the living soil were investigated, the extent of which depended on the availability of data and the best professional judgment (BPJ) of the researchers involved. No new research was started. Various researchers were interviewed or asked to make an estimate of expected relationships between soil threats and soil biodiversity. Other researchers were asked to specify criteria relevant to the Netherlands for the identification of priority areas requiring protection from organic matter decline and soil compaction.

The underlying principle (working hypothesis) of this research was formulated as follows (see Box 2): soil threats, in this case a decrease in organic matter content and/or increasing soil compaction, result in a decrease in soil biodiversity. The information required for this project was collected using quick scans and was used to illustrate the working hypothesis, or to disprove it. No comprehensive statistical analysis was carried out. Instead, the plausibility of the working hypothesis was verified based on a combination of an assessment of data, interviews with experts and existing literature. As a practical model for thought and discussion, the relationship between threat and effect was expressed as four different curves: as a sensitive, an insensitive, a sigmoidal and a proportional relationship (see Figure 1). An answer was also looked for to the question how this information may be used in future situations and which information is of use in the identification of priority areas, for example using a specific monitoring programme that focuses on a particular threat.

Figure 1. A figurative representation of the working hypothesis.
Four hypothetical dose-response curves representing the relationship between threat and ecosystem service performance or biodiversity:
A. sensitive
B. insensitive
C. sigmoidal
D. proportional



1.3 Structure of the report

This report provides a description and an overview of a number of activities that must answer the questions: i) do the soil threats named in the draft version of the Soil Framework Directive (SFD), in this case organic matter decline and soil compaction, result in a decrease in soil biodiversity, and ii) how can soil biodiversity loss be taken into account in the identification of priority areas. The research consisted of a quick scan and a written report of this scan, potentially useful in both the policy arena and practise.

Three chapters of the report are dedicated to determining the extent of the validity of the working hypothesis, which assumes a decrease in soil biodiversity following soil degradation, in this case organic matter decline or soil compaction. To answer this question, use was made of three potential information sources:

- quantitative data from field measurements taken from real soil systems stored in the Biological Indicator for Soil Quality (BISQ) database;
- literature data on organic matter and soil compaction research carried out in the laboratory and on experimental plots, and relevant field research in specific situations;
- the *best professional judgment* (BPJ) of researchers working in soil ecology, stress ecology and the assessment of soil quality.

Soil biodiversity loss is related to organic matter decline and soil compaction in chapter 2 and 3 respectively. In chapter 4, the hypothesised effect on biodiversity is expressed as the soil system function in terms of ecosystem service performance. In order to do this, use was made of BPJ interviews and a questionnaire (see Appendix 1).

In chapter 5, discussion is initiated into the possibility and legitimacy of taking soil biodiversity loss into account in the identification of priority areas. The discussion concerning the strengths and weaknesses of the research described in this report is illustrated using a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats; chapter 6).

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2 Organic matter and soil biodiversity

2.1 Introduction

Organic matter is an exceptionally important component of the soil, as it affects the soil's physical, chemical and biological properties. It is a source of energy and nutrients for soil biota and, through mineralisation, a source of nutrients (N, P and S) for plants. Organic matter influences the soil structure (in particular aggregate stability), water retention and water infiltration, and organic matter content and quality are therefore considered key factors in the assessment of the sustainability of soil management (Gregorich et al., 1994, 1997; Haynes, 2005).

There is no doubt that managing organic matter is essential in the maintenance of the soil ecosystem as a whole. The fact that organic matter is the primary food source for almost all soil biota is an important factor in the maintenance and promotion of life in the soil and therefore for the ecosystem services that the soil can provide (Faber et al., 2009). Maintaining organic matter is therefore of universal interest: directly for individual farmers working on the land and nature managers, as well as indirectly for water managers, water companies, investors, tourists, local residents and society as a whole.

Although the importance of soil organic matter is generally recognised, it seems to be difficult to identify priority areas requiring protection from a decline in organic matter (Körschens, 2006; Smit et al., 2007). Furthermore, generic acceptable thresholds are of no use as organic matter content varies greatly, depending on land use, soil management, soil type and climatic conditions. People working in various sectors (for example farmers or soil managers) experience few acute problems with organic matter. There is also no systematic monitoring network for determining trends in soil organic matter content. Though there are concerns regarding a decline in organic matter content, these are primarily based on data from outside the Netherlands. Smit et al. (2007) conclude that there is much interest in organic matter, but that there is a strong need for objective data to fuel the discussion. The present situation needs to be identified and defined, and data on the relationship between land use and changes in soil organic matter content are needed.

Both natural and anthropogenic factors play a role in soil organic matter dynamics. A decline in organic matter content is defined in the SFD as a steady downward trend in the organic fraction of the soil, excluding undecomposed plant and animal remains and their decomposition products, and excluding soil biomass. The SFD assumes that, in addition to natural factors and climate change, intensive rural management is also a risk factor for organic matter content (Box 3; EC, 2009).

Box 3. Table of criteria for the identification of priority areas requiring protection from a decline in organic matter content (EC, 2009).

SECTION 2 INDICATIVE ELEMENTS FOR THE IDENTIFICATION OF AREAS REQUIRING SPECIAL PROTECTION FROM SOIL ORGANIC MATTER DECLINE
Soil type (Soil Typological Unit (STU) level)
Total soil organic carbon (g C/kg dry matter) (STU level) (can be measured or derived)
Climate: temperature and precipitation (amount)
Land cover and land cover change (e.g. following Corine Land Cover nomenclature)
Soil texture (STU level): clay content
Stock of soil organic carbon (t C/ha) (STU level) (can be measured or derived)
Topography: slope, exposure and elevation
Land use, including land management, farming systems and forestry

Rural management is an important factor in the Netherlands as far as organic matter is concerned, as it is assumed that soil management that focuses on nature development presents little risk to organic matter content, due to the relatively nutrient-rich and young soils and the temperate climate (with the possible exception of the active management of drift sand and turf cutting on grassy heathlands). Eckelmann et al. (2006) indicate which soil and soil management properties may be of significance in the identification of priority areas, and that it is very difficult to derive generic threshold values, due to the dynamics and complexity of organic matter and the differences between soil types.

2.2 Organic matter thresholds

Although standards have been defined for soil pollution, there are no such thresholds for soil organic matter. A standard for organic matter could be defined as a minimum organic matter content, or an optimum organic matter content for crop production. The question however remains as to whether organic matter thresholds are an appropriate instrument for soil management. In addition, the available expertise is insufficient for the definition of such thresholds. Organic matter is a complex mixture of different compositions of small and large structural elements, making it difficult to define. In a healthy soil, organic matter is continually being supplied and removed, partly by natural processes and partly as a result of soil management. Furthermore, different organic matter thresholds would need to be defined for different soil types and land uses, making them difficult to apply.

A number of guideline values are suggested in the literature. Eckelmann et al. (2006) apply a lower threshold value of 2% organic carbon. This value is also cited in Loveland and Webb (2003), and is equivalent to an organic matter content of 3.4%. Römkens and Oenema (2004) set the threshold at 2% organic matter content. Smit et al. (2007) state that guidelines for optimum organic matter content are in use at the Dutch Agricultural Information Service (AIS), which applies the following values (with a brief remark concerning their feasibility):

- arable land on sand: 2.5% to 3.5%;
- sandy soils in general: 3% – lower values are more common, compared with other soil types;
- arable land on clay: 2.0% to 2.5% – below this is ‘low’;
- excavated peatlands have a higher organic matter content.

These indicative ranges are also further refined according to land-use and soil-type category. Extensively managed soils and grasslands, which in general have a higher organic matter content, are not included, though it should be noted that these categories too may show negative trends (Hanegraaf et al., 2009). The area however over which these thresholds are not achieved will not be very large (Smit et al., 2007).

Taking all the scientific limitations into account, Smit et al. (2007) propose that priority areas requiring protection from a decline in organic matter content be identified in mineral soils using a decision tree (the exclusion method, see chapter 6 in Smit et al., 2007). Using this method, it would seem that poor soils with an organic matter content of less than 3.4% (2% organic carbon) used for maize cultivation, arable land or tree plantations are the most at risk. Focusing on a specific organic matter content threshold does not currently seem to be a suitable method for the evaluation of soil quality (Eckelmann et al., 2006). Some soils have a naturally low organic matter content and are unlikely to experience further decline. Other soils with an average organic matter content are continually at risk of further decline, and also difficult to influence through soil management. Soil management strategies that give a high chance of improvement are sometimes described for soils with low organic matter contents. Organic matter dynamics can even vary significantly between bordering plots of land (Lebbink et al., 1994; Hanegraaf et al., 2009), making it difficult to derive area-specific or location-specific threshold values. This illustrates the undesirability of organic matter thresholds.

2.3 Trends in organic matter

It is a widely-known fact that organic matter content is dependent on soil type – young soils contain little organic matter. Land use management also has a large effect; natural soils often contain more organic matter than agricultural soils. The intensity of soil cultivation is considered to be one of the dominant factors that influence organic matter content. For example, during a 36 year-long field experiment near Ghent (Belgium), Van Eekeren et al. (2008) found the highest organic matter content in permanent grassland (6.1% DM), the lowest in permanent arable land (2.1% DM) and intermediate values for arable and grass rotations (3.3% and 3.5% DM).

The intensity of soil cultivation has supposedly been increasing for a long time, with the development of land for agricultural purposes, the drainage of agricultural land and, particularly during the last century, more intense agricultural methods using machinery. Overall, this has resulted in a lower average organic matter content in mineral soils in the Netherlands, but there is a lack of reliable data. However, recently-published data on measurements of organic matter content in agricultural soils in the Netherlands show no clear general negative trend, not even in sensitive soils (Hanegraaf et al., 2009), with individual fields showing both an increase and a decrease. This shows that local measures taken at individual field level have a large influence on organic matter content and that the monitoring of organic matter is therefore not straightforward.

Analysis of the Laboratory for Soil and Crop Analysis (Blgg) dataset indicates that sandy soils in which roughage – usually maize – has been cultivated for a long time usually showed a decline of about 1% organic matter content over the last 20 years (Smit et al., 2007). All sandy soils used for continuous maize production are at risk of dropping below the organic matter content threshold of 3.4%, as suggested by the AIS, in the near future. However, calculations made by Hanegraaf et al. (2009) show that there is no general negative trend in organic matter content in maize land and grassland on sandy soils in the Netherlands, though there is a normal distribution in the change in organic matter content. About a quarter of grassland and maize land fields, showed a decrease of at least 1% over 20 years. To prevent confusion, 1% is not a small relative decrease, but a significant decrease in absolute organic matter content. In the case of maize land, a quarter of the fields showed an increase; in the case of grassland, 60% of the fields showed an increase. It would seem that local measures taken on a single plot can have a large influence on organic matter content in the short term. This was also illustrated by Lebbink et al. (1994) using data from the pilot farm de Lovinkhoeve (Marknesse, the Netherlands), which showed that measures taken at plot level can, in the near future, ensure either a stable situation or a decrease or increase in organic matter content.

Land management has a greater and faster-acting influence on unstable (easily degradable) organic matter than on total organic matter content (Körschens, 2006). Cultivation in particular results in a decline in organic matter content; even if large amounts of organic fertiliser are applied, the level found in permanent grassland can never be reached in arable land. Organic fertiliser – manure and compost – does however have a beneficial effect on structure (larger aggregates and granule structure), though care should be taken not to apply too much as too much nitrogen is then released. There are indications that arable land has a maximum organic matter capacity, related to its clay content. Clay contains small pores that protect against decomposition. In long-term (>50 years) fertilisation experiments an increase in organic matter content of 25% was achieved in sandy clay, whereas an increase of only 11% was achieved in light sandy soil. Once these maximum levels were reached, no further increase took place. These figures are relative percentage changes and not absolute values.

The general picture from long-term experiments on arable land is that, after 20 years of organic fertiliser application, the organic matter content was 20-30% higher than when artificial fertiliser was used. This large difference between artificial fertiliser and organic fertiliser applied to sandy soils as well as clay. The higher organic matter content was accompanied by more soil biota, more N mineralisation and the better utilisation of nitrogen from organic matter (Faber et al., 2009).

Based on the literature, it is possible to produce a list of interventions and factors that have been shown to be important contributors to soil organic matter content decline (please also refer to Figure 2). These are, in order of decreasing significance:

- soil cultivation techniques (ploughing, harvesting root vegetables such as beet and potatoes);
- soil sterilisation (steaming, flooding);
- crops that contribute little to OM (e.g. root vegetables);
- narrow crop rotations (with few grains, grasses or green fertiliser);
- the removal of crop residue;
- artificial fertiliser and lime application (with exceptions);
- a warmer climate.

A warmer climate results in a decline in organic matter content as higher temperatures mean that the supply of organic matter can no longer keep pace with decomposition. The influence of temperature is reflected in the higher organic matter content in the soils of north European countries (Scandinavia) compared with central European countries (Berg, 2000; EC, 2005).

The factors named above are connected with the complex system of chemical, biological and agricultural processes that take place in the soil as shown in Figure 2. The influence of cropping systems is chosen as the point of reference in this diagram. Organic matter takes a central role in the identifiable chains of effects. The numbers in circles indicate where soil biota have an influence, though this is not addressed in detail here. The type of arrow (continuous or dashed) shows whether there are positive or negative effects on the compartments or on plant production. Plant production in Figure 2 is dependent on three factors: soil biota, soil fertility and damage by pests. Organic matter and fresh vegetation are the food source for soil biota and the stored minerals are released through the consumption and decomposition of organic matter. Biological mineralisation and chemical soil fertility together form the natural food source for plants, a process that is artificially enhanced through fertilisation, possibly in combination with irrigation.

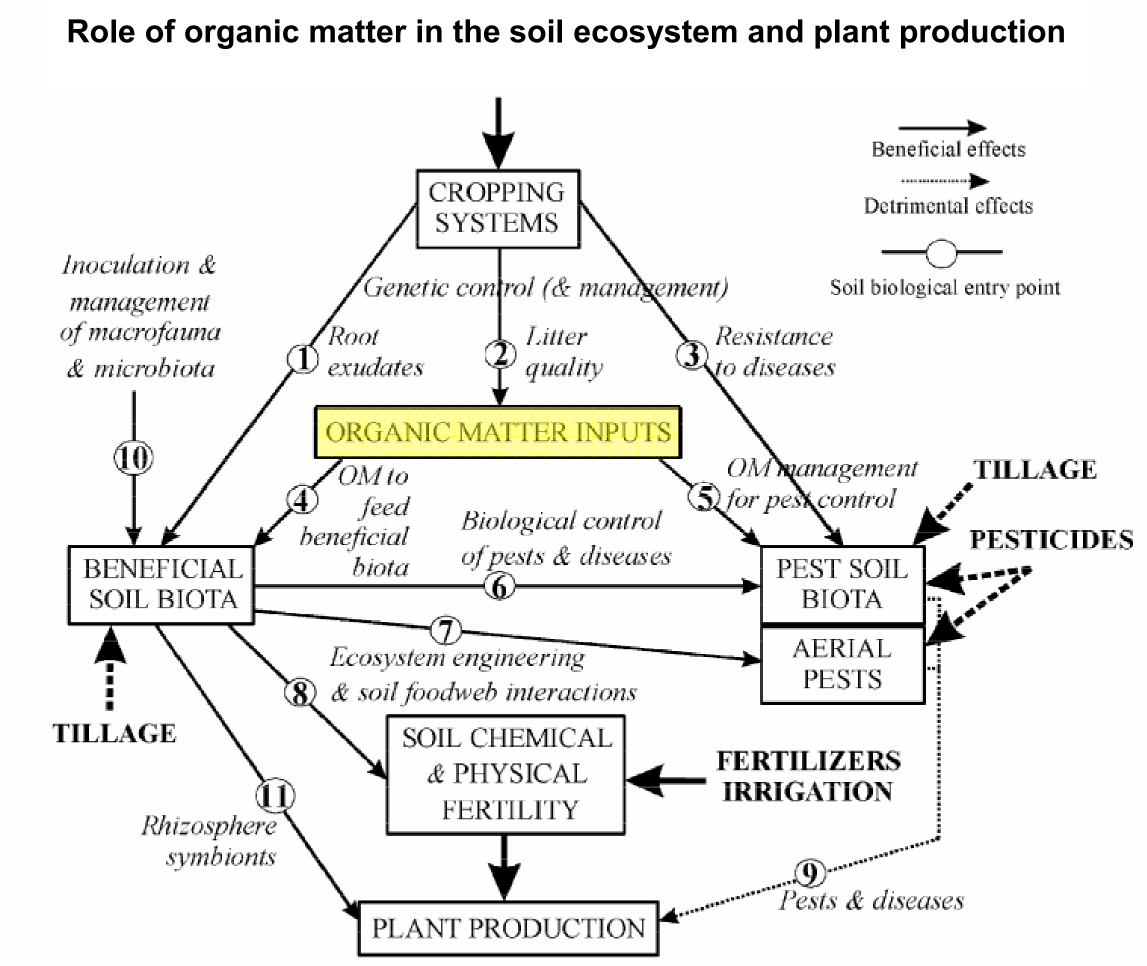

Figure 2. The central role of organic matter in the soil ecosystem and the influence of cropping systems through agricultural management (fertilisation, ploughing, irrigation and pesticides), beneficial soil biota, diseases and pests and soil fertility. ***OM=Organic Matter*** **(from Brussaard et al., 2007, adapted by Swift, 1999, and Susilo et al., 2004).**

2.4 Relationship between soil biota and organic matter

It has been shown in a large number of studies that organic matter has a positive effect on soil biota. The central role of organic matter in the soil ecosystem is shown, for example, in the diagram by Brussaard et al. (2007; Figure 2). Based on a study of the literature, an overview has been produced of the effects of a lower organic matter content (resulting from the interventions and factors named above) on the abundance and/or composition of soil biota (Table 1). The individual interventions, the direct or indirect consequences and the effects on soil biota are described in as much detail as possible. Almost all interventions that result in a lower organic matter content also result in a lower soil biota abundance and/or diversity.

Table 1. The effect of a low organic matter content on soil biota in relation to factors that cause a decline in organic matter content.

Causes	Indirect effects	Effect on soil biota
decline in OM content (general)		lower numbers and fewer species of soil biota (all groups)
		decline in nematodes and bacteria
		less OM: increase in earthworms, potworms and micro-arthropods (possibly related to high OM content in arable land in fen settlements in the northeast of the Netherlands) less OM: decrease in earthworms (Wardle, 1995; Van Eekeren et al., 2008)
high temperature: OM decomposition increases faster than OM production	OM content moves to lower dynamic equilibrium (Berg, 2000)	see: decline in OM content (general)
reduced supply of fresh organic material	reduced supply of unstable OM	mesofauna more dependent on roots (Eo and Nakamoto, 2008). Less fresh organic matter, fungi and bacteria (Pankhurst et al., 2003; Van Eekeren et al., 2008; Demšar et al., 2006)
reduced accumulation of stable OM (Adl et al., 2006)	reduced soil structure quality	less habitable pore space and therefore reduction in larger soil biota (Adl et al., 2006)
	reduced drainage	possibility of water saturation (resulting in decline in soil fauna)
soil sterilisation and similar interventions	increase in bacterial OM decomposition	strong decline in all species
	return of system to early successional phase	revival of rapid colonisers and opportunists
	reduced aggregate stability	less habitable pore space and therefore decline in soil biota
	nutrient flux	brief revival of plant growth and opportunistic soil biota

2.5 Abiotic monitoring data from the NSMN

Monitoring data from the Biological Indicator for Soil Quality (BISQ) database were used for the analysis in this chapter, which concerns abiotic monitoring data from seven categories of the Netherlands Soil Monitoring Network (NSMN); four in sandy soils (horticulture, arable land, dairy farms and semi-natural grasslands) and three in clay soils (arable land and dairy farms). Data from a total of 228 sampled field locations were evaluated (Table 2; data previously published by Rutgers et al., 2009).

Analysis of the locations in sandy soils shows that organic matter content is lowest in horticultural soils (field production; 2.8% on average based on dry matter – Table 2) and highest in semi-natural grasslands (8.8% on average). Though it may seem surprising that arable land on sand has, on average, an organic matter content that is roughly the same as that of dairy farms on sand (7.6% and 6.4% respectively; not significantly different), this is explained by the fact that many arable farms on sand are on excavated peatlands in the former fen settlements (the provinces of Friesland, Drenthe and Groningen). These soils contain the remains of organic matter in the mineral soils of the earlier peat. When arable farms on the higher sand deposits only are selected, the organic matter content is 3.5% on average. These results are consistent with the observation that intensive soil cultivation techniques have a negative influence on organic matter content (Faber et al., 2009; Van der Wal et al., 2008; Van Eekeren et al., 2008). Soil cultivation increases and organic matter content decreases in the order: semi-natural grassland, dairy farms (pastureland), arable land and horticulture. In addition to cultivation techniques, lime application (an increase in pH value) and the application of artificial fertiliser (no OM supply), also play a role in the increasing decline in organic matter content in arable land and horticultural land (Faber et al., 2009).

Analysis of the data from clay soils shows that organic matter content in arable land is relatively low (2.4% based on dry matter) and higher for dairy farms on marine clay and river clay (7.9% and 8.0% respectively, Table 2; Rutgers et al., 2009). More intense cultivation methods on arable land also seem to result in a lower organic matter content in clay soils.

The conclusion is that the total soil organic matter content varies for different forms of soil management. The highest organic matter content values are found in less intensively cultivated soils: semi-natural grassland (with extensive grazing of less than 0.5 LU per hectare) and dairy farmland. Lower organic matter content values are found in arable land and horticultural land. The same trend was found in both clay soils and sandy soils.

2.6 Relationship between land use and biodiversity in the BISQ database

A limited set of biological monitoring data from the BISQ database was analysed to investigate soil biodiversity in the seven NSMN categories. These data concern a set of measures which, for lack of a better, represent an estimate of soil biodiversity (proxy), that can be roughly divided into system complexity (ODU or operational diversity unit) and soil biota abundance (number of organisms or biomass). These are shown in Figure 3 in the first and second columns respectively for the following groups of organisms (from top to bottom): eelworms (nematodes), potworms (enchytraeids), earthworms (lumbricids), mites and springtails (micro-arthropods) and bacteria.

A negative correlation seems to exist between land use intensity and soil biodiversity proxies for the four categories on sand (the first four blue bars in each graph in Figure 3; from left to right: horticulture, arable land, dairy farms and semi-natural grasslands). This hypothesis seems plausible for most parameters, but not for bacteria diversity (insufficient data) and for number of potworms per square metre (no clear relationship). These results therefore agree with the hypothesis that land use intensity (cultivation techniques, as well as lime application and the application of artificial fertiliser) is correlated with a decline in organic matter content (previous section) and a decline in soil biodiversity in sandy soils.

Table 2. Some soil properties at locations in seven categories of the Netherlands Soil Monitoring Network (NSMN). The average and upper and lower threshold of the 95% Tukey confidence interval for organic matter content, pH and clay content are shown. Average differences are significant if the letters (a-g) are different. Data from Rutgers et al. (2009). The abbreviation of the category name is given in the first column.

	land use	soil type	number of sites	pH (H_2O)			organic matter (% dm)			clay particles (% dm)		
				average	*group*	*low high*	*average*	*group*	*low high*	*average*	*group*	*low high*
HoSa	horticulture	sand	18	**7.31**	ef	7.09 7.54	**2.8**	a	1.0 4.6	**6.5**	cd	3.2 9.9
ArSa	arable land	sand	33	**6.06**	b	5.89 6.23	**7.6**	bcd	6.3 9.0	**2.3**	a	-0.2 4.7
DaSa	dairy farm	sand	87	**6.08**	b	5.97 6.18	**6.4**	bcd	5.6 7.2	**3.1**	bc	1.6 4.6
SgSa	semi-natural grassland	sand	10	**5.45**	a	5.13 5.77	**8.8**	bcd	6.2 11.3	**3.9**	bcd	-0.8 8.6
ArMc	arable land	marine clay	30	**7.67**	f	7.49 7.84	**2.4**	a	1.0 3.8	**17**	fg	15 20
DaMc	dairy farm	marine clay	29	**7.14**	de	6.96 7.32	**7.9**	d	6.5 9.3	**29**	e	26 31
DaRc	dairy farm	river clay	20	**6.38**	bc	6.16 6.59	**8.0**	cd	6.3 9.7	**35**	g	32 38

The abundance or biomass of groups of organisms seems to be quite a bit higher in grasslands than in arable land for the three categories on clay (the last three bars in each graph in Figure 3; arable land on marine clay and dairy farms on marine clay and river clay). This also applies to system complexity (ODU) proxies for earthworm and micro-arthropod communities, but not to proxies for the other groups (nematodes, potworms and bacteria).

The results for clay soils therefore largely agree with the hypothesis that land use intensity is correlated with a decline in soil biodiversity (both system complexity and abundance). A number of proxies showed no clear relationship, and no proxy showed an inverse relationship.

The general conclusion from this quick scan analysis of the BISQ database in the preceding sections is that it is plausible that an increasing intensity in soil management, as identified within the various categories of the NSMN, results in a decline in soil biodiversity. This is accompanied by, or is caused by, a decline in soil organic matter content.

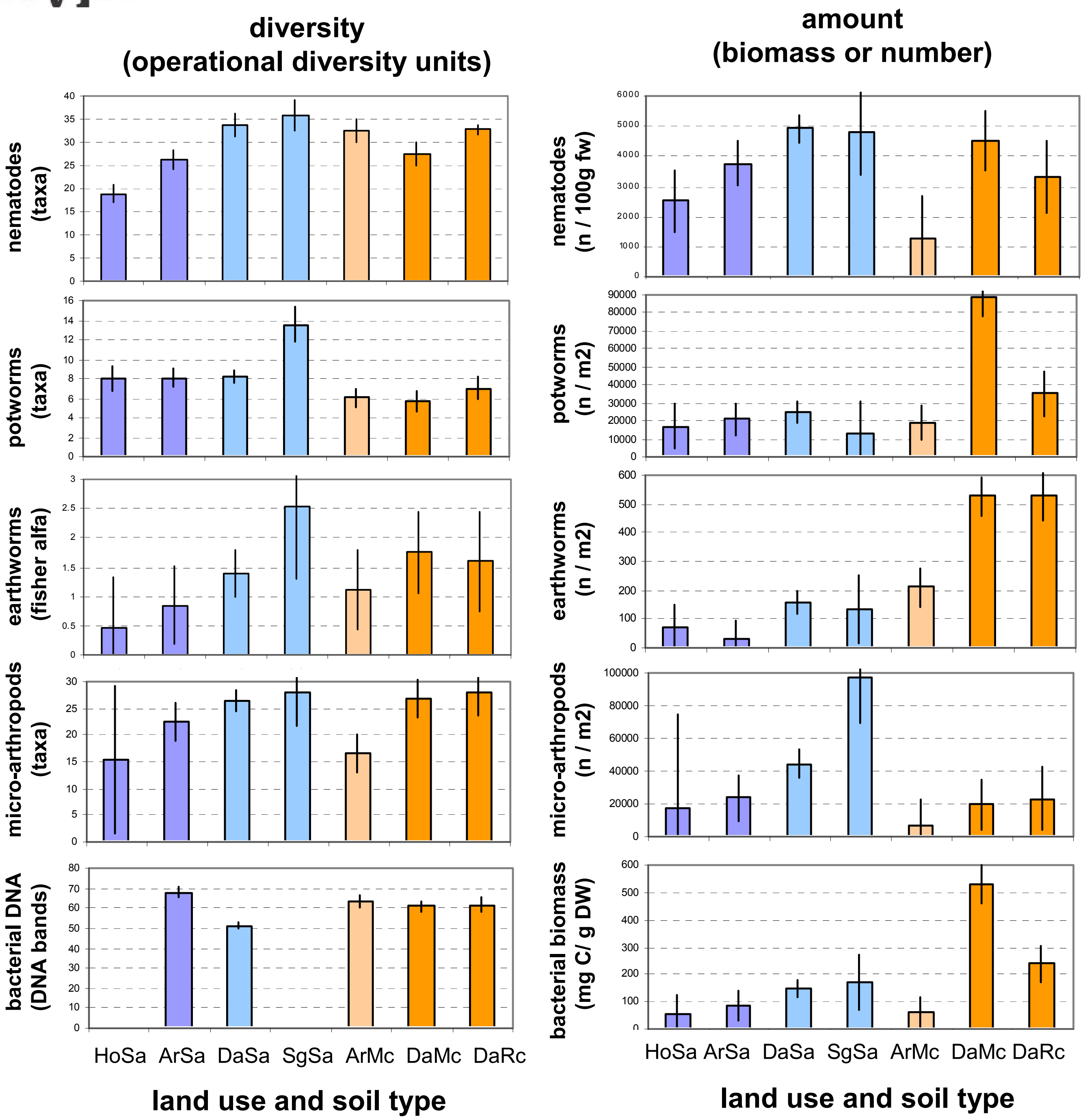

Figure 3. Soil biodiversity monitoring data from the BISQ database for seven land-use and soil-type categories in the Netherlands Soil Monitoring Network. System complexity is shown in the first column (ODU: operational diversity units). Soil biota abundance is shown in the second column (biomass or number). The categories (horizontal axis) are represented using the same abbreviations as in Table 2. The following groups are shown (from top to bottom): nematodes, potworms, earthworms, micro-arthropods and bacteria. The bars show the average for each category, including the Tukey 95% confidence intervals. From left to right, there are four categories on sand (blue: horticulture HoSa, arable land ArSa, dairy farms DaSa and semi-natural grassland SgSa) and three categories on clay (red: arable land and dairy farms on marine clay ArMc and DaMc, and dairy farms on river clay DaRc). Data from Rutgers et al. (2009).

2.7 Relationship between organic matter and biodiversity

The monitoring years 1999-2003 (the first complete round of monitoring data in the NSMN) were investigated in the BISQ database for relationships between organic matter content and soil biodiversity proxies, broken down by land-use and soil-type category. The aim was to discover the effect of a decline in organic matter content in each individual category, if this was possible using the data from the BISQ database. A standard regression analysis was carried out, after which the data was scanned by eye for positive and negative relationships.

The relationships between total organic matter content and soil biodiversity proxies are shown as graphs for the categories arable land and dairy farms on clay (Figure 4) and on sand (Figures 5 and 6). Linear regression is used to decide whether the relationship is positive or negative, or does not exist at all. A rising line in Figures 4, 5 and 6 corresponds to a positive relationship between organic matter content and the biodiversity-related proxy. The vertical axis is shown in reverse for some parameters (for example bacterial biochemical diversity) to keep the graphs uniform and to enable an assessment to be made by scanning the graphs by eye. Limited correlation analysis was carried out to determine the statistical significance of the regression lines, with critical values for the correlation coefficients ($P < 0.05$). Most relationships were not statistically significant, though a few were. No further analysis was conducted due to the exploratory nature of this study, though it is recommended that the significant and insignificant relationships be further investigated.

Twelve regression analyses were carried out, shown in Figures 4 and 5: six for the relationship between organic matter content and the diversity parameters (ODU – operational diversity unit, such as number of taxa, Fisher alpha diversity index and functional diversity) and six for the relationship with abundance per group and/or biomass. Four regression analyses were carried out for bacteria and two for all other organism groups. Each relationship was given a score according to whether it showed a rising line (+1), a falling line (-1) or no relationship (0). In the case of many positive though statistically insignificant relationships, it is nevertheless plausible to assume a positive relationship according to the principle of the weight of evidence; in other words, although each element does not in itself constitute convincing evidence, it does contribute to the complete set of evidence.

Figure 4 shows the results for the categories on clay. A scan of the graphs shows clear relationships with organic matter content, as no negative regressions were found: 11 (out of 12) and 12 (out of 12) respectively show positive relationships. For these categories, it is plausible that there is a positive relationship between organic matter content and soil biodiversity and the density (biomass) of the soil biota. Arable land and dairy farms on clay have very different organic matter contents, though combining them into a single gradient for organic matter shows that all the positive relationships either remain or are reinforced. Following an analysis of all clay soils taken together (ignoring land use), the conclusion remains regarding the positive relationship between organic matter content and soil biodiversity.

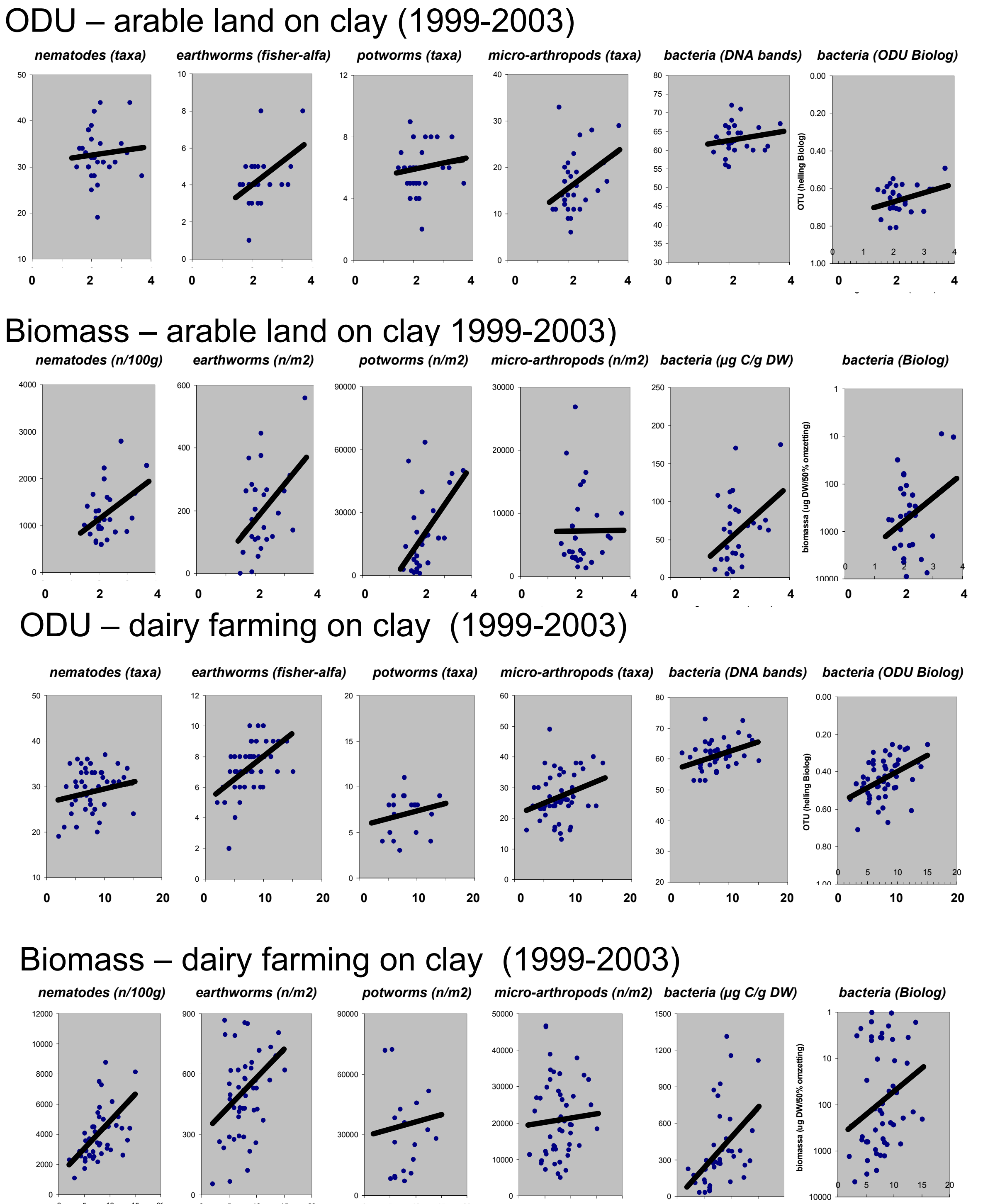

Figure 4. Relationships between total organic matter content and various soil parameters for arable land and dairy farms on clay. The data (points) are taken from the BISQ database, from the 1999-2003 sampling round. Organic matter content (% DM) is shown on the horizontal axis. A parameter to be related to soil biodiversity is shown on the vertical axis (ODU = operational diversity unit, number or biomass). A line that rises to the right indicates a positive correlation between organic matter content and the soil biodiversity proxy concerned. Data for the following groups of organisms are displayed (from left to right): nematodes, earthworms, potworms, micro-arthropods, bacteria (microscope or DNA analysis) and bacteria again (biochemically characterised using Biolog® plates).

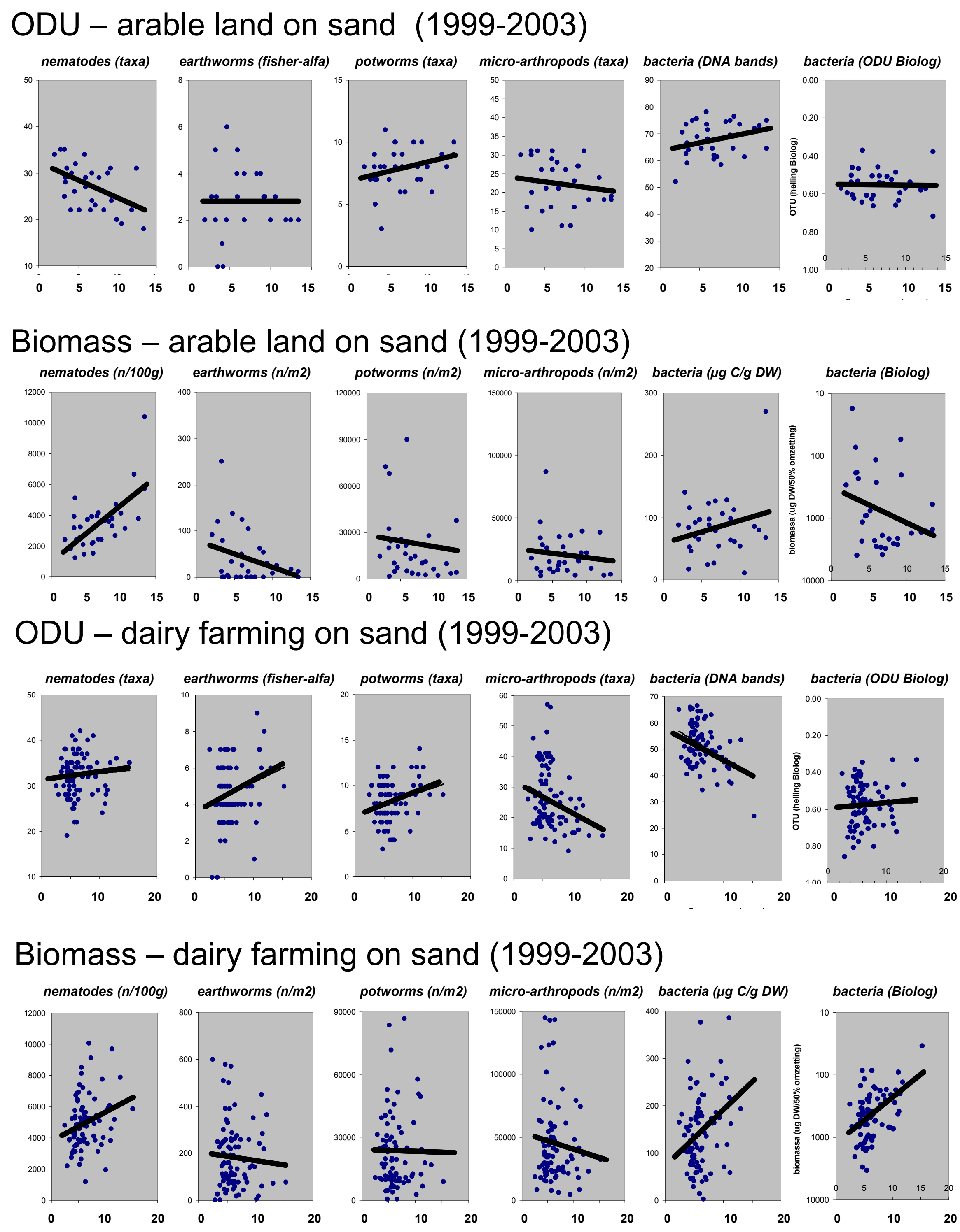

Figure 5. Relationships between total organic matter content and various soil parameters for arable land and dairy farms on sand. The data (points) are taken from the BISQ database, from the 1999-2003 sampling round. Organic matter content (% DM) is shown on the horizontal axis. A parameter to be related to soil biodiversity is shown on the vertical axis (ODU = operational diversity unit, number or biomass). A line that rises to the right indicates a positive correlation between organic matter content and the soil biodiversity proxy concerned. Data for the following groups of organisms are displayed (from left to right): nematodes, earthworms, potworms, micro-arthropods, bacteria (microscope or DNA analysis) and bacteria again (biochemically characterised using Biolog® plates).

Trends for the categories on sandy soil (Figure 5), based on the monitoring data from the 1999 to 2003 sampling round, were less clear. A scan of arable land on sand shows four positive scores, five negative scores and three neutral scores, though most trends were unclear (slightly positive or slightly negative). In other words, it was not possible to show a clear relationship between organic matter content and soil biodiversity. A complicating factor in this category concerns the sampling locations in the former fen settlement area in the northeast of the Netherlands, where the peat layer was excavated in the 18th and 19th centuries. All the farms with a high organic matter content are located in this area. If these farms are excluded from the analysis, too few data remain to be able to draw reliable conclusions. Analysis excluding farms in the former fen settlement area may be possible if horticulture and bulb growing are included, though this has not yet been done.

The relationship for the dairy farms on sand category is not much clearer than that for arable land, though there do seem to be more positive relationships (Figure 5, monitoring data 1999-2003, bottom two rows). Six positive, four negative and two neutral trends bring the score for this scan to +2 (out of a maximum of +12). It is possible that the large variation in data and the lack of clear relationships are partly the result of the scattered distribution of farms in the north (Drenthe, Friesland and Groningen), east (Overijssel and Gelderland) and south (Noord-Brabant) of the Netherlands. An additional set of data is available from the next NSMN monitoring round for the dairy farms on sand category (BISQ database 2005-2008). The analysis was repeated using these data, and mainly positive relationships found between organic matter content and soil biodiversity proxies: 10 out of 12 (Figure 6). An analysis of the geographical variation between categories in the BISQ database has not yet been carried out, partly because many more data are required to do so.

It would seem, based on the scans carried out using two sets of data, that the relationship between organic matter content and soil biodiversity for dairy farms on sand produces varying results. The first data series produces no clear results; the second shows a positive relationship. The reason for these differences must be further investigated. In the case of grassland on sand, the working hypothesis is generally supported as there are, overall, more positive relationships than negative relationships found with organic matter content.

The currently incomplete set of data for arable land on sand was also screened (BISQ database 2006-2008), but gave the same varied picture as the previous analysis in Figure 5: both positive and negative relationships (data not shown here). There therefore seems to be no clear relationship with organic matter content for this category. The previously-mentioned complications due to different soil subtypes (in particular excavated peatland in the former fen settlement area) and the lack of sampling locations are also relevant to the repeated data series and make it difficult to draw a clear conclusion. From this scan of the BISQ database it is possible to conclude that a positive relationship between organic matter content and soil biodiversity is plausible in the case of arable land and dairy farms on clay. Based on this, a decline in organic matter content (the threat) must be expected to result in a decline in soil biodiversity.

There seems to be a clearly positive relationship for dairy farms (pasture grasslands) on sandy soils, but this is less certain and needs to be investigated in more detail. It was not possible to show a relationship with organic matter content on arable land on sand, due to a lack of monitoring data and the less than optimum distribution of arable farms in the NSMN. Many arable farms on sand are situated on excavated peatland in the former fen settlement area, where the soils have an atypical and relatively high organic matter content.

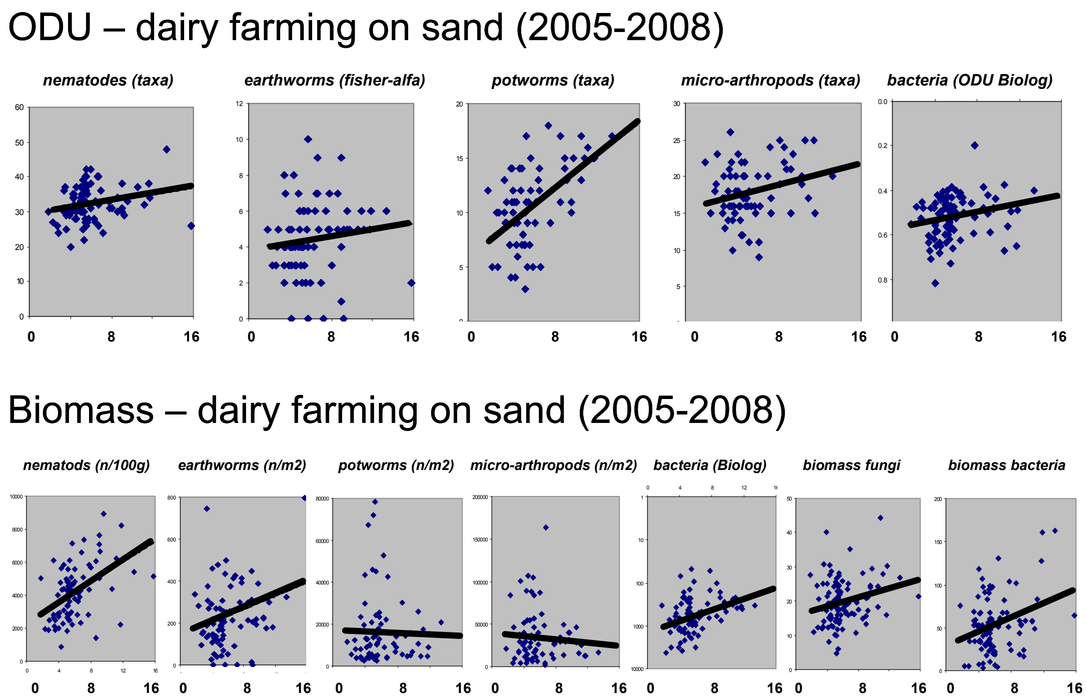

Figure 6. Relationships between total organic matter content and various soil parameters for dairy farms on sand. The data (points) are taken from the 2005-2008 sampling round from the BISQ database. The line represents a standard regression. A line rising to the right corresponds to a positive correlation with organic matter content. Data for the following groups of organisms are displayed (from left to right): nematodes, earthworms, potworms, micro-arthropods and micro-organisms (one or three parameters: bacteria or fungi analysed using a microscope or Biolog® plates).

2.8 Other soil properties: pH and clay particles

It is an accepted fact in soil ecology that a relationship exists between organic matter and soil biota through carbon and energy flows and the food chain. Ecological models are available for the underlying mechanisms. The quantitative scan of the data from the BISQ database in the previous section (section 2.7) is based purely on statistical calculations, without taking into account any lack of causality. It is generally known that, in addition to organic matter content, there are many other soil properties that are important to soil biodiversity. It is theoretically possible that, although organic matter content shows a statistical correlation with soil biodiversity, it has no ecological relationship with it, whilst other soil properties do. If this were the case then, based on the statistical analysis in the previous section, the conclusion that organic matter content and biodiversity are related could not be drawn. Research was carried out to obtain an idea of the occurrence of these ‘confounding’ relationships between soil biodiversity and other soil properties.

A simple correlation analysis was conducted between three properties important to soil biota: organic matter content, clay content and soil pH. The correlations between the three properties were in general fairly weak for the different categories (highest absolute value was 0.51; correlations between pH-H_2O and pH-KCl were not included as these scored very high, as expected). The highest absolute values were found for the category dairy farms on clay: -0.5 (organic matter versus pH-H_2O), 0.49 (organic matter versus clay content) and -0.51 (clay content versus pH-H_2O). The lowest absolute value (-0.28) was found for the correlation of organic matter with pH-KCl for the category dairy farms on sand (clay content not included for sand categories). The correlations between the measured soil properties within the various land-use and soil-type categories were not very high. This was as expected; the gradients for these properties within the categories are not very long, so that noise makes it difficult to discern any correlations. To get an idea of the relationships between biodiversity and the three measured soil properties (organic matter, clay content and pH), an initial multivariate analysis was carried out for the category with the strongest correlations – dairy farms on clay.

The results of this analysis are shown in Figure 7. Principal Components Analysis (PCA) was first carried out (Figure 7A), whereby all variation in the data is explained using mathematically derived variables that show a random association with the explanatory environmental factors. The possible explanatory environmental factors (organic matter content, clay content and pH) are shown as arrows. Almost all variation was explained in the first two axes (72% and 25%, respectively), partly due to the small number of soil biodiversity parameters (nine). Clay content and soil pH lie almost parallel to the first axis and organic matter lies parallel to the second axis. The significance of the variation explained by the three soil properties was determined using a redundancy analysis (RDA) and a Monte Carlo permutation test. Clay content and soil pH both explained a significant proportion of the variation in soil biodiversity: $P = 0.04$ and $P = 0.08$, respectively. A second RDA with permutation test was carried out, this time excluding the micro-arthropod community (both ODU and number), as it is suspected that this community has a strong relationship with clay content and/or soil pH (Figure 7B). In this case, organic matter content and soil pH both explained a significant proportion of the soil biodiversity (without micro-arthropod community): $P = 0.002$ and $P = 0.055$, respectively. In other words, a statistically significant relationship was found between organic matter content and part of the soil biodiversity for the category dairy farms on clay, which is definitely <u>not</u> explained by soil pH or percentage of clay particles. This strengthens the supposition that some of the relationships between organic matter content and soil biodiversity shown in the previous section (Figures 4, 5 and 6) cannot be explained by variations in soil pH or clay content alone.

The observation that there seems to be a good correlation between micro-arthropod community and pH and percentage of clay particles and not between micro-arthropod community and organic matter content for the category dairy farms on clay is interesting, but was not investigated any further. Multivariate analysis is expected to show many more interesting patterns, also for the other soil biodiversity-related soil properties and for other land-use and soil-type categories. In addition, no attention was paid to optimisation of the multivariate analysis by scaling and weighting.

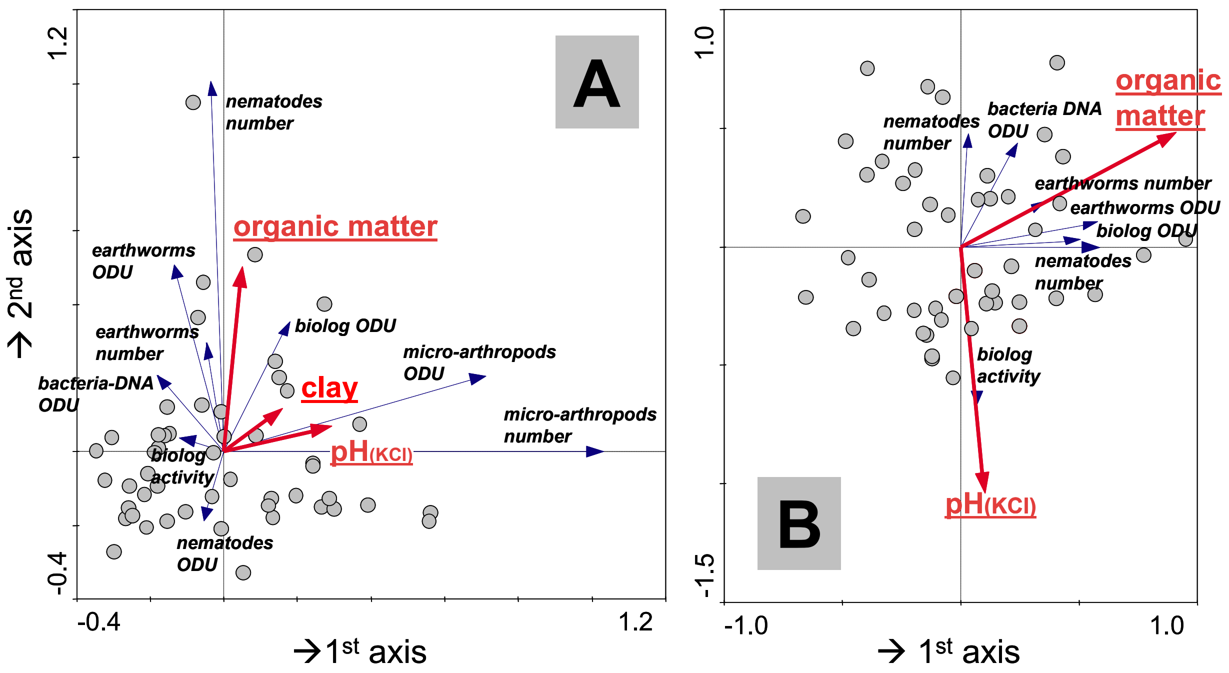

Figure 7. Ordination diagrams of the multivariate analysis of nine proxies for soil biodiversity at 49 farms in the dairy farms on clay category. The symbols represent the sampled farms, based on differences in soil biodiversity. Potentially explanatory soil properties (pH, organic matter content and clay content) are shown as large red arrows. The soil biodiversity proxies are shown in cursive next to the smaller blue arrows.
A: Principal Components Analysis (PCA). The explanatory variation was 72% for the first axis and 25% for the second axis.
B: Redundancy Analysis (RDA) with a Monte Carlo permutation test without the data from the micro-arthropod community. The variation explained by organic matter and pH was 14% for the first axis and 6% for the second axis (P = 0.002 for organic matter and P = 0.055 for pH). The clay content data were not significantly explanatory.

2.9 Conclusion and recommendations for organic matter

The general conclusion that can be drawn from this research is that a decline in organic matter content is related to a decline in soil biodiversity in agricultural soils. Support for this conclusion was provided by two exploratory analyses using the BISQ monitoring data from the NSMN:

1. Organic matter content and soil biodiversity decline in proportion to increasing intensity of soil management in the different land-use categories. The soil biodiversity proxies on sandy soils are relatively low for horticulture, average for arable land and dairy farms and high for semi-natural grassland. Organic matter content and soil biodiversity were also lower for arable land than for dairy farms on clay soils.
2. Within the land-use categories, there was a clear positive relationship between organic matter content and soil biodiversity for both arable land and dairy farms on clay soils. This positive relationship was plausible for dairy farms on sandy soils: most proxies showed a positive

relationship, a few showed no relationship, and very few showed a negative relationship. It was not possible to draw fundamental conclusions using the data in the BISQ database for arable land on sand, due to the lack of and skewed distribution of sampled farms.

3. Other soil properties probably also have an effect on soil biodiversity, but an initial random survey of the dairy farms on clay category showed a statistically significant relationship between organic matter content and soil biodiversity proxies, which was not explained by variations in pH or clay content.

Data from the literature supports a relationship between organic matter and soil biota. Based on our knowledge of the soil system, it is to be expected that organic matter and soil biota are closely related as organic matter is the primary carbon and energy source for most soil organisms. The amount, relative availability and composition of organic matter components have a direct influence on the system complexity and abundance of soil biota.

This research has produced a clear recommendation, which is that the data in the BISQ database should be further investigated for relationships between soil properties and the various soil biodiversity proxies. The initial steps taken here have revealed patterns that justify further analysis, for example the relatively strong relationship between the micro-arthropod community and pH and clay content for the dairy farms on clay category. The provisional conclusions concerning the supposed general relationship between organic matter content and soil biodiversity should also be substantiated by statistical analysis of the BISQ database. The general conclusion described at the beginning of this section is of use in the identification of priority areas: a decline in soil organic matter content threatens soil biodiversity.
No signs are found that this relationship does not exist, even where there is a limited decline in organic matter content. Establishing the relationship between organic matter and soil biodiversity in specific situations, using a location-specific or area-specific monitoring programme, would seem to be achievable with sufficient effort for clay soils in a geographically-defined area. More effort needs to be made to monitor and quantify sandy soils, due to the greater variation in soils and farms, or soil management.

3 Soil compaction and soil biodiversity

3.1 Introduction

The process of soil compaction often takes place naturally over a long timescale. Gravity and the evaporation or drainage of water cause newly-formed or drained land to settle. The weight of subsequently-deposited new layers compresses the deeper-lying layers, causing a change in the subsurface structure and, in time, in the subsurface material itself. This is how sedimentary rock is formed on a geological scale – rock which, due to the movement of the earth's crust, can again be forced upwards to form mountains.

Soil formation (pedogenesis) takes place in a thin layer at the earth's surface on a smaller time and spatial scale, through the erosion of parent rock or changes in the uppermost sedimentary layer. Biological activity and leaching play an important role in the formation of the soil profile, often forming characteristic horizons. Metals that leach from the top layer may be deposited deeper in the soil, where they cement together to form a hard layer. Plant roots break through these layers and earthworms mix the soil up to a depth of several decimetres. Human activity has a large influence on soil formation, through cultivation, levelling, the felling or planting of large forested areas and the maintenance of certain types of ecosystems, such as heathland. Developments in town and country planning, infrastructure, nature and agricultural activities all affect the soil structure considerably, in most cases disturbing the natural soil formation process. Tillage, digging and loosening the soil are old and much-used agricultural practises. On the one hand, this ensures that organic remains are worked into the soil more quickly, oxygen travels further and plant roots can grow more easily through the soil but, on the other hand, tillage means that the organic matter in the soil decomposes more quickly, so that nutrients are made available for plant growth sooner and the soil more quickly depleted.

Agriculture in the Netherlands and the rest of the Western world has intensified during recent decades, with increasingly larger and heavier vehicles used, with wheel loads of up to 12 tons (Van den Akker et al., 2006). This contributes to an acceleration in artificial soil compaction, sometimes up to a depth of a metre. The use of wide low-pressure tyres makes it easier to access the land, but also makes it possible to use larger and heavier vehicles. The pressure that the soil needs to withstand has therefore actually increased rather than decreased. The use of grassland for grazing also results in the land being 'trampled' by cattle. The following list provides a summary of interventions and situations that result in soil compaction, with high wheel loads in particular causing an irreversible compaction of the subsoil.

Soil compaction is caused by (in order of decreasing significance):
- high wheel loads (heavy vehicles or harvesting trolleys)
- wet soil (less resistance)
- soil cultivation (potato harvesting, tillage)
- soil type (light sandy clay does not recover following compaction)
- low OM content (less resistance/elasticity)
- flooding
- compact soil (heavier equipment required for tillage – vicious circle)
- intensive grazing and increase in grassland production.

Deformation of the soil structure can have various undesirable effects. A dense layer develops underneath the cultivated (tillage) zone at a depth of 20 to 35 cm, called the plough pan. Though the name would suggest otherwise, this layer is not caused by the plough, but by the tractor wheels driving through the topsoil when ploughing. Air, water and roots find it difficult to penetrate through the plough pan, and its development therefore has a negative effect on the infiltration capacity, the saturated water permeability, biological and biochemical processes and the ability of the soil to allow good root growth. In addition, oxygen-depleted conditions result in an increase in soil denitrification. Accelerated erosion, the formation of pools and nutrient run-off are other possible side-effects.

Soil compaction is only experienced as a problem if water is unable to drain away and crop yields decline. The prevention and repair of subsoil compaction is an important factor in sustainable agriculture. It is possible to prevent compaction of the topsoil by tillage or harrowing, though this means that the subsoil, which has a relatively poor recovery capability, becomes even denser and can only be loosened using deep tillage, which is costly and a waste of energy. Furthermore, research shows that both the recovery capacity and the effect of tillage quickly decrease with depth. Also, loosened soils may become compact again after just three years and the physical properties of the soil even worse than before (Van den Akker and De Groot, 2008). Various physical and biological processes are able to repair soil compaction naturally. Examples are the effect of frost, cracks in dry soil, soil biota activity (bioturbation and aggregate formation) and deep-rooted crops.

A summary is given of the factors (properties) involved in the identification of priority areas in chapter 3 of Annex 1 of the draft version of the Soil Framework Directive (EC, 2009). In contrast to the now commonly held view that the EU only considers compaction of the subsoil to be important, this chapter refers to 'topsoil and subsoil bulk density' and 'topsoil and subsoil texture'. Due to mechanical cultivation techniques, compaction of the topsoil cannot usually be measured using bulk density, and this therefore seems to be irrelevant. However, the process does take place, certainly in soils that vehicles drive on but that are not ploughed every year. It is possible to determine the structure from the form of the aggregates (angular, crumbly or rounded, or square, flat or elongated; Horn and Peth, 2009). Compaction sometimes results in a deterioration in structure. The soil structure in the topsoil of arable land is seriously disturbed, making the soil susceptible to degradation in general.

Furthermore, the highest concentration of soil biota is found in the topsoil.

Box 4. Table of criteria for the identification of priority areas requiring protection from soil compaction (EC, 2009).

SECTION 3 INDICATIVE ELEMENTS FOR THE IDENTIFICATION OF AREAS REQUIRING SPECIAL PROTECTION FROM COMPACTION
Soil type (Soil Typological Unit (STU) level)
Topsoil (30 cm or plough layer in arable land) and subsoil texture (STU level)
Climate: temperature, precipitation (distribution) and evapotranspiration
Land cover and land cover change (e.g. following Corine Land Cover nomenclature)
Total soil organic carbon (STU level) (can be measured or derived)
Topsoil and subsoil bulk density (STU level) (can be measured or derived)
Topography: slope and land form
Land use, including land management, farming systems and forestry

3.2 Monitoring soil compaction

The problem of soil compaction has not yet been systematically monitored in the Netherlands. However, because physical soil properties may be important factors in the density and diversity of soil biota, specific measurements have been carried out within the framework of the BISQ monitoring programme for several years. Measurements of topsoil bulk density and penetration resistance to a depth of 80 cm have been carried out at about 175 locations from 2004 onwards. The penetration resistance is measured using a penetrologger (Figure 8).

In accordance with the sampling methods used in the BISQ programme, penetration resistance was measured on six plots (or parcels) at various places on each farm. Five measurements were taken within a 10 m radius on each plot, resulting in a total of 30 measurements for each farm. The size of the farms varied greatly, but was 50 ha on average. The penetration resistance data have not yet been input into the BISQ database and have until now mainly been used on an ad hoc basis. The bulk density and pore volume were only measured in the topsoil (5 to 10 cm depth); these measurements therefore give no indication of compaction deeper in the soil. Water infiltration measurements were also carried out at some locations, providing a measure of permeability and soil structure.

Figure 8. Measuring penetration resistance in the field using a penetrologger. A cone (top angle 60°) with a surface area of 1 cm^2 is placed at the end of the rod (about 1 m long). The rod is pushed into the soil with a speed of about 2 cm/s. Speed and depth are measured using a sensor that sends a signal to the reflector plate resting on the soil surface.

The penetration resistance generally shows a clear density profile, though the soil can also show a large degree of heterogeneity, even over a distance of just a few decimetres. Geological origin and former land use are also important. It is therefore not always easy to make a clear distinction between soil types or forms of land use. Soil resistance is also very much influenced by moisture content, as well as density, soil type and structure. For comparison purposes, therefore, measurements should always be taken at field capacity (i.e. maximum saturation). A higher moisture content means a lower soil resistance, so that the cone penetrates the soil more easily. This is not only the case in topsoil following a period of rain, but also in subsoils in the presence of a high water table. No method has yet been developed to transform the complete density profile into one or more indicator values for compaction, though it should be possible to look at the depth and hardness of the plough pan in different soils, and critical thresholds have been defined for a number of soil properties (Van den Akker and De Groot, 2008). The cover provided by monitoring data is currently insufficient for the production of a soil compaction map, although it would be possible to name areas in which soil compaction is highly likely or could be a problem, based on experience and theoretical considerations. Figure 9 illustrate the kind of density profiles that may be found in various soils.

The monitoring data are used to demonstrate soil characteristics and to give examples of soil compaction for the purpose of this report. The data require further processing before they can be used to analyse soil compaction at the various locations, and the data have not yet been related to the measured soil biodiversity.

Penetration Resistance Profile 1 in Figure 9 shows a number of individual measurements in a zero tillage field experiment on loess soil in Limburg, the Netherlands. The soundings generally give the same pattern though, as can be seen in Profile 1, there are considerable differences between measurements (pressure displayed on the x-axis). The average profile of the measurement series shown in Profile 1 is displayed in Profile 2, and the frequency distribution shown for each 10 cm depth. The soil provides little resistance up to a depth of about 12cm, after which resistance increases rapidly up to a maximum at a depth of 22 cm, then gradually decreases again. The plough pan is easily recognisable in this profile, and has a maximum penetration resistance of 4.4 MPa (44 kg/cm^2). As a rule of thumb, 1.5 MPa is the threshold for good root growth, above which roots find it difficult to grow through the soil. The critical root growth threshold for agricultural crops is 3.0 MPa. The effect of excessive soil density is reduced water and nutrient absorption and a decline in crop yield.

Figure 9 shows examples of a sandy soil under arable land (Penetration Resistance Profile 3) and grassland (Profile 4). Again, the profiles represent the average of five measurements taken within a 10 m circle. The plough pan is easily recognisable in the arable land profile, at a depth of about 30 cm. There seems to be slight compaction at a depth of between 10 and 20 cm under grassland (Profile 4). Resistance is low for a large proportion of the soil profile, only increasing much deeper in the subsoil.

Profiles 5 and 6 in Figure 9 show the difference between two neighbouring arable farms in the Hoeksche Waard in the Netherlands. The topsoil in Profile 5 is loose up to a depth of 35 cm; this then becomes a very dense layer, and underneath this again there seems to be another dense clay layer. It is not possible to tell from these measurements whether this deeper compact layer is naturally formed, or whether compaction has taken place in the deep subsoil. Profile 6 shows a very different picture: the plough pan has formed at a relatively shallow depth (20 cm) and the soil shows little resistance up to a depth of 80 cm. The plots of land in which measurements were taken for Profile 6 are situated just behind the Hollands Diep dike. This is probably newly reclaimed land where the water table has influenced the penetration resistance of the subsoil.

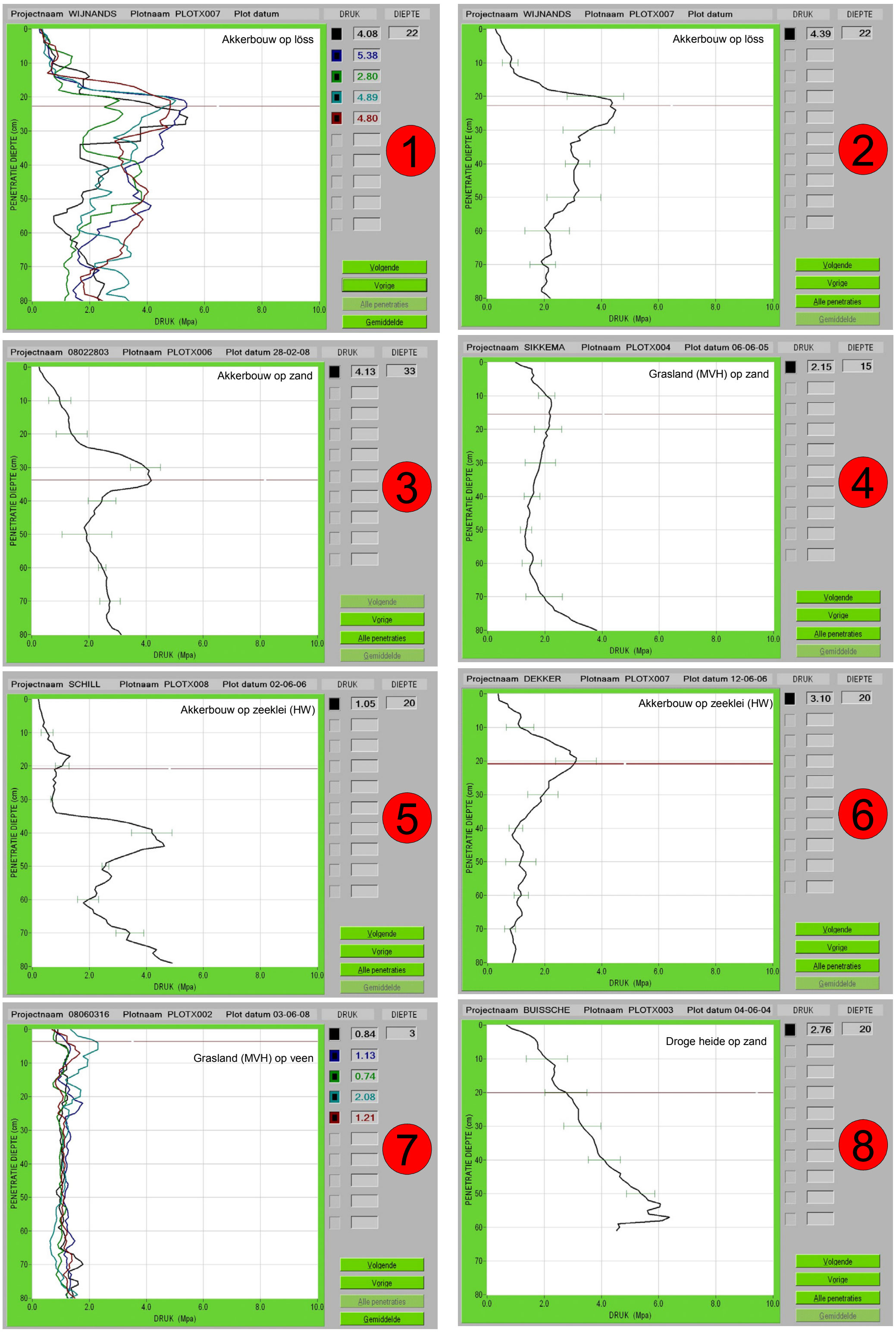

Figure 9. Penetration resistance profiles (1 – 8) for different soils. Depth is shown on the y-axis; measured pressure is displayed in megapascals (MPa) on the x-axis. 1 MPa is equivalent to 10 bars, or 10 kg/cm². The profiles refer to several different soil types and locations and are not generally valid for a particular land-use category. Please refer to the text for further explanation.

Profiles 7 and 8 in Figure 9 are very different. Profile 7 shows the results of measurements in peat soil. Each sounding reveals a small compact layer just below the surface, but the required pressure is slight and very constant at all depths, with just a small variation. The low penetration resistance of this soil is due to its high organic matter content and the moisture content of the soil, and means that this soil has limited bearing capacity. Profile 8 is from a heathland on higher lying sandy soil, which has probably remained undisturbed for a considerable length of time. There are no compact layers in the topsoil though density does increase gradually with depth, to a maximum value of over 62 kg/cm^2. Gravel banks are sometimes found under heathland, making it difficult to obtain a good picture of the density profile. Dry sandy soils also have a high penetration resistance as they lack the 'lubricating' effect of clay particles, organic matter and moisture.

The available data in the BISQ database provide insight into soil profiles and soil compaction for a variety of locations, though the data were not specifically for the indication of areas of soil compaction. Soil compaction generally occurs in any agricultural soil that is driven over and ploughed using heavy equipment, with arable land showing the largest effect of compaction in the form of a clear plough pan. However, dense layers are also found under grassland. It is more difficult to show artificial compaction in the deeper subsoil (below about 40 cm) as this often coincides with geological phenomenon such as iron pans or clay layers. There is also a great amount of variation on differing spatial scales, due to both human activity and nature. It is recommended that suitable instruments and assessment methods be further developed and, preferably, a focused monitoring programme carried out in order to obtain a national overview.

3.3 Susceptible soils according to the EU

The EU project RAMSOIL compares soil threat risk assessment methodologies. The methodologies named are used to combine data on soil properties and field measurements to produce maps of areas susceptible, amongst other things, to subsoil compaction (Van den Akker and Hoogland, 2009). A risk map based on an empirical approach (Jones et al., 2003) predicts that sandy subsoils are susceptible to compaction; clay subsoils are, according to this approach, less susceptible. Van den Akker (2004) came to the same conclusions, though using a more deterministic, soil mechanics approach based on soil strength and wheel loads. However, a map based on subsoil compressive strength (Van den Akker and Hoogland, 2009) shows that sandy soils are in fact the least susceptible to compression, though this does not take shearing strength into account. The shearing strength of sandy subsoils is exceeded if heavy wheel loads are applied, and this property is therefore indicative of the maximum permissible wheel load for the soil.

A susceptibility map has been produced by the EU Joint Research Centre (JRC in Ispra, Italy) for European soils, based on a grid of 1 km^2 (Figure 10). Soil type, texture, water regime and other data were used as input. A large area of the Netherlands, in particular the sandy soils, are designated moderately (yellow) and highly (orange) susceptible to compaction. Only the clay areas in the north of Groningen, in Friesland, the Ijsselmeer polders and Zeeland are designated as having a low susceptibility. Also noteworthy are the presumed artificial differences (sudden changes) at either side of national borders. Another provisional soil compaction map of Europe is included in the 'Soil Atlas of Europe' (EC, 2007).

Measurements from the BISQ programme (see Profiles 2, 5 and 6 in Figure 9) and research carried out by Alterra show that this JRC compaction susceptibility map is too general and not suited to typically Dutch soils. The origin and development history of this map means that it deviates too much from the major soil

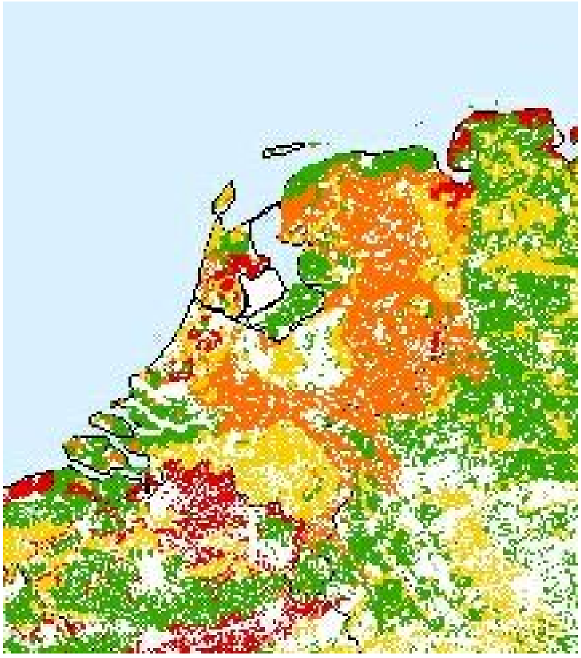

Figure 10. Part of the JRC map of the 'natural susceptibility of soils to compaction'. The colours green, yellow, orange and red represent low, moderate, high and very high susceptibilities to compaction.
Source:
http://eusoils.jrc.ec.europa.eu/library/themes/compaction /Resources/Compaction_300dpi.jpg

categories found in the British Isles and on the European continent, on which the map is based. This is also made apparent in a statistical analysis and prediction of the bulk density of Dutch soils, based on data from the Dutch Soil Information System (BIS, *Bodemkundig Informatie Systeem*). The calculations show that density increases with time in the majority of subsoils. A prediction of density in 2010 is shown in Figure 11, from which it would appear that it is the clay soils that will become much more compact, and the sandy soils less compact. Nevertheless, the prediction is that 25-45% of sandy soils will become excessively compact. A field survey, however, showed a much higher proportion (Van den Akker and De Groot, 2008).

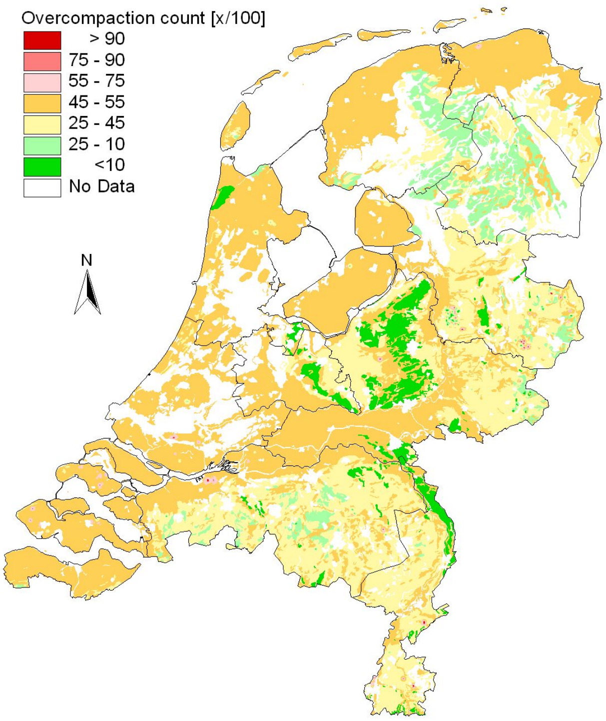

Figure 11. Predicted 'over-compaction' of Dutch subsoils, based on the expected number of times out of 100 samples that excessive bulk density will be measured in 2010 (from: Van den Akker and Hoogland, 2009).

The difference between the prediction and the measurements in sandy soils is in this case probably due to the fact that most of the data in the BIS were collected prior to 1986, at a time before the introduction of heavy mechanised vehicles, including low emission slurry spreading using heavy vehicles in the early, wet spring.

An interview was conducted with J. van den Akker (Alterra, Wageningen) for the purpose of this quick soil scan. He indicated that current agricultural methods mean that, in theory, all arable land is susceptible to soil compaction. As far as relative susceptibility to compaction or its consequences is concerned, the following general classification can be made, based on the recovery capacity of the soil:

- good recovery capacity: clay soils with sufficient organic matter and soils with good drainage (rough sand), or organic and mineral soils with a nutrient-rich top layer (fimic anthrosols; in Dutch, *eerdgronden*);
- moderate recovery capacity: heavy clay;
- poor recovery capacity: light sandy clay (unfavourable combination of properties).

Based on our knowledge of soil science, the combination of properties found in sandy and clay soils in the Netherlands means that it is possible for soils to recover naturally from soil compaction. The light sandy clay soils have the least chance of recovery; they lack as it were the favourable properties of both the sandy and the clay soils, making them the most susceptible to compaction. Sandy soils are permeable to both water and oxygen, and an active soil life is possible in the air-filled pores. Organic matter contributes to the fertility and the elasticity of the soil. Fimic anthrosols contain a deep, homogenous organic-rich layer that supports biological activity at greater depths (over 50 cm).
Clay soils shrink and crack when they are dry, increasing their permeability, and freezing also has a structure-forming effect. Clay soils are capable of absorbing and retaining a lot of water, but they may also close up and become waterlogged if drainage is too slow. Clay soils are probably more susceptible to compaction, and the sandy soils in the Netherlands more compact than was previously thought. Soil compaction in arable land can be limited by using lighter machinery, adapting ploughing to spread the wheel load more evenly and cultivating the land as much as possible using fixed paths, or cultivating it as little as possible. Driving over land in wet conditions must also be avoided. Deep-rooted crops and earthworms are also important to soil structure and smaller organisms help distribute organic matter throughout the soil and assist in aggregate formation. The ultimate result is a loose, crumbly structure, favourable to crop production.

3.4 Relationship between soil biota and soil compaction

Soil compaction can occur in all layers of the soil, from the topsoil, to the plough pan directly under the cultivation layer, to the subsoil. Few data are however available on soil biota in deeper layers (> 20 cm). Based on the assumption that the effects will be comparable, this chapter therefore provides an overview of the effects of soil compaction on soil biota, primarily based on research carried out in the topsoil. The percentage of organic matter is usually low in deeper layers in the soil, though exceptions are the gley soils (in Dutch, *beekeerdgronden*) and fimic anthrosols (in Dutch, *enkeerdgronden*) which, due to the way they have developed, can contain a lot of organic matter deep in the soil. This deep-lying organic matter is predominantly old and very stable, which is why organic matter decline in the subsoil receives little attention in discussions concerning soil compaction.

Soil compaction has a negative effect on soil biota in several ways (e.g. review by Brussaard and Van Faassen, 1994). The soil becomes more compact, so that it is more difficult to grow or dig through the soil. This means that plants need to use more energy to grow roots through the soil and that digging animals, such as worms, need to use more energy to move through the soil which, in turn, means there is less energy left over for other processes. Plants with a smaller root system almost always produce a lower yield, or need more artificial fertiliser and water (irrigation) to produce the same yield. A smaller root system can also endanger the water supply in the soil, especially if the presence of a plough pan combined with a low organic matter content means that the thin soil layer of the root zone quickly dries out. Worms that need to dig through dense soil grow more slowly and therefore also reproduce later, which slows population growth.

Agricultural machinery has the greatest compacting effect on larger pores in the soil (Blair et al., 2006), with the result that it is primarily the larger soil biota that suffer. The situation is more complicated in the case of micro-organisms, for which negative, positive and neutral (no) effects have been found. It is possible that bacteria increase in number when their predators decline in number. In compaction studies in the Wieringermeer in the Netherlands, Bouwman and Arts (2000) found more plant roots as well as more herbivore nematodes in the top layer of a compact soil. However, the numbers of bacterivorous and predatory nematodes had decreased. Micro-organisms may also be better protected against grazing as compaction results in a greater number of small pores. This can result in a higher biomass of micro-organisms with a lower activity, so that mineralisation also declines (Breland and Hansen, 1996). If compaction means that rainwater is no longer able to infiltrate the soil, the soil becomes saturated with water and the result may be oxygen deficiency, in which case some of the soil biota will die and anaerobic bacteria will cause denitrification. This will release nitrogen into the air, partly as nitrous oxide – a strong greenhouse gas. In comparison with organic matter, little is known about the effects of compaction on soil biota.

Pulleman et al. (2003) carried out a comparative study in permanent grassland, organic arable land and conventional arable land on light sandy clay soils in the southwest of the Netherlands. Their conclusion was that the positive effects of organic farming on organic matter content, earthworm activity and soil structure (aggregate stability) are often reversed by soil compaction resulting from tillage of the soil and harvesting, with negative consequences for mineralisation, root growth and the workability of the soil.

A literature overview by Wardle (1995) based on 106 studies in which conventional tillage was compared with no tillage (Figure 12) clearly shows that soil compaction usually harms soil biota. It should however be mentioned that farmers who apply no tillage in a wet climate (such as the Netherlands) will have to deal with the problem of weed control (Peigné et al., 2007).

Kladivco (2001) converted various data from the literature into a dimensionless effect measure on a scale of -1 to +1. An effect size value V = -1 means that tillage has a 100% negative measured effect; a value V = 1 means that the measured effect of tillage is in fact very positive. Figure 12 shows the percentage of studies (usually based on a number less than 106 as not every effect is investigated in every study) in which a particular effect on the soil biota was found. The darker the shading, the greater the decline due to conventional tillage compared with no tillage. It can be seen that the negative effects (the black bars and the two darkest forms of shading) are dominant amongst the microbiological parameters and most mesofauna and macrofauna groups. Potworms (enchytraeids) and nematodes seem to be less sensitive, as a negative effect was found in a maximum of 50% of the studies for these groups. This literature review also shows that effects can greatly differ, even within a single group of soil organisms, making it difficult to make a general estimate of susceptibility. The effects are partly dependent on location-specific circumstances

A summary of the direct and indirect effects of soil compaction on soil biota (Table 3) has been produced, based on a literature review. This focuses on the direct and indirect consequences of soil interventions and the ultimate effects on soil biota. Soils that contain more organic matter are generally better able to cope with compression, as the aggregates in these soils are more stable and more pressure is required to reduce the number of air-filled pores (Soane, 1990).

Severe soil compaction shows similarities to soil sealing, as the soil becomes almost impermeable to water and biological activity. A sealed soil is practically incapable of providing ecosystem services such as soil fertility and climate regulation (MEA, 2005; TCB, 2009). It is therefore expected that, in the case of severe compaction, the soil will also no longer be able to provide ecosystem services. In the case of moderate compaction, the soil will still be able to provide ecosystem services, though no longer at an optimum level.

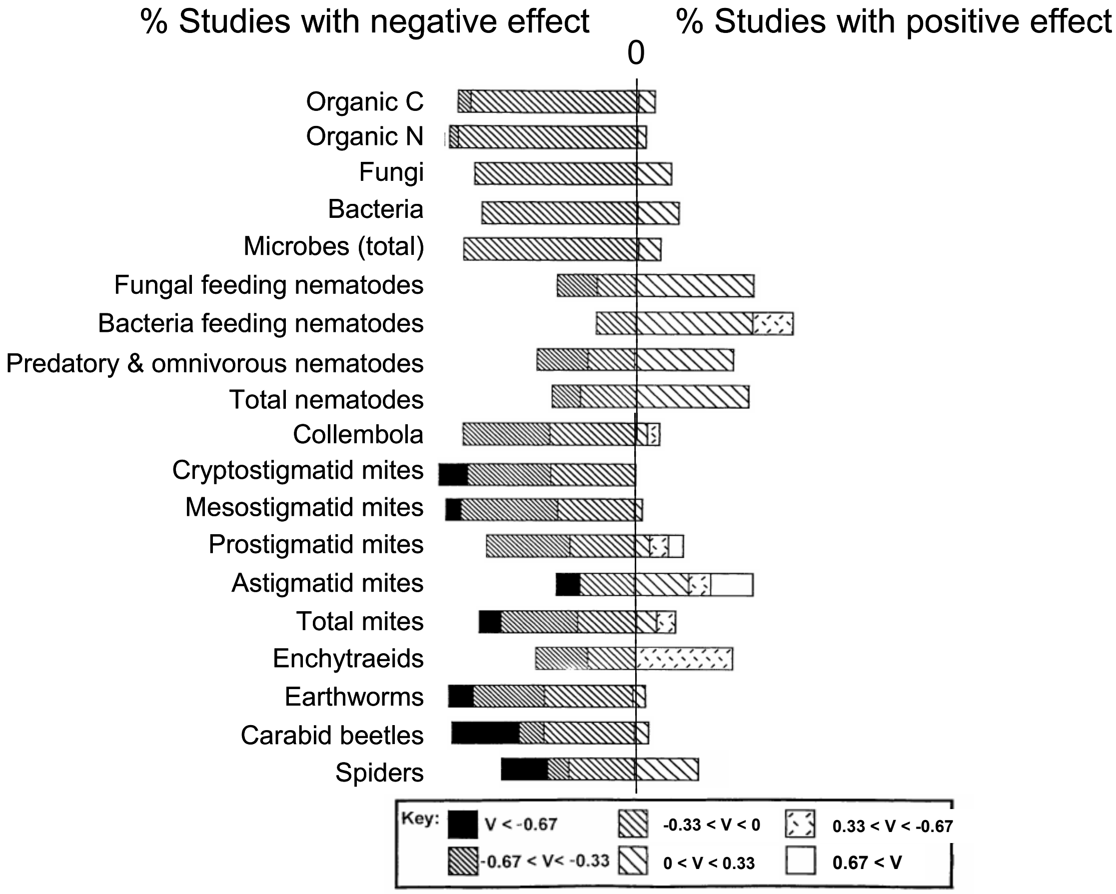

Figure 12. An overview of the effects of tillage on soil biota in the literature, expressed as the percentage of studies with positive and negative effects. The diagram is an adapted version of calculations made by Kladivko (2001), from a literature review by Wardle (1995) of 106 studies into the effect of tillage on the soil. The diagram is based on a comparison of no tillage with conventional tillage. Changes found in soil biota groups are expressed as an effect size V (percentage difference) which may be either positive or negative. The shading shows six effect classes: the darker the shading, the greater the decline in V as a result of soil compaction. The graduation within each horizontal bar represents the ratio of the number of studies in each effect class.

rivm

Table 3. The influence of soil compaction on soil biota in relation to the direct and indirect effects of compaction. This assessment is based on a compilation of data from the literature.

Causes	Indirect effects	Effect on soil biota
compaction (through disturbance of aggregates and compression) (effect clearly less the drier the soil; Dexter, 1997; Watts et al., 1996)	smaller pores, less habitable pore space for large organisms	decline in large species, including predatory mites (Vreeken-Buijs et al., 1998) and mites, springtails, spiders, worms and ground beetles (Kladivko, 2001; Wardle, 1995)
		if pore size becomes smaller than spore cases these fungi may disappear (Visser, 1985; Anderson et al., 1984)
		increase in bacteria
	reduction O_2 and CO_2 diffusion	general: slower growth
	poor drainage	less habitable pore space
		anaerobic conditions
	higher mechanical resistance	root system undersized, nutrient uptake closer to the plant (Bouwman and Arts, 2000)
		reduced root growth (Whalley et al., 1995) and lower crop yield (Bouwman and Arts, 2000)
		less worms (Radford et al., 2001), worms grow and dig more slowly (Klok et al., 2007)
		less food and pores (Ball et al., 1988)
	decline in crop yield, relatively greater decline where little fertilisation (Bouwman and Arts, 2000, Chamen et al., 1992)	increase in plant parasitic nematodes, decline in bacteria-feeders, fungal feeders and predators (Bouwman and Arts, 2000)
OM content decline due to oxidation following disturbance		lower numbers and fewer species of soil biota (all groups)
		fewer nematodes and bacteria, more earthworms, potworms and micro-arthropods (BISQ)
digging through soil profile (tillage, e.g. rotary)	conventional tillage: subsoil more nutrient-rich, topsoil less nutrient-rich	fewer animals in topsoil, more in subsoil (Miura et al., 2008)

Causes	Indirect effects	Effect on soil biota
	decline in successional phase	dominance of early successional species, general species, r-strategists (BISQ; Osler and Murphy, 2005)
	mechanical compaction	pressure kills organisms (also occurs if OM content remains constant)
local high pressure		direct mortality
disintegrated aggregates	aggregates washed away	less habitable pore space
		reduced aeration
plough pan formation	poor subsoil drainage	mortality due to flooding and possible anaerobic conditions. Sensitivity of species varies (Plum, 2005)
		denitrification
irreversible compaction of sand in subsoil	subsoil compaction	indirect effects through risk of flooding, more roots in topsoil
		reduced deep root growth, plants more sensitive to desiccation if water supply in topsoil exhausted

3.5 Conclusion and recommendations for soil compaction

The general conclusion that can be drawn from this research is that, in agricultural soils, soil compaction probably results in a decline in soil biodiversity. This conclusion is supported by a consideration of various data from the literature. Soil compaction data are not yet available from the NSMN and it was therefore not possible to apply this general conclusion to the various soil types and land use forms found in the Netherlands. However, despite the lack of quantitative data, it is assumed that soil compaction forms a real threat in the Netherlands. Based on the general conclusion, soil biodiversity should probably be taken into account in the identification of priority areas for soil compaction, despite the lack of reliable data. It is therefore recommended that a robust indicator for soil compaction be developed and applied to monitor the situation in the Netherlands. When monitoring soil compaction, attention should also be paid to the expected decline in soil biodiversity, for example in the BISQ monitoring programme.

4 Relationships between soil threats and ecosystem services

The data in the BISQ database represent measured biological soil parameters only and are not directly linked to ecosystem services (TCB, 2003; Rutgers et al., 2005, 2009). Ecosystem services can be thought of as the intentional or unintentional benefits provided by a properly functioning and healthy soil, benefits that are advantageous to many land users, on various time and spatial scales and include:

1. production function: the soil's capacity to supply products, such as crops, cattle, garden plants, natural areas and landscapes;
2. the soil’s robustness and flexibility: the soil’s capacity to cope with and recover from stress and to permit other forms of land use;
3. environmental functions: a healthy soil is an important condition for a healthy climate and pleasant surroundings due to its contribution to local and global cycles (C, N, P, H_2O, et cetera), its buffering capacity (temperature, water and the composition of air, water and soil compartments) and its ability to break down toxic and other substances and to produce stable organic carbon.

The set of ecosystem services can be ordered in various ways (Faber et al., 2009; MEA, 2005; EC, 2006), of which that outlined above is just one (Rutgers et al., 2005). What is important is that the definitions of the ecosystem services in question are clearly defined in a process that involves all the relevant land users, before attempting to quantify and assess the services themselves (Boyd and Banzhaf, 2007; Rutgers et al., 2007).

It is generally assumed that most ecosystem services show a positive correlation with soil biodiversity. It is therefore expected that a decline in organic matter content or an increase in soil compaction will also have a direct effect on ecosystem services. No multi-criteria, quantitative evaluation of the relationships between soil threat and ecosystem service performance were carried out for this project. Instead, seven researchers were asked to make a best professional judgment (BPJ) of the relationship between the soil biodiversity proxies, including ecosystem service performance, and organic matter content decline and soil compaction, by choosing one of the four curves shown in Figure 1. One of three scores could be given: 3 (sensitive, curve A in Figure 1), 2 (moderately sensitive; curves C and D) or 1 (insensitive, curve B). The aim of the exercise was to develop, given the limitations of this project, a ‘sense of scale’ of ecosystem service performance, also in relation to soil biodiversity

Table 4 shows BPJ results for the relationships between the soil threats, loss of soil biodiversity and ecosystem service performance. The average value for the various soil biodiversity proxies and ecosystem service performance varied between 2.0 and 2.3. Significant is that, according to the researchers, ecosystem service performance has a similar sensitivity to threats as the soil biodiversity proxies, which supports the hypothesis that the performance of most ecosystem services is directly related to soil biodiversity. It was also interesting to note that the researchers often gave the same answers when estimating the sensitivity of groups of organisms, but different answers when estimating the effect on soil ecosystem services, in particular those services that represents the soil’s robustness, buffer functions and reactor functions. This was not unexpected: the concept of ecosystem services is new and not necessarily assimilated in current research practice. Though ecosystem services are recognisable to land users, it is not possible to place them directly in a quantitative, sustainable soil management framework. Nevertheless, ecosystem services must be introduced into this field of research as they are an essential part of an assessment framework for decision-making with respect to the development and management of our living environment (Apitz, 2008; Chapman, 2008; Daily et al., 2009).

Other patterns are also recognisable in the summary of BPJs in Table 4. Micro-organism diversity is estimated to be less sensitive to soil threats than soil fauna diversity: the biomass of these organisms is expected to decrease less slowly in response to soil compaction than to a decline in organic matter content, whilst the opposite is in fact the case for soil fauna. These effects are also discussed in chapters 3 and 4 and agree with current opinions found in the academic literature. The ecosystem services assessed seem to be more sensitive to a decline in organic matter content (average score 2.3) than to soil compaction (average score 2.1), though the difference is slight. That the ecosystem service ‘soil structure’ was unanimously considered very sensitive to both soil compaction and a decline in organic matter was predictable, as these threats are directly linked to soil structure.

The conclusion may therefore be drawn from this exercise that there is a high level of agreement amongst the researchers consulted in their assessment of the relative effect of the two soil threats on soil biodiversity. The implication is therefore that the trends reported in the literature also permit a general conclusion to be drawn concerning the relationship between the two soil threats and loss in soil biodiversity, despite the fact that some proxies for soil biodiversity seem to increase in specific cases. The sensitivity of certain soil biodiversity proxies to, for example, a decline in organic matter content, does not indicate the suitability of the relevant indicators for quantifying the effect of soil threats (Doran and Zeiss, 2000). It is wrong to automatically nominate the most sensitive proxy as the ideal candidate when selecting an indicator. For example, though micro-organisms seem to react on average less sensitively to soil compaction, they are in fact often used as an indicator due to their suitability for application in a wide range of settings, cost considerations, reproducibility, sensitivity and the speed with which analyses can be carried out (Winding et al., 2005). Total soil biota abundance is often determined by microbial biomass for over 90%; microbial indicators are therefore an essential part of monitoring (Ritz et al., 2009).

Table 4. Estimates (BPJs) of the sensitivity of various soil biodiversity proxies and the performance of various ecosystem services in response to soil compaction or a decline in organic matter content. Seven researchers[1] were presented with a questionnaire (see Appendix 1) and asked to make an assessment based on the relationships given in Figure 1. A sensitive relationship (curve A in Figure 1) received a score of 3; an insensitive relationship (curve B) a score of 1 and an intermediate sensitivity a score of 2 (curves C and D). The background colours used for the average score indicate the variation in answers: white – little variation in scores, light grey or yellow – average variation in scores, dark grey or orange – large variation in scores.

	OM decline	compaction
soil biodiversity		
ODU nematodes	2.6	2.0
ODU earthworms	2.1	2.7
ODU enchytraeids	2.1	2.3
ODU micro-arthropods	2.4	2.9
ODU bacterial DNA	1.1	1.0
ODU bacterial functions	1.1	1.0
biomass nematodes	1.9	2.0
biomass earthworms	2.4	3.0
biomass enchytraeids	2.1	2.3
biomass micro-arthropods	2.0	2.9
biomass bacteria	1.7	1.1
biomass fungi	1.7	1.6
average (soil biodiversity)	2.0	2.1
ecosystem services		
nutrient retention and release	2.1	1.6
soil structure	3.0	3.0
natural suppression of disease	1.6	1.6
resistance and resilience	2.3	1.9
flexibility of land use	2.1	2.3
OM degradation and retention	2.6	2.1
natural attenuation	1.7	2.0
water absorption, retention and release	2.6	3.0
climate functions	2.6	1.9
average (ecosystem services)	2.3	2.1
average (all)	2.1	2.1

[1] Four researchers from outside the Netherlands took part in the project: Dr Jörg Römbke (ECT Oekotoxikologie GmbH), Prof. Bryan Griffiths (TEAGASC, Johnstown, Ireland), Prof. David Spurgeon (CEH, Lancaster, UK) and Prof. Ryszard Laskowski (Jagiellonian University, Kraków, Poland). The other three researchers are also contributing authors to this report: Dr Jaap Bloem, Dr Gerard Jagers op Akkerhuis and Dr Michiel Rutgers.

5 Towards a framework for the identification of priority areas

The results of the quick scan described in this report (monitoring data, literature review and best professional judgments) show that it is likely that there is a loss of soil biodiversity resulting from the soil threats investigated (soil compaction and decline in organic matter content). This loss of soil biodiversity is an extra justification for the identification of priority areas requiring protection from these threats. It is not expected *a priori* that situations will occur in which soil biodiversity does not decline as a result of these soil threats. It is however not possible to provide a good quantitative estimate of the loss of soil biodiversity resulting from the various soil threats, first of all because the soil threats themselves have not yet been properly quantified. It therefore follows that it is also not possible to properly quantify the decline in ecosystem service performance, though a preliminary comparison has been made between the two threats and ecosystem service performance (chapter 4). For now, it is reasonable to assume that soil biodiversity and ecosystem service performance both decline as a result of soil compaction or organic matter content decline.

It is not yet clear how the identification of priority areas will be implemented within the framework of the SFD, or which methods and arguments will be used (Eckelmann et al., 2006; Smit et al., 2007; Van den Akker and Hoogland, 2009). Two approaches are possible:

1. To consider the sensitivity, or the potential sensitivity, of the soil to the relevant threat. Soil properties provide insight into the sensitivity of the soil to certain threats: for example, sandy clay soils are believed to be the most sensitive to soil compaction and sandy soils the most sensitive to a decline in organic matter content (this report). By considering the sensitivity of the soil, it is relatively simple to define geographical areas and to assess these, based on the effect of the threat concerned.
2. To consider the effect of land management (land use and/or land-use management) on the development of a threat. Whether or not the soil is actually affected depends, in the Netherlands, to a large extent on the type and intensity of land management. A number of soil threats are defined based on the fact that they are caused by human activity through land management and that specific policies need to be developed to address this. One consequence of this approach is that additional soil policies may be unnecessary for extensively managed soils (often used as nature reserves), so that it is not necessary to identify priority areas for these soils (one exception could be forested areas used for wood production). The need to develop specific policies and to identify priority areas is partly due to factors such as overly intensive tillage, the excessive use of additives (manure, fertilisers and pesticides) and the use of too much and too heavy machinery. However, unlike soil properties, land use management intensity is not necessarily restricted to a specific geographical area, but to the management practise of individual soil managers on various time and spatial scales, and is therefore much more difficult to map. Sustainably-managed agricultural areas would not be subject to extra legislation if priority areas were identified based on soil management aspects and the conclusion, therefore, is that good agricultural practise needs to be better defined.

The discussion regarding the preferred method for the identification of priority areas continues. From a practical point of view, both approaches are valid as both soil properties and land management influence the assessment of the severity of a threat at a particular location or in a particular area. Smit et al. (2007) applied a procedure of elimination to produce a hierarchy in the criteria, by first considering the specific susceptibility of the soil to the threat (e.g. organic matter decline) and then the expected effect of management practise on the development of the threat. The danger here is that no priority area can be identified for a relatively insensitive but overexploited soil, and a relatively sustainably managed but sensitive soil is identified as a priority area. To prevent such an imbalance, it is suggested that both criteria should receive equal attention in the identification of priority areas. This can be done effectively using a parallel assessment method (Figure 13). If one of the assessment paths shows that there is a strong indication of a threat at a particular location or in a particular area, the decision can be taken to start a procedure for the identification of a priority area. If both assessment paths show a moderate indication of a threat at a particular location or in a particular area, then again the decision can be taken to start a procedure for the identification of a priority area. In other words, integration of the assessment paths means that the assessment of one path can modify or reinforce the assessment of the other.

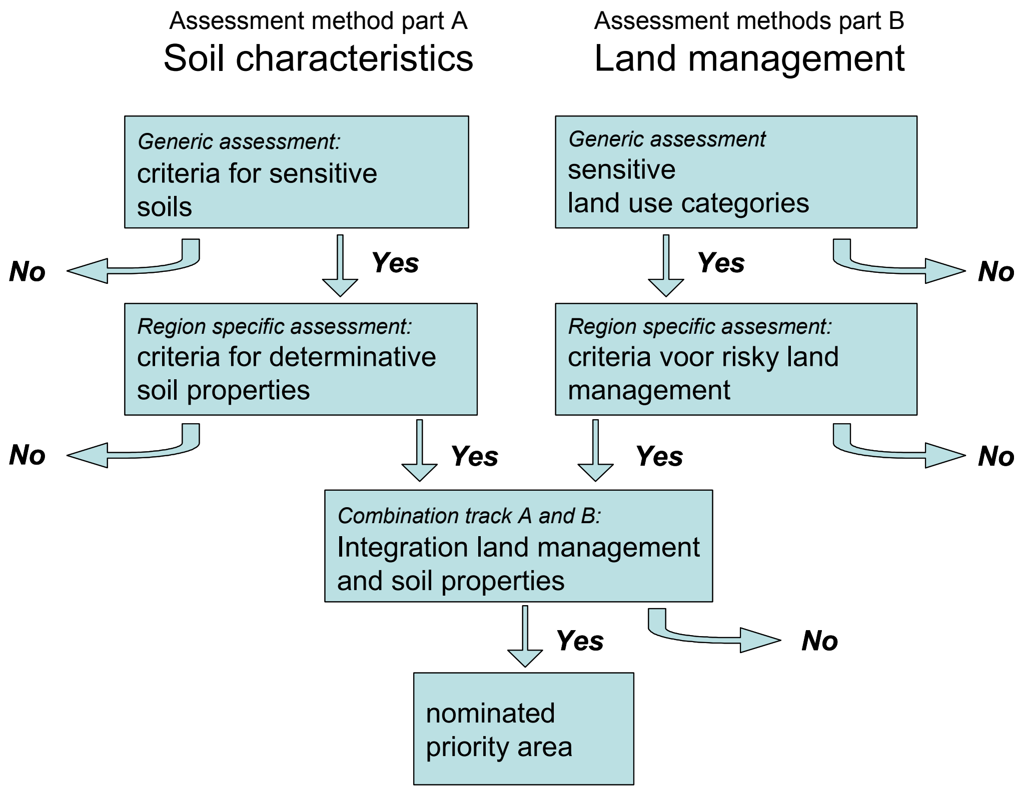

Figure 13. A double assessment method that allows both soil properties and soil management to be taken equally into account when assessing the relevance of a soil threat. This is a modification of the procedure of elimination from Smit et al. (2007) for the threat 'decline of organic matter content'. A distinction is made in the first two steps between a generic assessment (standard assessment for all soils in the Netherlands) and an area-specific or location-specific assessment. It is not possible at this stage of development to determine whether both steps are in fact necessary.

6 SWOT analysis of the quick scan

The results of a strengths and weaknesses analysis are presented in this chapter. The term SWOT analysis comprises the four elements Strengths, Weaknesses, Opportunities and Threats.

Strengths
Data in the Biological Indicator for Soil Quality (BISQ) database were first subject to a preliminary analysis of relationships between organic matter content and soil biodiversity. The analysis provided a clear result: an overall relationship exists between soil organic matter content and a series of simple indicators for soil biodiversity (proxies: operational diversity units and abundance or biomass of various groups of soil biota). The following general conclusion was drawn: a decline in soil organic matter content causes a loss of soil biodiversity. This relationship was also supported by the literature research and best professional judgments (BPJs). The BISQ database analysis is particularly effective as it provides a relatively general picture of certain land-use and soil-type categories (in this case dairy farms and arable land on sand or clay) in the Netherlands. This complements published research that, as it is often carried out in the laboratory and on experimental plots or under specific field conditions, is less easy to generalise. Although no quantitative soil compaction data is available in the BISQ database, it is plausible, based on the literature, specific research and BPJs, that soil compaction results in a loss of soil biodiversity.

The up-to-date knowledge applied in this report supports the hypothesised relationships between soil biodiversity and soil compaction and/or soil organic matter content decline, through the collation and integration of different types of information to form a single final conclusion.

BPJs enable the loss of soil biodiversity resulting from specific soil threats to be assessed based on soil system function, in terms of ecosystem service performance. Ecosystem services form an essential link in the evidence base for anthropogenic influence on the surroundings and in the support for environmental policies.

This report describes the results of a quick scan and not of a scientific research project. This facilitates the transfer of knowledge to the soil management and soil policy arenas, as the terminology and reporting method are more in keeping with such areas (for example with SFD terminology). The concept of soil biodiversity adopted in this report (a combination of the variety and abundance of soil biota) is in keeping with that applied in the SFD, but not with the scientific view of soil biodiversity. From a scientific point of view, soil biodiversity is still insufficiently specifically defined, and this is not expected to change in the near future. This particularly applies to fungi and soil bacteria and to processes (functional diversity).

Weaknesses
This report contributes to the policy development process. It does not present the results from new scientific research, but a combination of an exploratory analysis of the BISQ data, a literature review and BPJs. The BISQ monitoring programme was not carried out specifically for this study and the data are therefore not optimally suited for use in such an analysis. This has two consequences: i) the results from the quick scan have not been controlled through the normal academic channels (for example by independent peer review), and ii) the soil biodiversity and organic matter content measures applied have not been evaluated in a scientific context, but involve approaches which may still be subject to

much discussion. Nevertheless, this approach can also be seen as one of the strengths of this project (see Strengths, above).

Only seven people assessed the effects of threats on ecosystem services using BPJs and there is therefore scope for differences in interpretation and for the further development of the concept.

The relationship between organic matter content and soil biodiversity was investigated using total organic matter content monitoring data from the BISQ database. These measurements provide no information on the relationship between the stable and unstable organic matter fractions; an essential distinction, even for a simple analysis and assessment of the soil system. Organic matter is a complex and dynamic entity, containing different elements with dynamics that vary over different timescales.

Neither of the two terms applied in the SFD (organic matter content decline and loss of soil biodiversity) are yet in general use or firmly established in scientific research. This means that here too there is scope for differences in interpretation and further development.

Opportunities
Though named as a threat in the EU Soil Strategy, no general approach is defined for loss of soil biodiversity in the SFD (as is the case for soil sealing and soil pollution), nor is it addressed in the identification of priority areas (for instance as is the case for organic matter decline). Much still needs to be done to substantiate the loss of soil biodiversity as a relevant threat. Including soil biodiversity with the other soil threats will give a better idea of the gaps in our knowledge. It will also increase our understanding of the significance of soil biodiversity as a crucial link in soil ecosystem function, which is threatened by anthropogenic influences. This will make it possible to estimate the value of soil biodiversity as an important and essential part of the soil system. It will also make it possible to substantiate other areas of soil policy development (soil biodiversity proxies and the ecosystem services concept).

Threats
Discussions concerning soil quality are often characterised by semantic questions and differences in attitude concerning the significance of soil to society. The problems are due to a lack of clear definitions, the wide range of interests and the uneven distribution of costs and benefits in soil management and land use (the management costs and user benefits often rest with different parties). Ecosystem services have a communicative function and form a link between research and soil management and policy practise. If any one of the parties involved fails to adopt the concept of ecosystem services, knowledge transfer cannot take place and soil policy is not further developed. Signals from the field and from policymakers that ecosystem services are too abstract, and signals from academia that the measurement and definition of ecosystem services are overly complex, must therefore be taken seriously.

Varying terminology is applied relating to ecosystem services in the relevant documentation, for example in the SFD, the recommendations of the Technical Committee on Soil Protection and the Millennium Ecosystem Assessment.

Deliberations on the SFD are not yet complete within the political arena of the EU; the first serious opportunity for this will be when Spain holds the presidency of the EU in the first half of 2010, as Sweden has indicated that it has no interest in the implementation of the SFD. The final wording of the SFD is not yet known, and important changes could still be made. Further postponement will delay the development of instruments that could be used to assess soils, with the risk that developments in individual Member States will no longer keep pace with European Soil Policy. It is however clear that the assignment of priority areas will receive attention once the SFD comes into force.

The SFD does not define specific, operational and measurable soil threats in detail; there is scope for differences in interpretation. This applies to most threats, including organic matter decline, soil compaction and loss of soil biodiversity. There is a clear difference in interpretation as far as the definition of soil compaction is concerned: although the SFD explicitly mentions the top soil layer, the EU project RAMSOIL only defines soil compaction for the subsoil (the layer below the plough pan, deeper than about 30 cm).

It is not yet clear which method will be used to identify priority areas within the framework of the SFD. It is generally assumed that Member States will have a large degree of freedom in the identification of priority areas and that there will be little control imposed by the SFD. Various approaches can be used to identify priority areas: soil properties may be used as criteria, or soil management may be a determining factor. Soil properties are geographically determined so that it is relatively simple to identify an area requiring protection. However, this approach ignores the sometimes very local differences in soil management that may aggravate a threat. It is this aspect that is brought up by the Member States that until now have voted against implementation of the SFD (EC, 2007).

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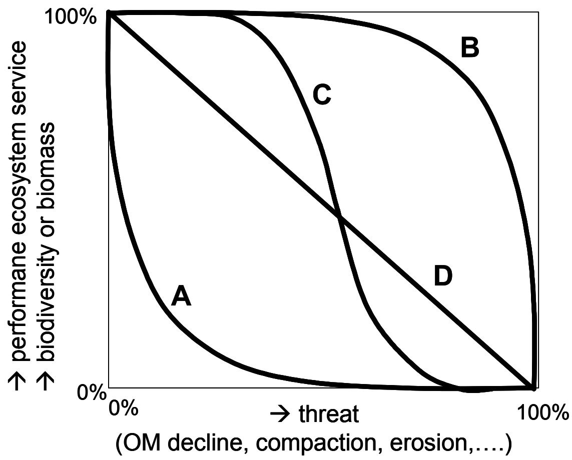
Appendix 1

Dear Expert,

Would you be so kind to contribute to our project entitled ‘priority areas in the SFD and the aspect of soil biodiversity’ by filling in this scoring form? In the project we aim to contribute to the possibility for addressing soil biodiversity decline in the priority areas of the SFD, specifically soil organic matter decline and soil compaction.

The general thought is that we have a lack of data on soil biodiversity and soil threats, despite some data collection in the Netherlands Soil Monitoring Network and in other countries. On the other hand there is a strong expert vision on the decline of soil biodiversity related to soil organic matter decline and soil compaction (also for the other threats like erosion, salinisation, et cetera). The objective is to collect some views on this issue from experts outside the Netherlands.

Our null-hypothesis is: there is a negative correlation between a soil threat and soil biodiversity, particularly organic matter decline and soil compaction. This null-hypothesis is schematically drawn in the figure. We ask you to think about the three (or four?) different possibilities which fit to the null-hypothesis, for any aspect of soil biodiversity (i.e. taxonomic diversity and biomass/abundances of different soil dwelling organisms, or the performance of ecosystem services). The choices are: sensitive (curve A in the figure), intermediate (curves C and D) or insensitive (curve B).



I did this exercise myself. The outcome is given below for illustration. On the other side of this from, you can fill in your opinions. The results will help us to provide a stronger argumentation for including biodiversity decline as a useful aspect in the labeling of priority areas in the regime of the SFD.

Of course, we will provide you with the results of this questionnaire and with the final report (expected for September 2009).

Thanks for your time. I’m available during SETAC for clarifying things and other questions. Afterwards you can mail me. Please return filled in questionnaires to me.

Best regards

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Sensitivity:
higher number relates to higher sensitivity towards soil threat
1 curve B **insensitive**
2 curve C D **intermediate**
3 curve A **sensitive**

	Decline OM	Compaction
Biodiversity organisms		
nematodes	3	2
earthworms	2	3
enchythraeids	2	2
micro-arthropods	3	3
bacterial DNA	1	1
bacterial catabolic diversity	1	1
Biomass (abundance) organisms		
nematodes	2	2
earthworms	2	3
enchythraeids	2	2
micro-arthropods	2	3
bacteria	2	1
fungi	2	2
Ecosystem Services (production)		
nutrient retention and release	2	1
soil structure	3	3
natural disease suppressiveness	2	2
Ecosystem Services (robustness)		
resistance and resilience	3	2
flexibility land use	2	2
Ecosystem Services (environment)		
OM fragmentation, mineralisation and stora	3	2
natural attenuation	2	3
water retention and transport	3	3
climate functions	3	2
Total score	47	45

Name soil biodiversity expert: ……………………………………………………………………

Sensitivity:
higher number relates to higher sensitivity towards soil threat

1	**curve B**	**insensitive**
2	**curve C D**	**intermediate**
3	**curve A**	**sensitive**

	Decline OM	**Compaction**
Biodiversity organisms		
nematodes		
earthworms		
enchythraeids		
micro-arthropods		
bacterial DNA		
bacterial catabolic diversity		
Biomass (abundance) organisms		
nematodes		
earthworms		
enchythraeids		
micro-arthropods		
bacteria		
fungi		
Ecosystem Services (production)		
nutrient retention and release		
soil structure		
natural disease suppressiveness		
Ecosystem Services (robustness)		
resistance and resilience		
flexibility land use		
Ecosystem Services (environment)		
OM fragmentation, mineralisation and storage		
natural attenuation		
water retention and transport		
climate functions		

Total score

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