I International Conference
SOIL AND COMPOST ECO-BIOLOGY
September 15th – 17th 2004, León - Spain

SOIL BIODIVERSITY: MEASUREMENTS, INDICATORS, THREATS AND SOIL FUNCTIONS

Anton M. Breure

RIVM, National Institute for Public Health and the Environment

Laboratory for Ecological Risk Assessment

P.O. box 1, NL 3720 BA Bilthoven, The Netherlands, E-mail ton.breure@rivm.nl

Introduction

A proper soil functioning now and in the future is a key life support function. There is a growing interest in the assessment of the present and to predict the future quality and performance of soils that are or may be influenced by human activities. Keywords in this respect are 'sustainable development' (World Commission on Environment and Development 1987) and 'sustainable use of biodiversity' (UNCED 1992). This can also be found back in the European legislation and policy aims. A general European soil policy is to be launched because of its nature as a non-renewable resource, and of its functions that have to be used in a sustainable way. Ecological functions and soil biodiversity are important because of their role in: structure formation, stability of structure and functions, fertility, buffering and in providing possibilities to have the soil acting as a carbon sink (important in the UNFCCC = United Nations Framework Convention on Climate Change). Within the framework of preparation of this European soil policy a taskgroup produced a report on the importance of soil biodiversity (EC 2004), which has extensively been used for the preparation of this paper.

Governmental concern is growing how to attain a sustainable use of soils, e.g. its agricultural use. There is increasing consensus, that protection of the biodiversity in the soil is a major way to maintain the proper functioning of the soil. In agro-ecosystems ecological functioning of the soil can be seen as a production support function of biodiversity, next to e.g. pollination and natural pest control.

Soil organisms are major components of all soils. Often their biomass is low compared with the mineral or humus fraction, but the organism activity is absolutely crucial for a functioning soil. The soil biota can be regarded as the "biological engine of the earth" and is implicated in most of the key functions soil provides in terms of ecosystem services, by driving many fundamental nutrient cycling processes, soil structural dynamics, degradation of pollutants, and regulation of plant communities. Microbially driven soil processes play key roles in mediating global climate change, by acting as C sources and sinks and by generation of greenhouse gases such as nitrogen oxides and methane.

What is biodiversity

In the Convention on Biological Diversity (CBD) Biodiversity is defined as: "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

Biological diversity is a function of several components:

- The total number of species present, species richness;
- The genetic diversity within species;
- The diversity of ecosystems (agriculture, nature areas);
- The distribution of individuals among those species (evenness).

Functional diversity (as an additional biodiversity descriptor) describes the biological role of species or groups of species in an ecosystem. It is a description of the different ecological processes, performed by single organisms, populations, and communities.

E.g. if we are interested in the function "nitrogen fixation from the air", we are not only interested in species diversity and abundance, but also in the actual and maximal capacity of the ecosystem performing that function.

In this sense, Biodiversity *sensu lato* may be regarded as the ecological capital in the soil.

What is soil biodiversity

Soil biodiversity refers to all organisms living in the soil. Depending on the size class organisms may be divided into macro, meso and microfauna. Beyond that, bacteria, fungi, protozoa and algae are grouped as microorganisms. Regarding the preferred living environment, aboveground (e.g. foraging on top of the ground, or inside the litter/fine woody debris layer) and belowground specialists can be distinguished.

Soil is one of the most diverse habitats on earth and contains the most diverse assemblages of living organisms. Biological activity in soils is largely concentrated in the topsoil. The biological components occupy a tiny fraction (<0.5%) of the total soil volume and make less than 10% of the total soil organic matter. This living component consists of plant roots and soil organisms. Soil microorganisms are responsible for a large part of biological activity (60-80%) which is associated with processes regulating nutrient cycles and decomposition of organic residues.

Earthworms often form a major part of the soil fauna biomass and can represent up to 50% of the soil fauna biomass in some temperate grasslands, and up to 60% in some temperate forests. High levels of biodiversity, particularly at the microbial scale accompany the huge numbers of soil organisms. 10^4 bacterial species g^{-1} soil is not an extreme number. Next to this, hundreds of other species are present.

The organisms interact in the soil in food webs, resulting in a flux of matter, nutrients and energy through the biological component of the soil.

Human practices that threaten soil biodiversity

Soil management strongly influences soil biodiversity, e.g. in agricultural ecosystems. Different practices cause shifts in habitat quality and in substrate availability, resulting in changes in abundance of individual species.

A question is, which management practices threaten the functioning of soil ecosystems. Many processes carried out by soil organisms persist in native ecosystems as well as in intensively cultivated soil. There is only a limited insight to what extent these changes in management intensities are accompanied by changes in spectrum of soil microorganisms responsible for the processes involved.

The most important factors affecting the soil biodiversity comprise:

- Habitat fragmentation;
- Resource availability (amount and quality of nutrients and energy sources);
- Temporal heterogeneity (seasonal effects);
- Spatial heterogeneity (spatial differences in the soil);
- Climate variability;
- Interactions within the biotic community;

Reduction in biological diversity of soil macrofauna is one of the most profound ecological consequence of modern agriculture, as an example, the number of earthworm species is largely decreased in agricultural soils.

The biodiversity of the soil organisms lead to the control (natural biological suppression) of plant root diseases. The management practices used in many agro-ecosystems (e.g. monocultures, extensive use of tillage, chemical inputs) degrade the fragile web of community interactions between pests and their natural enemies and lead to increased pest and disease problems.

Decline in soil biodiversity is expected to affect soil turnover, decrease natural soil aggregation, increase crusting, reduce infiltration rates, and thus exacerbate soil erosion.

The main driving forces that influence biodiversity in agricultural soils are:

- *Intensification of land-use.* The introduction of agriculture and its expansion have changed the diversity of habitats, and thus the number of species occurring in the environment at the landscape scale. The increasing intensity of land use on the other hand has destroyed habitat and thus has substantially decreased biodiversity. E.g. a consequence of agricultural practices is the loss of trees and surface litter and consequently of the groups of macrofauna dependant on trees and surface litter (e.g. termites, ants, soil-dwelling insect larvae). Increased use of

heavy machines in agriculture leads to soil compaction, and thus to degradation of habitat for soil organisms.

- *Influences of crops*. Systems that increase belowground inputs of C and N through inclusion of legumes or fibrous rooted crops in rotations may increase microbial populations and activities in comparison to application of commercial fertilisers. The chemical composition of crop residues may have a significant effect on the structure of decomposer communities. E.g., the application of animal manure leads generally to increased abundance and activity of a specific part of the soil biota.

- *Influences of plants.* Plants have an impact on soil microbial communities through C flow and competition for nutrients. It has been shown that there are distinct differences in bacterial community structure between the bulk, non-rhizosphere and rhizosphere soil. Numbers of bacteria in the rhizosphere are greater than numbers in non-rhizosphere soil. Bacterial activities are stimulated in this area because of the nutrients provided by roots. The variability in chemical composition of root exudates may also influences the composition of soil microbial communities. Also, crop rotation is a key component, which influences the composition of the soil microbial community. The fact that crop rotation can change aggressiveness of pathogens approves changes in soil biodiversity and function because of management.

- *Influence of fertilisers and pH*. Application of fertilisers and the soil pH both influence the structure of the soil biota. Low pH favours fungi over bacteria, and high nitrogen concentrations result in increased bacterial concentrations. pH influences on soil fauna are also clear. E.g. a low pH in the soil leads to a decrease in abundance of earthworms.

- *Influence of tillage crop residues*. Periodic tillage reverts soil to an earlier stage of ecosystem succession. Physical disturbance caused by tillage is a crucial factor in determining soil species diversity in the agro-ecosystem. Tillage causes the loss of stratified soil microhabitat, which results in a decreased abundance of species that inhabit such agro-ecosystems. Tillage aerates the soil and therewith causes rapid mineralisation of organic matter and an often-substantial loss of nutrients. Activity and diversity of soil microbial communities are influenced by distribution of crop residues. Soil tillage can indirectly impact physical processes in soils through changes in the diversity and activity of soil communities. Reduced tillage with surface placement of residues creates relatively stable environments, which results in more diverse decomposer communities and slower nutrient turnover. No-till system favours fungi over bacteria, as decomposition of plant residues occurs on top of the soil.

- *Pesticides application*. Pesticides have both targeted and non-targeted effects that may cause a shift in the composition of the soil biota. When organisms are suppressed others can proliferate in the vacant ecological niches. The effect of pesticides strongly depends on soil physical and chemical properties, which affect their availability.

- *Influence of pollution on soil biodiversity and functioning (ecotoxicological studies).* Pollutants in general influence the organisms living in the soil. Exposure of organisms to sub-lethal doses of stress (e.g. a pollutant chemical) over a long time period results in different effects:

- Initially these interactions may occur at the level of biochemical and cellular processes and lead to physiological effects;

- Subsequently the structure of the DNA in organisms may be affected in the organism, leading to modification and eventual evolution of organisms;

- Consequently such patterns of evolution of resistance or tolerance to the stress factors also occurs in entire communities (e.g. shifts in the composition of plant communities in the vicinity of polluted sites, which might result in the evolution of plant species that accumulate metals).

In soils contaminated by heavy metals the ratio of the resistant and sensitive bacteria increases in the contaminated soil, and the metal-resistant bacteria are much less effective in the decomposition of a number of organic pollutants than the trace elements sensitive bacteria.

Interference of different soil stresses complicates the assessment of effects of single stresses and pollutants.

Role and functions of soil organisms

Soil organisms interact in a soil food web, where each trophic layer is food for the next trophic layer. In general a soil food web is based on the degradation of roots and dead organic material (detritus). The stability of the performance of an ecological function is dependent on the stability of the soil food web. It can be said, that the soil food web stability increases with an increasing number of interactions between the organisms. When predators have an increasing choice in their food, the chance that they will predate on a specific species until its extinction decreases. This is an important interest of biodiversity of soil organisms.

Different classes of soil organisms have a different function. In this paragraph a short overview is given of the functions of different groups of soil organisms.

The role of macrofauna includes:

- Direct processing of organic matter (e.g. snails, earthworms, enchytraeids, millipedes, ants, and termites). Earthworms can improve the incorporation of organic matter below the soil surface, increase the numbers of water stable soil aggregates, improve water infiltration, aeration and root penetration and increase microbial activity;

- Predation (e.g. spiders, ants);

- Creation of soil structure (e.g. earthworms, termites);

The micro- and mesofauna (protozoa, nematodes, collembola, and mites) are important regulators of the bacterial and fungal activities. They predate on these organisms (and on each other) and are involved in the decomposition of organic matter. Soil nematodes occupy an important position in the soil detritus food web and are thus significant regulators of decomposition and nutrient mineralisation.

Soil particles may be moved into various positions by earthworms, roots, wet-dry and freeze-thaw cycles and other forces thus forming soil structure. Production of faeces by mesofauna, fungal hyphae and polysaccharides of microbial origin play an important role in soil.

Soil microorganisms perform a wide range of functions: they decompose organic matter, release nutrients into plant-available forms and degrade toxic residues, they also form symbiotic associations with plant roots, act as antagonists to pathogens, influence the weathering and solubilisation of minerals and contribute to soil structure and aggregation. The time-table of microbial metabolism is meaningful for human interference with turnover rates in soil typically being 0.2-6 years for the soil microbial biomass compared to > 40 years for the bulk of organic matter. The majority of vascular plants is associated with arbuscular mycchorizal or ectomycchorizal fungi and benefits from an increased capacity to extract phosphorus and other nutrients from the soil. Mycchorizal fungi thus have an important role in plant community development, nutrient cycling and the maintenance of soil structure.

One of the most essential soil functions controlled by soil biota is the recycling of organic matter. Soil organic matter (SOM) is a direct product of the combined biological activity of plants, microorganisms and animals plus the myriad of abiotic factors. It is responsible for crucial aspects of soil function such as aeration and fertility. Production of SOM, including extracellular polysaccharides and other cellular debris, increases the capacity of the soil to maintain structure once it is formed. This means directly, that exogenous organic matter such as compost and sewage sludge is very different from soil organic matter and only after processing by soil organisms may contribute to its content. Such wastes contain high concentrations of organisms. These organisms interfere with the local soil organisms and may cause shifts in soil communities. The survival of such "exogenous" organisms is not always clear. Many will not survive in soil and on the long run will contribute to its organic content. However, some may survive and these may be unwanted organisms, e.g. pathogenic fungi.

Determination of soil biodiversity

Species diversity

Soil biodiversity comprises many different types of organisms: bacteria, fungi, protozoa, nematodes, enchytraeids, earthworms, mites, springtails, etc. Many techniques exist to characterise the microbial community. Also for the higher organisms there are several well-described techniques. All these techniques are widely applied, especially in the field of microbiological research, with modifications and recent new method developments. Using them in a harmonised and comparative way requires method comparisons and standardisation. However the most substantial research gap currently relates to the lack of knowledge regarding the link between species abundance and diversity parameters and soil functioning.

Soil biological activity

The functional role of soil biodiversity is difficult to quantify directly. Due to the high variation in environmental conditions in the soil in space and time (daily and seasonal courses, water content, temperature, vegetation), the actual activity is highly variable and not easy to measure in comparable ways between different (national or local) inventory systems and research projects. First solutions can be found in the determination of soil respiration, potential nitrogen or carbon mineralisation. However, based on ecological insights there is also the possibility to assess fluxes of material and energy by the use of ecosystem models and food web models, filled with monitoring data.

Organic matter decomposition, nutrient mineralisation etc. are processes driven by the organisms, and when organism activity is restricted (e.g. by water-logging) the processes slow

down and organic matter accumulates. Even under such conditions, the composition of the decomposer community and its activity is optimised in relation to nutrient take-up by vegetation and sustainable storage needs for nutrients (e.g. in naturally N-limited forest ecosystems).

Models also become more and more important, s indicated above. However, they require data of the abundance and diversity of organisms, such data are scarce and urgently needed.

Major problems with regard to the set up of a soil biological monitoring programme are:

- sampling frequency;
- spatial set up;
- selection of the type of monitoring sites;
- selection of sampling techniques;
- statistical techniques to interpret the monitoring data;

All these frame conditions of course initially depend on the monitoring objectives and targets.

Indicators for soil biodiversity in monitoring programmes

In the preceding paragraph some major problems on the set up of monitoring programmes are given. However, when a set up has been achieved, the monitoring data need interpretation. Therefor a framework is needed to evaluate the data, based on soil quality and health standards. Therewith problems in production areas may be identified, to make realistic estimates of sustainable food production, to monitor changes in environmental quality in relation with management and to assist government agencies in formulating and evaluating sustainable agriculture ant other land-use policies.

A huge number of methods to investigate soil organisms activity, biomass, biodiversity, toxic effects or bioaccumulation exists, but for reasons of cost efficiency, inventory quality, and inventory “repeatability”, often only a few of them can be selected as indicator parameters. In many cases the selection of indicator or flagship species helps to come to an efficient operational system.

In general, a broad range of desired properties related to indicators has to be distinguished:

- use for diagnostic purposes (identifying the potential causes of particular dysfunction),
- use for general screening purposes (overall assessments of soil health),
- use for risk assessment (to evaluate potential losses, which may not yet have surfaced, as a result of particular types of stresses impacting the environment).
- There are specific needs for soil biodiversity indicators depending on the interests involved e.g.:

- national / international (OECD, UN-CBD, national governments policy needs, state of the environment reports);

- research (research knowledge on soil biodiversity, process studies, impact studies);

- public/farmer's needs for enhancing production, best practices, protection of the environment, part of countries' heritage.

The choice of organisms to sample within a monitoring system should:

- correlate well with ecosystem processes (reflect the structure and/or function of ecological processes in soils);

- respond to changes in soil health;

- integrate soil physical, chemical and biological properties and processes and serve as basic inputs needed for estimation of soil properties or functions which can not be measured directly;

- have a short response time.

They should be:

- based on available technologies;

- easy to use under field conditions and be assessable by both specialists and producers, (at least it is desirable that samples can be taken by a non-scientist at a reasonable cost), especially if there is a large number of samples;

- sensitive enough to reflect the influence of management and climate on long-term changes in soil quality but not be so sensitive as to be influenced by short-term weather patterns and robust enough not to give false alarms;

- components of existing soil data bases where possible (availability of references);

- low cost approaches, especially if there is a large number of samples;

- meaningful, resonant and easy to understand;

- generally applicable to all soil types and geographic locations (accuracy and precision);

- relevant to the ecosystem(s) under study and to the objectives of any assessment programme.

Such measurements must be robust and not subject to rapid (and unstable) rates of change, related to the basic methodological problem that soil biodiversity is highly dynamical. In soil monitoring, at least at a large spatial scale with low measurement intensities, measures are needed, which are indicative of a permanent or semi-permanent state.

Biological evaluation systems for soil quality assessment currently designed in different countries such as Germany, The Netherlands, Italy, France, Switzerland and the United Kingdom. (e.g. OECD 2004). It must be clear, that monitoring data *an sich* not be evaluated

without an evaluation framework in which standards and references are described, and that can be used to value data.

Monitoring activities in different countries

Studying soil biodiversity is based on the interpretation and combined evaluation of various parameters, some of them which can be incorporated in monitoring. Until now, all monitoring systems must be regarded as national systems. National monitoring programmes have been established in various countries (see also OECD 2004). None of the systems have mandatory parameters related to soil faunal or microbiological activity.

Hereunder a short description is given of monitoring systems in different countries:

Netherlands: bacterial biomass, bacterial growth rate, bacterial functional diversity, bacterial genetic diversity, potential C and N mineralisation, abundance and diversity of nematodes, mites, enchytraeids and earthworms,

Switzerland: earthworms, microbial biomass (CFE), respiration and N mineralisation,

The Czech Republic: C, N microbial biomass, basal respiration, respiration curves, anaerobic N ammonification, nitrification,

United Kingdom: microbial biomass (CFE), respiration and microbial diversity (CLPP, PLFA)

New Zealand: microbial biomass (CFE), respiration and N mineralisation.

In France two monitoring systems are under development:

A monitoring concept was developed to determine the effects of application of sewage sludges to forest soils: microbial biomass, respiration, specific respiration, N mineralisation, nitrification, microbial activity, phenotypic diversity and genotypic diversity;

There is also the process of setting up a national monitoring programme on a grid of 16 x 16 km where abiotic and biotic parameters of soil are monitored, including microorganisms and meso- and macro-fauna.

In Germany there are different soil monitoring systems, for agricultural as well as forest soils (EC 2004).

It appears that microbial biomass; respiration and potential N mineralisation are commonly regarded as part of a minimum data set to describe the microbial part of the soil organisms. The main functional groups of the soil food web should be added in order to be able to describe biodiversity, and to relate the structure of the soil community to functions. In most countries a relatively small amount of variables is monitored, usually at a relative large number of sites (up to 500 in New Zealand). In some other countries, in contrast, a large number of methods and variables are used at a limited number (e.g. USA with 21 long term ecological research sites). A sophisticated synthesis of both approaches may lead to a general picture of the quality of soil biodiversity on a broader scale.

Organisms with indicator function for soil monitoring

Soil ecosystems are complex and cannot be monitored meaningfully with only a few simple tools, or with only a few *a priori* selected indicator-organisms supposed to be the most sensitive ones. Many different aspects need to be measured and it is important to use a set of various indicating variables. Some indicating organisms or processes are more sensitive to contamination (e.g. bacterial growth rate); others are more sensitive to differences in soil fertility and agriculture management (e.g. N mineralisation).

The complexity of soil biodiversity implies that time and money are major impediments for thorough monitoring. Many techniques are available, but intensive monitoring is expensive.

Two measurement intensity levels may be distinguished for monitoring purposes:

Level 1 for the observation of general trends of soil quality and the mapping and statistical treatments at a national or regional level. These sites may be placed in a grid, e.g. 16 x 16 km, as has been chosen in France, or in the ICP Forests soil condition monitoring.

Level 2, containing sites that are selected on a thematic basis (e.g. pesticides effects on soils, atmospheric deposits, sewage sludge spreading, tillage and residue management). Such monitoring may be on fewer locations and be more heavily instrumented than Level 1. This level allows for the understanding of processes, causes and impacts. These sites are also valuable experimental objects that are needed for the development, calibration and validation of new methodologies and monitoring procedures.

The two levels must be complementary: a grid of level 1 sites, combined with large-scale maps (e.g. soils, climate, land use), would allow the upscaling and regional evaluation of what has been measured and observed at a more intensive (and expensive) level 2 network. In such a system both levels must be established for long-term monitoring purposes.

Biological indicators which have to be measured at Level 1 sites, must be developed and observed in a representative manner for all dominant soil types, climatic conditions (pedo-climatic fitness) and land uses. The system must be cost-efficient and not too dense (because of the large number of sites, which could make it economically impossible).

A general proposal for soil biodiversity monitoring

The highest amount of the soil ecological capital is in the form of microbial biomass (bacteria and fungi). The absolute and the relative amount of these organisms give a good indication of the activity and stability of the ecosystem. Both can be determined in one measurement, e.g. by automised spectroscopy.

When the monitoring activity will be on a large scale, it is possible to do these measurements very well standardised and automised with standardised microscope and computer equipment. (e.g. confocal laser scanning microscopy).

Furthermore two groups of eukariotic organisms are very indicative for the status of the soil:

Nematodes: They are present in high numbers, have a high species diversity and the relative and absolute amounts give good information of the diversity and stability of the ecosystem.

The organisms are easy to handle and there are many companies who have the possibility to do the taxonomic work routinely.

At the moment there are different groups who are developing genetic tools to identify nematode species. That will also give information of the genetic diversity mentioned in the biodiversity treaty, and it helps to simplify the taxonomic work.

Earthworms: They may be present in high numbers, are not very diverse, so easily characterised, and also easy to count. They are very appealing to:

Farmers, who know that earthworms are important for the structure of the soil and who have the (essentially good) idea that more is better, so that they can see by their own hands and eyes whether management practices have a positive or negative impact on the soil;

Nature conservationists, earthworms are the main food source for many aboveground living animals (birds, badger, etc);

Ecotoxicologists: Earthworms are good organisms to determine whether or not pollutants are present in a form that the organisms living in the soil experience their negative impact;

Organic matter suppliers: Earthworms play important roles in the degradation and transport of organic matter in the soil.

The above does not mean that other groups of organisms are not good indicating organisms for soil quality: Enchytraeids, springtails, mites, flagellates, are also important, and perhaps in specific areas better indicator organisms.

The first types of information that must be obtained are status and trends. The type of data obtained with the measurements indicated above will be sufficient to derive such information.

When the information of the monitoring data is translated in an indicator value, the managerial and political value increases very much when the indicator value can be compared with standards. That means, that standards have to be derived from the initial monitoring programme and ecological know how. A second aspect is that the managerial value of an indicator increases, when it is possible to influence it. That means, that it is clear what has to be done, once the indicator value is at an undesired level, or e.g. the land use is to be changed. The above-mentioned organisms all have potential for such opportunities.

Abiotic and other parameters to be monitored

In the framework of large-scale monitoring, in combination with ecological monitoring the main focus is to be steered towards parameters connected to the specific living and feeding conditions of indicator species. These are mainly morphological and soil chemical characteristics that are often already part of soil mapping/monitoring. These parameters comprise pH, water content, organic matter content, bulk density of the soil, type of soil (e.g. sand peat, clay) degree of pollution with heavy metals and organic pollutants, but also type of management (agriculture, application of manure and/or fertiliser, nature, recreation area etc) and vegetation (crop rotation). It is important that the monitoring of biotic and other parameters takes place at the same location and at the same time. For interpretation of the

monitoring data it is also important to register the exact date and place of the monitoring, to be able to interpret the data in relation with local climate conditions.

Mapping soil biodiversity in the Netherlands

In the Netherlands the ecological soil quality is being assessed on a national scale. We achieved a biological indicator for soil quality (BISQ), based on belowground food web interactions and ecological processes. Within this project, we monitored the biodiversity of soil organisms (microorganisms, microfauna and mesofauna) on more than 200 sites and correlate the monitoring data with the abiotic conditions and the management on each site.

The following processes were selected as a basis for the monitoring activities:

- Fragmentation and degradation of organic material,
- Recycling of nutrients,
- Soil structure evolution (bioturbation and aggregate formation),
- Availability of nutrients for plants,
- Stability of the belowground ecosystem.

The indicative variables are potential rates of several processes, and biodiversity within and abundance of functional groups.

Monitoring data as such do not have indicative power. The aim of the soil quality indicator is to produce an integrated view of the ecological status of the soil relative to the (desired) optimal situation, with respect to a series of specific life support functions of the soil. Therefore it is necessary to deduce references or goals. So far, political or managerial goals have not been chosen, other than the claim that soil has to be used in a sustainable way. In general, pollution or disturbances force the selection of a very few resistant species. In such situations the ecological basis for belowground processes may become very narrow. When even resistant species disappear – or become inhibited – as a result of future and as yet unknown human activities, the related process stops and the life support function remains permanently affected. Hence, we based the indicator system for life support functions of the soil on the following hypothesis: *The threat to vital soil processes can be expressed by comparing the number of species in functional groups in a certain area with its reference (undisturbed locations).* Due to redundancy of species, a process may continue to exist with fewer species (in the case where other species of the same functional group disappear). However, it is obvious that the risk of instability and uncontrolled fluctuations will increase.

The monitoring activities are performed within the framework of the Dutch soil quality network (DSQN), a national monitoring network, originally designed to obtain national information on abiotic soil status and trends. The biotic variables measured were abundance and diversity of nematodes, earthworms, enchytraeids, and micro-arthropods, nitrifying activity, microbial functions, genetic diversity, total activity and numbers of bacterial cells).

The DSQN data on chemical soil composition were used to relate the occurrence of organisms to abiotic conditions and land-use. All biotic and abiotic data are collected in a database.

At the moment we are in the process of deriving statistical relationships between the diversity and abundance of soil organisms and the type of soil and its use. Using these relationships, reference compositions of sustainably used soil may be derived, that are to be used in a soil policy aiming at sustainable use of soil and soil processes.

In our study the resulting data are presented in the form of a centripetal diagram of all indicator values scaled against a historical, undisturbed or desired situation (Figure 1). Field indicator values could then be uniformly scaled against indicator values measured at the reference sites. The indexed indicator values can be further aggregated into an SQI using the average factorial deviation of the biological indicator reference value. This index is calculated as:

$$SQI = 10^{\log r - \frac{\sum_{i=1}^{n} |\log r - \log S_i|}{n}}$$

where r is the value of an indicator on the reference site, S is the value of the indicator at the site under investigation; i is the number of indicators measured on the site. (r and S expressed as percent). In this SQI, a value of 50 % has the same weight as one of 200 % of the reference value (both a factor of 2). For our reference, SQI equals 100 % and each deviation from that value reflects a decrease of SQI (i.e. too many species is also regarded as negative effect).

From the results so far it is clear that there is a negative correlation between aboveground farming intensity and the belowground functional diversity of soil organisms. The decreases in abundance and biomass of microorganisms, microfauna and mesofauna indicate a decrease in sustainability of soil use, resulting in a negative effect on the soil buffer capacity (a phenomenon that will consequently affect other ecosystem processes) and top-down effects of management (Mulder *et al.*, 2003).

Concluding remarks

Soil biodiversity can be identified as a major component of soil. Soil organisms a crucial for many processes taking place in that environmental compartment. A sustainable use of soil is therefore necessary and that is being accepted also in the European policy in its Soil Thematic Strategy. Therefore, by protection of soil biodiversity the functioning of the soil may be secured.

Another aspect of soil biodiversity is its application as indicator for soil quality and the sustainable use of soil. As biodiversity is important for soil functioning and as living organisms are reliable indicators of environmental quality, providing the best reflection of the actual fitness of their habitat and ecological changes therein, diversity, abundance and activity of soil organisms may indicate the degree of sustainability of soil management.

Therefore in many countries monitoring systems are being established. Although much research is still needed, the recognition of the importance of soil biodiversity has taken place and the direction of the developments in protection of biodiversity and its application of soil monitoring and in man-used ecological services is promising.

References

EC (European Commission) 2003 Working Group on Organic Matter and Biodiversity, Task Group 3 on Soil Biodiversity, Draft Final Report. March 2004, http://forum.europa.eu.int/Members/irc/env/soil/library,

Mulder Ch., De Zwart D., Van Wijnen H.J., Schouten A.J. and Breure A.M. (2003) Observational and simulated evidence of ecological shifts within the soil nematode community of agroecosystems under conventional and organic farming. *Functional Ecology*, 17, 516-525

OECD(Organisation for Economic Development and Cooperation) (2004) Proceedings "OECD Expert meeting on Soil erosion and soil biodiversity indicators", Rome, March 25-28, 2003

UNCED (United Nations Conference on Environment and Development) (1992) Agenda 21. Rio de Janeiro, June 1992

WCED (World Commission on Environment and Development) (1987) Our Common Future. Oxford